Concentrations of cyanide in waters of the Grand Calumet River and Indiana Harbor Canal have sometimes exceeded the maximum permissible levels for protecting aquatic life. During the period from 1988 to 1989, the chronic aquatic life criterion for cyanide (5.2 µg/L) was violated 28 to 71 percent of the time at the monitoring stations on the Grand Calumet River and Indiana Harbor Canal. Violations of the acute aquatic criterion for cyanide (22 µg/L) were also detected at monitoring stations GCR 34, GCR 42, IHC 2 and IHC 3S during the 1988 to 1989 period. Violations of the AAC for cyanide are also observed in some samples collected during the 1991 through 1993 time period. (Indiana Department of Environmental Management [1994?]).

High levels of cyanide (up to 175 µg/L) have been measured in effluents from some wastewater outfalls along the Grand Calumet River (Indiana Department of Environmental Management, [1990]). Non-point sources may also contribute significant amounts of cyanide to the Grand Calumet River and Indiana Harbor Canal. For example, it is estimated that the discharge of contaminated ground-water alone accounts for at least 10 percent of the total cyanide load in the Grand Calumet River (Fenelon and Watson, 1993).

Uncontrolled combined sewer overflows (CSOs) and stormwater discharges have been identified as possible sources of toxic substances in the Grand Calumet River and Indiana Harbor Canal (Indiana Department of Environmental Management, 1991). In order to describe their possible environmental effects, the IDEM has conducted toxicity testing of CSO effluents and stormwater runoff discharging into the East Branch of the Grand Calumet River. A total of nine CSO effluent samples and 14 stormwater discharge samples were analyzed for selected metals and chemicals and were rated to describe their relative toxicity. Four of the CSO effluent samples were classified as toxic, four were considered non-toxic and one sample was rated as slightly toxic. Of the stormwater discharge samples, two were rated as toxic, four rated slightly toxic and eight were classified as non-toxic. The results of this toxicity assessment may indicate that CSO effluents have higher toxicity than stormwater discharges along this section of the Grand Calumet River (Indiana Department of Environmental Management, [1994?]).

Coliform bacteria

A commonly-used test to determine if a stream or lake may contain water-born pathogens involves estimating the abundance of coliform bacteria in water samples. Coliform bacteria are usually found in the intestines of humans and warm-blooded animals and are excreted with body wastes. High levels of these bacteria in a lake or stream could thus, indicate possible contamination by raw or undertreated sewage, and the subsequent risk that disease-causing microorganisms are present in the water. Therefore, lakes and streams which do not meet limits on coliform bacteria are not considered safe for use as a drinking-water supply or for body-contact recreation.

The presence of unacceptable levels of coliform bacteria in many streams is a chronic water-quality problem in the Lake Michigan Region. In 1965, the U.S. Department of Health, Education and Welfare (1965) noted that very high levels of coliform bacteria had been measured in the Indiana Harbor Canal (380,000 organisms per 100 ml average), Burns Ditch (120,000 organisms per 100 ml average) the Grand Calumet River (approximately 1 million organisms per 100 ml) and the Little Calumet River (approximately 1 million organisms per 100 ml).

At present, coliform-bacteria levels in many of the major streams of the Lake Michigan Region still frequently exceed the standard for body-contact recreation. During the 1991 to 1993 period, the E. coli criterion was exceeded up to 86 percent of the time at each of the monitoring stations on the Grand Calumet River/Indiana Harbor Canal system. E. coli levels above the standard were also detected in 90 percent of all samples collected from West Branch of the Little Calumet River over the 1990 to 1993 period (Indiana Department of Environmental Management, [1994?]).

Trail Creek is classified as non-supportive of designated recreational uses because of violations of the E. coli standards during the 1990 to 1993 period. Non-point sources and storm runoff may be significant sources of bacteria to this stream, because high levels of E. coli in Trail Creek can often be associated with heavy rains and runoff (Indiana Department of Environmental Management, [1994?]; Northwestern Indiana Regional Planning Commission, 1993).

Other streams classified by the IDEM as non-supportive of recreational uses because of high E. coli bacteria levels include the East Branch of the Little Calumet River, Burns Ditch, Dunes Creek, and Salt

Creek (table 15).

Water quality and stream biology

Analyzing the types and numbers of organisms in a stream or lake can provide a general overview of water-quality conditions and the ability of a stream to support aquatic life. Such biological assessments are based on the principal that different organisms respond to pollution in different ways. Many organisms are considered pollution intolerant because they are killed, driven from part of a stream, or otherwise reduced in number after their habitat is degraded. Examples of pollution-intolerant organisms are caddisflies, mayflies, fresh-water clams, salmon and trout. Pollution tolerant organisms are more capable of withstanding the low dissolved-oxygen levels associated with pollution by organic matter. Leeches, air-breathing snails, midges, horse-fly larvae, certain aquatic worms, carp and catfish are usually classified as pollution-tolerant animals. Certain organisms such as damselflies, dragonflies, and gill snails are classified as facultative because they can live under a variety of water-quality conditions. Facultative species can usually survive some water-quality degradation and may be found in moderately polluted or eutrophic waters (Terrell and Perfetti, 1991).

Water pollution can affect both the total number of organisms and the number of different species in a stream or lake ecosystem. The aquatic community in an unpolluted body of water will generally be composed of numerous types of organisms, including pollution-tolerant, pollution-intolerant and facultative species. By contrast, turbid, oxygen-deficient water bodies will often be populated by a few species of pollution-tolerant organisms. Surface waters which are affected by toxic substances may be characterized by a low total population of animals and a lack of biological diversity (Terrell and Perfetti, 1991).

In addition to water pollution, various naturally-occurring factors, such as low flow, high suspended sediment levels, and inappropriate streambed material, may also limit the types and numbers of organisms in a particular surface-water system.

In 1988, the IDEM conducted sampling of the macroinvertebrate community at five locations along the Grand Calumet River and Indiana Harbor Canal. Although most of the organisms collected in this study were pollution-tolerant forms, certain types of facultative organisms and a few pollution-intolerant species were also present. The presence of these pollution-intolerant organisms may indicate that violations of minimum dissolved oxygen standards do not occur frequently.

The IDEM [1990] 305(b) reports that biological sampling in Trail Creek has been conducted since 1979. Monitoring surveys of lower Trail Creek in 1984 and 1986 determined that the fish population was composed of few individuals and species. Macroinvertebrate samples collected in 1986 at the Franklin Street Bridge (monitoring station TC 0.5) were dominated by organisms tolerant of low DO, There were also greater numbers of the types of midge larvae indicative of sewage pollution in the 1986 samples relative to 1984 biological samples.

The macroinvertebrate samples collected from Trail Creek during 1988 contained some species characterized as intolerant of toxins and high suspended sediment levels. The presence of these intolerant organisms may reflect improved operations at the Michigan City wastewater treatment plant. However, the overall biological assessment of lower Trail Creek was interpreted to indicate that dissolved oxygen levels are insufficient for certain organisms some of the time (Indiana Department of Environmental Management, [1990]).

Macroinvertebrate samples collected from Burns Ditch in 1988 were dominated by organisms facultative of low dissolved-oxygen levels, but some species characterized as sensitive to toxins were also present.

During the past, low biological-diversity has been observed in segments of the Little Calumet River. During the early 1960s, biological assessments determined that the aquatic community of the Little Calumet River near the state line was dominated by pollution-tolerant organisms such as sludgeworms and blue-green algae. The poor biological diversity in this river was partially attributed to low dissolved-oxygen levels and the presence of organic-matter in bottom sediments (U.S. Department of Health, Education and Welfare, 1965). No violations of minimum DO standards for aquatic life are observed in samples collected from the Little Calumet River in 1991 and 1992 (figure 46). Nevertheless, the IDEM presently classifies the Little Calumet River as non-supportive of aquatic-life uses. The non-support status for this river is based on recent violations of the acute aquatic criterion for cyanide and the fish consumption advisory for Lake Michigan and tributary streams (Indiana Department of Environmental Management, [1994?]).

In addition to the Grand Calumet River/Indiana Harbor Canal system, Trail Creek, Burns Ditch, and the Little Calumet River system, most of the remaining streams within the Region are classified by the IDEM [1994?] as non-supportive of aquatic-life uses (table 15). Non-supportive status for these streams is partially based on results of biological surveys. The only streams in the Region which are presently classified as fully supportive of aquatic-life uses include the Galena River and its tributaries, Kaiser Ditch, Plum Creek, Hart Ditch, an unnamed tributary of the Little Calumet River near the town of Pines in Porter County, and Reynolds Creek near Pines (Indiana Department of Environmental Management [1994?]).

Fish and Water Quality

Fish, for a number of reasons, have been a major part of any aquatic study designed to evaluate water quality (Simon, 1991). Not only are fish a highly visible part of the aquatic resource, they are also relatively easy to sample by professional biologists. Fish continually inhabit the receiving water and assimilate the chemical, physical, and biological histories of the waters. Fish also represent a broad spectrum of community tolerances from very sensitive to highly tolerant and they react to chemical, physical, and biological degradation in characteristic response patterns. These and additional attributes of fish make them desirable components of biological assessments and monitoring programs.

Fish population sampling has been chosen by the U.S. EPA, Region V and the Indiana Department of Environmental Management (IDEM) as one biological method for assessing Indiana water quality. In response to a mandate in the Clean Water Act Amendments of 1987 to develop biological criteria for evaluating the nation's surface waters, IDEM and EPA staff sampled a total of 197 headwater and wading stream sites in the Central Corn Belt Plain *ecoregion* of the State in order to develop and calibrate an Index of Biotic Integrity for use in Indiana.

An Index of Biotic Integrity relies on multiple parameters which are based on biological community concepts to evaluate complex systems. Quantititive criteria are established to determine quality of water based on: species richness and composition, trophic and reproductive constituents, and fish abundance and condition. Biotic Integrity classes of water quality range from no fish to excellent (table 20).

Based on inherent variance within the Central Corn Belt Plain ecoregion, sub-basins were established in Indiana based on the concept of natural areas (Simon, 1991). The three sub-basins sampled in July and August of 1990 include the major drainage units of northwest Indiana: Kankakee River, Iroquois River, and Lake Michigan drainageways. The water resources of the three drainage sub-basins were evaluated using the Indiana Biotic Integrity Index based on criteria calibrated for the Central Corn Belt Plain ecoregion.

The quality of the water resource of each of the three northwest Indiana sub-basins was evaluated by examining the distribution of the water quality values of the 197 individual sampling sites throughout the sub-basins. Water quality values for both the Kankakee and Iroquois drainageways displayed a nearly normal distribution. Most stations within the two sub-basins had intermediate water quality but a few had very poor water quality and a few had excellent water quality. For both the Kankakee and Iroquois drainageways, a trend of improving water quality was observed with increasing drainage area. Water quality values for the Lake Michigan drainageways, however, displayed a highly skewed distribution toward degraded or very poor water quality. Furthermore, in contrast to the Kankakee and Iroquois sub-basins, a trend in declining water quality with increasing drainage area was observed in the Lake Michigan sub-basin.

A brief summary of the findings of the Central Corn Belt Plain ecoregion fish sampling study for the Lake Michigan sub-basin follows. Detailed information such as site specific data, locality information, and species specific scoring criteria for tolerance classification may be found in the 1991 Simon study. Additional fish sampling information for streams and lakes within the Region, provided by the Indiana Department of Natural Resources-Fish and Wildlife Division, may be found in appendix 8.

The Lake Michigan sub-basin is made up of two divisions: the East Branch Little Calumet River Division and the Lake Michigan Division. The East Branch of the Little Calumet River Division includes the area from Burns Ditch, the East Branch of the Little Calumet River, and all tributaries such as Salt Creek, Reynolds Creek, and the unnamed tributary in LaPorte County. The Lake Michigan Division includes the Grand Calumet River basin and the West Branch of the

Table 20. Attributes of Index of Biotic Integrity (IBI) classification, total IBI scores, and integrity classes {From Karr and others (1986)}.

Total IBI score	Integrity class	Attributes
58-60	Excellent	Comparable to the best situation without human disturbance; all regionally expected species for the habitat and stream size,including the most intorerant forms, are present with a full array of age (size) classes; balanced trophic structure.
48-52	Good	Species richness somewhat below expectation, especially due to loss of the most intolerant forms; some species are present with less than optimal abundance or size distributions; trophic structure shows some signs of stress.
40-44	Fair	Signs of additional deterioration include loss of intolerant forms, fewer species, highly skewed trophic structure (e.g. increasing frequency of omnivores and other tolerant species); older age classes of top predators may be rare.
28-34	Poor	Dominated by omnivores, tolerant forms, and habitat generalists; few top carnivores; growth rates and condition factors commonly depressed; hybrids and diseased fish often present.
12-22	Very Poor	Few fish present, mostly introduced or tolerant forms; hybrids common; disease, parasites, fin damage, and other anomalies regular.
	No fish	Repeated sampling finds no fish.

Little Calumet River and its tributaries, such as, Deep River, Turkey Creek, and Hart Ditch. The two divisions of the Lake Michigan drainageways sub-basin are based on presence or absence of salmonid species, since keystone species such as salmon and trout determine the characteristics of a fish community. The East Branch of the Little Calumet River Division contains a salmonid component, whereas, the Lake Michigan Division does not have a salmonid component for headwater sites.

A total of 48 individual stations were sampled in the entire Lake Michigan sub-basin. More than half (58.3 percent) of the stations sampled were classified biotically as very poor. Less than a third (31.3 percent) of Lake Michigan sub-basin stations were classified as poor. Only 10.4 percent of the stations were classified as fair. Of the two divisions within the sub-basin, the East Branch of the Little Calumet Division displayed better water quality in headwater streams than the Lake Michigan Division.

East Branch Little Calumet Division

Twenty-eight (28) headwater and wading sites were sampled for fish community structure analysis in the East Branch Little Calumet River Division. A total of 48 species were collected and were numerically dominated by *centrarchid* species. Fish were collected at all sites in the division.

Using the Index of Biotic Integrity scoring criteria developed during the investigation, the overall water quality of the East Branch Little Calumet River Division ranged from fair for one station, to very poor for three stations (table 20). Only four of the 28 stations in this division (14.29 percent), were given an index of fair; while the majority of stations, 13 or 46.43 percent were given a rating of poor; 11 stations were considered very poor (39.29 percent). The biotic integrity of the East Branch Little Calumet River division declined with increasing drainage area.

Low index values were assigned to many sites primarily because of poor habitat and anthropogenic influences from industrial and municipal dischargers. Low index scores were also influenced by low flows of some tributaries which caused accumulation of soft substrates in adjacent riffle and pools and effectively reduced available habitat. In addition, streams which had been dredged had a reduction of habitat complexity and were assigned low index values.

The headwaters of the East Branch of the Little Calumet River, Reynolds Creek and the unnamed tributary, however, possessed high biological integrity comprised of many salmonid species in addition to more tolerant species from Lake Michigan. Of special note were the relatively high index of biotic integritly scores for headwaters near the Indiana Dunes National Lakeshore's Heron Rookery and the unnamed tributary. Reynolds Creek was also cited as an exceptional stream in the East Branch Calumet Division. It should be noted, however, that even though the specific areas cited were the best that were observed in the entire Lake Michigan sub-basin, they only achieved a fair evaluation for water resource classification.

Lake Michigan Basin Division

A total of 20 headwater and wading sites were sampled in the Lake Michigan division during Central Corn Belt Plain ecoregion sampling. A total of 36 species were collected and were numerically dominated by centrarchid species. Fish were collected at all sites in the division.

Using the Index of Biotic Integrity scoring criteria developed during the investigation, the overall water quality of the Lake Michigan Division ranged from fair at one station to very poor at numerous stations. Only one station (5 percent) of 20 Lake Michigan Division stations received a fair index classification; the majority of stations in this division (17 or 85 percent) received an index of very poor; and only two stations (10 percent) received a rating of poor. The biotic integrity of the Lake Michigan division was relatively degraded throughout, but a declining trend was evident with increasing drainage area. Nowhere in the Lake Michigan division was there an outstanding reference location. Even the single highest scoring station, the Little Calumet River at Cline Avenue, only achieved a fair evaluation for water resource classification.

Low index values were assigned to sites which had poor habitat and were influenced by discharges from industrial and urban land uses. Low index scores were also influenced by low flows of some tributaries which caused the accumulation of soft substrates and effectively reduced available habitat. In addition, streams which have been dredged had a reduction of habitat complexity and were assigned low index values.

The West Branch of Little Calumet River has a peculiar flow regime with a portion of the river flowing eastward toward Burns Ditch and a segment which flows westward toward Illinois. The eastward-flowing river segment was identified as having relatively better quality potential than the westward-flowing segment.

Simon (1991) identified barriers to overall improvement in water quality for the West Branch of the Little Calumet streams including the presence of landfills and frequent oil and hazardous waste spills into the river. Waste diversions from municipalities were also identified as pollutant sources which result in resident fish communities of only the most tolerant taxa inhabiting many of the streams. The headwaters of Deep River were cited as one example within the West Branch of the Little Calumet River system of degraded water quality attributed to municipal discharges.

Although many studies have been done of the Grand Calumet River, the 1991 ecoregion study was the first to quantify the expected variation in water quality of the river. The trends in water quality identified in the ecoregion study were similar to trends in historical data. Overall, Simon (1991) indicated that habitat is not the limiting factor in the improvement of fisheries in the Grand Calumet River basin since enough refuges exist to facilitate the colonization of impacted areas if damaging perturbations were alleviated. The high degree of industrialization along the river's banks was identified as the principal cause of toxic influences impacting its aquatic communities.

Fish Consumption Advisories

Because fish may accumulate certain contaminants from the environment in fat, muscle and other tissues, the state of Indiana issues fish consumption advisories for streams and lakes that may contain fish exposed to bioaccumulating contaminants. Fish consumption advisories are suggested (non-enforceable) restrictions on the size and/or type of fish that should be eaten. The state issues a fish consumption advisory when tissue concentrations of certain bioaccumulating contaminants exceed their corresponding *action levels.* A stream or lake will also be placed under advisory when fish-tissue concentrations of *polychlorinated biphenyls* (PCBs) exceed the U.S. Food and Drug Administration's 2.0 ppm tolerance level for PCBs.

The IDEM collects fish specimens for tissue analysis at locations throughout the state. Rivers and streams in the Lake Michigan Region included in the IDEM fish-tissue monitoring program are listed on page 110. Contaminant levels in fish from Lake Michigan are monitored in samples collected offshore of Lake and LaPorte Counties by the IDNR (Division of Fish and Wildlife). An interagency Fish Consumption Advisory Committee, consisting of representatives from the IDNR, the IDEM, and the ISDH, evaluates the results of the fish-tissue analysis and develops the fish-consumption advisories. The Indiana State Department of Health officially issues the final fish consumption advisories for the state. (Indiana Department of Environmental Management, [1994?]).

The Indiana portion of Lake Michigan and tributary streams (Burns Ditch, Little Calumet River, Trail Creek and Kintzele Ditch) are all included in a joint fish-consumption advisory primarily due to concerns about PCBs. The advisory applies to the following species of the given length: brown trout (under 23 inches), chinook salmon (21 to 32 inches), coho salmon (over 26 inches), and lake trout (20 to 23 inches). The advisory states that women of child-bearing age and children should avoid eating these fish, while all other individuals should limit consumption to one meal (one-half pound) per week. More stringent consumption advisories, however, are in effect for other types of fish in Lake Michigan and tributary streams of the Lake. The following fish from these waters should not be consumed by anyone: brown trout and lake trout (over 23 inches), chinook salmon (over 32 inches), carp and catfish.

Fish sampled from the Grand Calumet River and Indiana Harbor Canal have also been tested for potentially-toxic compounds in their tissues. Although no tissue samples have been collected from the Grand Calumet River in several years, levels of PCBs in fish specimens from this river have historically exceeded the FDA tolerance level. Every fish tissue sample collected from the Indiana Harbor Canal during 1990 and 1992 contained PCB concentrations above the U.S. Food and Drug Administration's tolerance level for this compound. Some fish samples from the Grand Calumet River and Indiana Harbor Canal also contain detectable quantities of hydrocarbons. The current state fish-consumption advisory recommends avoiding consumption of all fish from the Grand Calumet River or Indiana Harbor Canal (Indiana Department of Environmental Management, [1994?]).

The IDEM evaluated the long-term trends in the levels of PCBs, chlordane, dieldrin and DDT in fish tissue from fish-sampling sites throughout the state (Indiana Department of Environmental Management, [1994?]). Sites within the Lake Michigan Region included in this analysis are Burns Ditch and the Indiana Harbor Canal. This analysis appears to indicates that levels of PCB, chlordane, dieldrin and DDT in fish tissue are decreasing at most of the sites analyzed, including Burns Ditch. A notable exception to this apparent trend, however, is the Indiana Harbor Canal. Analysis of data collected biennially from 1980 to 1992 did not indicate that levels of PCBs, dieldrin and total DDT are decreasing in fish from the Indiana Harbor Canal (Indiana Department of Environmental Management, [1994?]).

Because many organic compounds, (such as PCBs, dieldrin, DDT and chlordane), generally accumulate in fat tissue, skinning, filleting and removing excess fat before cooking can significantly reduce the levels of persistent organic compounds in fish. Cooking does not destroy persistent organic compounds in tissues, but broiling or baking fish on a rack or grill can allow fats and oils to drip away from the fish. These cooking techniques thus may also reduce the levels of contaminants in edible tissues. Certain metals such as lead and mercury, however, generally concentrate in the muscle and organ tissues of fish. The only way to guarantee reduced exposure to these metals from fish is to reduce consumption of potentially-contaminated fish (Indiana Department of Environmental Management, [1994?]).

Sediments and water quality

Sediments, the unconsolidated material on the bottoms of rivers and lakes, consist primarily of clay, silt, sand, gravel, and organic material from decomposing plants and animals. Such materials may be transported over long distances by moving water, especially during storms. The fine particulate silt and clay of sediment deposits may bind tightly to many organic compounds, heavy metals, and nutrients and may effectively isolate the attached constituents from interactions in the water column. Physical, chemical and/or biological processes may, however, eventually cause the attached constituents to separate and interact in the water column.

Sediments of some lakes and streams have been contaminated, as a result of human activities, with toxic chemicals such as pesticides and herbicides, heavy-metals like lead and mercury, and other pollutants such as ammonia, cyanide, and PCBs. Such contaminated sediments represent a potential threat to human health, aquatic life, and the environment (U.S. Environmental Protection Agency, 1992). Furthermore, degradation rates of some of the toxic chemicals are so slow that the chemicals tend to remain in sediments for long periods of time.

Creatures that live on the bottoms of rivers and lakes (such as crustaceans and insect larvae) may ingest or absorb toxic chemicals from contaminated sediments in their environment. Because these animals form an integral part of the aquatic food chain, problems that affect them may affect the fish and wildlife population.

Contaminants in sediments may also affect humans directly through the food chain. When small fish and shellfish eat contaminated materials, the contaminants collect in their bodies. When larger fish eat the smaller ones, the contamination is passed on. Eventually, important fish species like lake trout and wildlife are affected. Humans may be at risk by eating contaminated fish and/or wildlife (U.S. Environmental Protection Agency, 1992).

Every year, large volumes of sediments are transported into the Great Lakes System by the rivers flowing into the Lakes. If the sediments are contaminated, the chemicals attached to the sediments are also carried into the Lakes. Contamination is difficult to reverse in the Great Lakes because the System has a low ratio of outflow to storage volume (Great Lakes Basin Commission, 1976b).

Lake Michigan, one of the largest of the Great Lakes loses less than one percent of its volume annually. Water residence time for Lake Michigan is estimated to be approximately 100 years. In addition to the low ratio of outflow to storage volume for Lake Michigan, pollutant loads from southern Lake Michigan are isolated to some extent by a semiclosed circulation gyre in the southern basin of the Lake (Great Lakes Basin Commission, 1976b).

In Lake Michigan, a three-mile plume of sediments stretches into the lake from the mouth of the Indiana Harbor to within one-half mile of public intake pipes for the cities of Whiting, Hammond, and East Chicago.

Sediment monitoring is, therefore, important for developing strategies to improve water quality. It can be an important tool for detecting the presence of certain types of pollutants and for providing insights about pollutant loadings, potential sources and historical trends.

Toxicants may be more readily detected in sediments than in the water column because they can accumulate in sediments at levels far greater than normal for the water column. Hence, pollutants that are present in quantities below detection limits in the water column may be detectable in sediments. Also, because sediments are less mobile than water, pollutants attached to sediments are more likely to remain closer to the source than those transported by water. Furthermore, relatively undisturbed sediments may provide historical perspectives about loadings and sources of pollutants.

The IDEM has compiled and analyzed numerous records of chemical analyses for selected priority pollutants of sediment samples taken from lakes, reservoirs and streams throughout Indiana. In addition to sediment data, IDEM has used information such as fish tissue data, biosurveys, and water chemistry to document a possible correlation between contaminated sediments and non-support of uses for some Indiana streams. Within the Lake Michigan Region, the IDEM has identified the Grand Calumet River and the Indiana Harbor Canal as areas where sediment contamination may be contributing to non-support of uses. Known contaminants on sediments for both the Grand Calumet and the Indiana Harbor Canal are cyanide, metals, PCBs, PAHs, and other organic compounds. Portions of Trail Creek have had elevated levels of metal and pesticides in sediments.

Contaminated sediments are thought to present one of the most serious threats to water quality in the Region. The actual extent to which the "in place" pollutants contribute to overall water quality is uncertain.

The USEPA, USGS, USACE, and the Indiana State Department of Health have also been involved in sediment sampling in the Grand Calumet and Indiana Harbor Canal to determine the degree of contamination of sediments. A summary of existing information about contaminated sediments in the Grand Calumet River has been prepared by the USACE (1991).

The USEPA (1991) found that some of the Grand Calumet River sediments may be sufficiently contaminated to be subject to regulation under the Resource Conservation and Recovery Act (RCRA).

Strategies for management of contaminated sediments[1]

Options to deal with contaminated sediments may vary from site to site and can range from leaving them in place, to removing or isolating them by various methods. If the contaminated sediments at a site are a threat to human health, aquatic life, and the environment; or if they occur in navigable waterways, the sediments need to be removed. Contaminated sediment are removed by dredging; that is, by digging them up and moving them to another location. Before dredging, a decision must be made on how to dispose of the dredged material. The simplest option is to dump the material in the deep part of a large lake or in the ocean. However, this is not acceptable for contaminated sediments.

A second option is to place the dredged contaminated sediments in a Confined Disposal Facility (CDF). These are diked areas usually built in shallow water, but sometimes on land, in which the dredged material can be placed and confined. Some CDFs have walls lined with materials that keep the sediment isolated, while allowing water to move through. Other CDFs restrict the movement of water as well.

A third option is to place the contaminated sediments in a CDF designed to function like a hazardous waste landfill. Although this method is used for highly contaminated sediments, it is very expensive for large amounts of dredged material.

A variety of methods to treat the most contaminated sediments are being studied and tested. No single method has proven to be superior to others and each site may suggest a different approach or combination of approaches. Most of the methods require excess water to be removed from the sediments prior to treatment.

Unfortunately, advanced treatment technologies tend to be expensive and this limits the volume of sediments that can be treated by these methods. In the end, the specific circumstances at each site will suggest the combination of dredging, treatment, and disposal options employed there.

Leaving sediment in place may be the best solution if they do not affect human health and the environment. Moving the sediments has the potential for stirring them up and resuspending contaminated material, thereby increasing the exposure to fish and allowing the contaminated material to be transported to uncontaminated areas.

It may not be necessary to remove contaminated sediments if the sources of contamination have been eliminated, erosion of the sediments is unlikely, and clean material is being deposited on top of the contaminated material. In time, the contamination may be naturally capped by the layer of clean sediment and isolated from disturbance by storms, floods, or burrowing organisms.

If clean sediments are not deposited fast enough naturally, and erosion is unlikely, it may be possible to cap the contaminated sediment artifically. Capping the sediment can confine the contaminants and keep them from interacting with the environment. However, capping has not been proven in the Great Lakes, where constant shifting of bottom sediments creates unfavorable conditions for such an approach.

However, doing nothing is not always safe. The contaminated sediments may be picked up and transported elsewhere, either by absorption by organisms, during flood events, or by wave action. Or, if the sediments lie in a navigation channel, they can be stirred up by passing ships and resuspended. This can be especially bad if the material is then carried into an uncontaminated area, such as one of the Great Lakes.

Finally, although many organic contaminants degrade with time, this process can be very slow and other contaminants—such as heavy-metals— do not degrade at all, and contamination can persist for a very long time.

[1] This discussion was taken from a Region V USEPA Fact Sheet– Contaminated Sediments, June 1992

The USACE estimates that the Grand Calumet River and the Indiana Ship Canal contain 4 million to 5 million cubic yards of contaminated sediments (United States Environmental Protection Agency, 1991). The Corps has expressed an opinion that the capacity of the Harbor has been reached and that sediments are no longer settling in the Harbor Canal, but are traveling directly into Lake Michigan.

It has been estimated by USEPA (1991) that 180 million pounds of contaminated sediments enter Lake Michigan each year from the Indiana Harbor Canal, including 420 pounds of PCBs, 2,300 pounds of Cadmium, and 111,000 pounds of lead.

Although the natural rate of sedimentation is very low in Lake Michigan compared to the Lower Great Lakes, contaminated sediments have been found to constitute a major reservoir of pollutants in Lake Michigan (U.S. Environmental Protection Agency, 1991). Most experts agree that the Grand Calumet River/Indiana Harbor Canal is a very significant source of pollution to the southern end of Lake Michigan.

The USEPA (1991) estimates that by dredging the Federal Navigation Channel in Northwest Indiana alone, a 50 percent reduction could be achieved in the amount of contaminated sediments which reach Lake Michigan from the Grand Calumet River and the Indiana Harbor Canal.

Dredging sediments

Navigational waterways, such as the Indiana Harbor and Canal and Trail Creek, require periodic dredging to remove and dispose of accumulated bottom sediment. Until the 1970s, disposal of almost all dredged material from the Great Lakes System occurred in open water. However, open water disposal has become less desirable and is now subject to restrictions under the Clean Water Act because sediments have become increasingly contaminated from industrial and municipal discharges, agricultural runoff, and airborne deposits (U.S. General Accounting Office, 1992).

The Rivers and Harbors Act of 1970 (P.L. 91-611) provided authorization of the Confined Disposal Facility (CDF) Program as a means of providing for disposal of contaminated dredge material from the Great Lakes. The act allowed the Secretary of the Army to grant waivers of the 25-percent share of CDF costs if EPA determined that sponsoring communities were in compliance with EPA-approved plans for waste treatment facilities and if federal water quality standards were not being violated (U.S. General Accounting Office, 1992).

The Environmental Protection Agency (EPA) and the Corps establish sediment testing guidelines which are used by the Corps to decide whether disposal of dredged material may occur in open water or should take place in a Confined Disposal Facility (CDF) (see box on page 130). EPA also sets sediment criteria for the amount of toxins that pose a risk to the environment (U.S. General Accounting Office, 1992).

In the Lake Michigan Region, the USACE has periodically dredged the Indiana Harbor and Canal to permit shipping of materials and products to and from the industries that line the canal. The Congress authorized a harbor depth of up to 27 feet for the Indiana Harbor; and in the past, disposal of the materials that were dredged to maintain the harbor occurred in open water. Although portions of the harbor are now reported to be between 8 and 15 feet deep, the Harbor has not been dredged for about 20 years because no disposal site has been approved for its contaminated sediments. Consequently, according to Corps and industry officials, navigation has been adversely affected. Commercial carriers who use the port have to reduce the draft of each vessel by reducing the cargo loads. An official of one company using the harbor told GAO in April 1991 that it was light-loading each of its vessels.

The Corps began to look for a CDF site for Indiana Harbor in 1972 and identified and evaluated 16 possible sites. In 1977, the Corps proposed one site and submitted a draft environmental impact statement. However, EPA rejected the site because the disposal area as designed would not retain the dredged material (U.S. General Accounting Office, 1992).

In 1983, the Corps recommended to the sponsor an in-water CDF site in East Chicago and in 1986, released the draft environmental impact statement. Community and environmental groups protested the plan and labeled the site "toxic island." After the state of Indiana declined to support the site, the Corps dropped the proposal (U.S. General Accounting Office, 1992).

In 1987 and 1988, the Corps held public meetings with local agencies and groups to identify acceptable sites. The Corps has now recommended an upland site that is a former oil refinery which has been identified as a RCRA facility. The CDF is to be placed on top of the RCRA site; and its cap will complete post-closure design requirements under RCRA. For containment, a slurry wall is to be constructed around the perimeter of the facility. Additional information about the site may be found in the Environmental Impact Statement which is soon to be released (Rick Sutton, USACE- Chicago District, personal communication, June, 1994).

The U.S. Army Corps of Engineers has also dredged the Michigan City Harbor numerous times in the past to restore the federal navigation channel to its designated depth. The Corps is authorized to maintain an 18-foot deep navigation channel in the lower reaches of Trail Creek.

The quality of sediments dredged from Trail Creek varies considerably, depending on location. Results of sediment sampling studies range from non-polluted in the outer harbor and the upstream limit of the navigation channel, to heavily-polluted in some areas in-between. At times in the past, sediments in Trail Creek have been considered sufficiently polluted to preclude open water disposal and unrestricted upland disposal. A confined disposal facility was, therefore, approved in 1978 for disposal of contaminated sediments. Upon three occasions, the CDF was used for disposal of sediments from Trail Creek (United States Department of Agriculture and others, 1993). The CDF was filled to capacity in 1987.

More recently, the quality of dredge material from Trail Creek has been considered suitable for disposal in the LaPorte County Landfill; and early 1994, dredged sediments were considered suitable for an upland disposal site.

The Congress envisioned the need for CDFs as short-lived when it authorized the CDF program for the Great Lakes in 1970, expecting federal water pollution programs to eventually eliminate the source of contamination (U.S. General Accounting Office, 1992). However, there are 26 existing CDFs, and 18 of them are located in the vicinity of geographic Areas of Concern (AOCs). AOCs have been designated as having acute water quality and/or contaminated sediment problems (See discussion of AOCs beginning on page 99 of this report). Because none of the AOCs has yet been cleaned up, dredging in these areas will likely require

CDFs for many years (U.S. General Accounting Office, 1992).

In addition, the Corps was authorized under the Water Resources Development Act of 1990 to perform additional cost-share dredging as part of maintenance work in order to enhance the environment and improve water quality outside navigation projects. The General Accounting Office (GAO) projects that all of these activities will increase the need for CDFs.

Contaminated sediment remediation

A 1987 amendment to the Clean Water Act authorized the U.S. EPA's Great Lakes National Program Office (GLNPO) to conduct a 5-year study and demonstration project to examine the control and removal of toxics from bottom sediments. In the 1987 amendments to the Clean Water Act, the Grand Calumet Area of Concern was one of the areas specified for a demonstration project.

GLNPO's Assessment and Remediation of Contaminated Sediments (ARCS) Program is not a cleanup program for contaminated sediment, but is a program which is to identify issues and investigate potential removal and sediment treatment technologies. GLNPO is working with IDEM, the USACE, U.S. Fish and Wildlife Service, National Oceanic and Atmospheric Administration, and with other USEPA regional offices and laboratories to assess the nature and extent of contaminated sediments and evaluate and demonstrate remedial options.

As part of the ARCS Program, sediment and biological samples were collected from throughout the Grand Calumet River and Indiana Harbor Canal in 1989 and 1990 for conducting a series of toxicity tests. A health risk assessment was prepared to estimate the risk associated with the sediments in the river. Also, a series of advanced treatment technologies have been tested in the laboratory on sediments from the Grand Calumet River.

A *solvent extraction* technology unit was brought to the area in 1992 and several hundred pounds of sediment were treated on-site. The technology successfully removed the organic contaminants; however, because the Grand Calumet River sediments are also contaminated with heavy metals and other inorganics, the solvent extraction technology is not adequate to remediate the sediments.

Lake Quality

Lake Michigan

The approximately 240 square miles of Lake Michigan under Indiana jurisdiction can be considered one of the most important natural resources in the state. Lake Michigan provides a reliable source of water for both public and industrial users in the Region. The Lake is utilized for recreational activities, provides access for transportation throughout the Great Lakes and the St. Lawrence Seaway, and is an important habitat for fish and other freshwater organisms. Lake Michigan will probably continue to be an important source of water for the Region. Thus, maintaining and protecting water-quality in Lake Michigan will be necessary for the continued use and development of this resource.

Three other states, Michigan, Wisconsin and Illinois, also administer designated portions of Lake Michigan. The following section on water quality however, is primarily based on data from the part of Lake Michigan under Indiana jurisdiction. Therefore, the description of water-quality conditions in Lake Michigan will be limited to the Indiana portion of the Lake unless otherwise stated.

The Indiana portion of Lake Michigan and its contiguous harbors have been designated by the IDEM for multiple uses including recreation, aquatic-life support, public water-supply and industrial water-supply. All applicable standards established for these designated uses apply to the Indiana portion of Lake Michigan. Additional limits on the concentrations of specific chemical constituents in Lake Michigan are also defined in the state's water-quality statutes (table 16). State legislation also defines specific limits for ammonia concentrations in Lake Michigan and its contiguous harbors, and establishes temperature standards for thermal discharges into the Lake.

Factors affecting water quality in Lake Michigan

Relations between ambient climate and water chemistry were examined as part of an assessment of water quality in the Indiana portion of Lake Michigan by the Indiana State Board of Health (ISBH - now Indiana State Department of Health). During 1980 and 1981, the ISBH measured physical properties and collected water samples for chemical analysis at numerous locations within the part of Lake Michigan under Indiana's jurisdiction. Water samples for analysis were collected at near-shore and offshore sampling sites in Lake Michigan during different seasons in order to observe possible spatial and seasonal trends in water chemistry. Data at each of the chosen sampling sites was simultaneously collected near the lake surface and deeper in the water column. The near-surface samples were collected from 5 feet below the water surface and near-bottom samples were collected from 5 feet above the lake bottom.

Data from the ISBH study indicates that a distinct thermal gradient may form across Lake Michigan in Indiana during the spring and summer months. The ISBH used the term "thermal bar" to describe the situation in which near-shore waters warm sooner than the offshore waters, creating a zone of warmer water which approximately parallels the shoreline. Density differences associated with this temperature gradient are large enough to effectively prohibit the mixing of waters on opposite sides of the thermal bar. This inhibition of mixing may produce some of the spatial variability in constituent levels observed during the ISBH study.

The ISBH (1982) detected statistically significant differences in the concentrations of certain ions between near-shore and offshore samples during periods when the thermal bar was present off the Lake Michigan shoreline. In general, the concentrations of chloride, total phosphorous, ammonia, nitrate and total nitrogen were found to be significantly higher in nearshore samples than in samples collected offshore during the period of time between late spring to early autumn. The higher near-shore levels of these constituents may reflect the input of ions from shoreline sources, and inhibited mixing of near-shore and offshore waters due to thermal segregation.

Water-temperature data from the 1980-81 ISBH study also indicates that thermal stratification due to vertical differences in water temperature can also occur in the Indiana portion of Lake Michigan. During the spring of 1980, higher water temperatures were detected in the shallow water samples than in samples collected near the lake bottom. Later in the year, a distinct layer of warm water similar to an *epilimnion* had developed over a layer of lower temperature, denser water similar to a *hypolimnion.* Seasonal cooling during the autumn however, disrupted this thermal layering and isothermal conditions were again observed in the study area by late autumn.

The vertical thermal-layering previously noted is not equivalent to the thermal-stratification process observed in many lakes. In true stratified lakes, the epilimnion and hypolimnion are stable during stratification, and wind-induced currents are generally limited to above the *thermocline*. However, Lake Michigan in Indiana is shallow enough that disturbances such as strong winds or storms may disrupt vertical thermal-layering. Such a disruption of layering was observed by the ISBH after a storm on Lake Michigan during July 1981. A stable temperature profile, which inhibits mixing between the epilimnion and hypolimnion during periods of stratification, does not exist in Lake Michigan above approximately 72 feet (22 meters) depth (Indiana State Board of Health, 1982).

Although thermal layering in the Indiana portion of Lake Michigan does not appear to be permanent or seasonally stable, statistically significant differences in the concentrations of some ions were observed between near-surface and near-bottom samples collected at the same location. During the spring and summer, significantly higher concentrations of phosphorus, silica, combined nitrate plus nitrite, and ammonia were detected in near-bottom samples than in samples collected near the surface. Furthermore, during periods of vertical thermal-segregation, pH levels were up to 0.5 standard units lower in near-bottom samples than in samples collected near the surface. The pH differences between the near-surface and the deep-water samples during periods of stratification were attributed to higher carbon dioxide solubility and less photosynthetic activity in the low-temperature waters near the lake bottom relative to the warm waters near the surface (Indiana State Board of Health, 1982).

Some chemical changes often associated with lake stratification are generally not observed in the 1982 ISBH study of Lake Michigan. During periods of thermal stratification, decaying organic matter may consume most of the dissolved oxygen in the hypolimnion. This decay process may result in low DO concentrations and reducing chemical conditions at the lake bottom. Most dissolved oxygen measurements in the ISBH data, however, are approximately equal to the saturation level. Metals such as iron and copper can concentrate in the hypolimnion during periods of stratification, but the ISBH did not observe statistically significant differences in the levels of iron and copper between near-surface and deep-water samples. The vertical distribution of iron, copper and dissolved oxygen in the Indiana portion of Lake Michigan may indicate that seasonal thermal-segregation does not last long enough for anoxic conditions to develop (Indiana State Board of Health, 1982).

Water quality in Lake Michigan can also be influenced by the movement of water due to wind-induced currents. In general, the action of currents may dilute and disperse chemical constituents in a lake. The extent of dilution, however, will be determined by numerous physical factors such as current velocity and the rate at which a substance is discharged. Another important factor in current-mediated transport and dilution is the density of the substance in question. Substances that are less dense than water, such as oil and grease, will generally float on the water surface. In contrast, materials which have higher densities than water will tend to sink to the bottom after being discharged. The dispersion and movement of substances more dense than water may thus, be influenced by deep-water circulation patterns.

A study of chemical dispersion of materials from the Indiana Harbor Canal into Lake Michigan was conducted by the IIT Research Institute under the sponsorship of the U.S. Environmental Protection Agency (Snow, 1974). Using aerial photographs and water-chemistry analysis, the researchers were able to discern the direction and dispersion of a pollutant mass spreading in the Lake from the mouth of the Canal. The researchers also identified physical factors, including currents, vertical mixing, and the tendency to concentrate pollutants in near-shore areas, which influence the movement of pollutants in the Canal and Lake Michigan. The results of this study were published by the USEPA in 1974, and provided evidence that pollution from the Indiana Harbor Canal could enter Lake Michigan (Lake Michigan Federation, 1983).

Another study of current movement and pollution transport in southern Lake Michigan was done by the Argonne National Laboratory in March of 1977. This study utilized rare-earth elements as tracers for tracking the flow of water from the Indiana Harbor Canal into Lake Michigan at different depths. Water within the Canal was tagged with the element samarium and rhodamine dye, and water at the Canal surface was tagged with oil containing the element dysprosium. Movement of the tagged water from the Canal into Lake Michigan was monitored by sampling down-current from the confluence of Lake Michigan and the Indiana Harbor Canal, and by collecting raw water samples at the shore and offshore intakes of the Chicago South Water Filtration Plant (SWFP).

By comparing tracer levels in samples collected at different locations in Lake Michigan, the researchers in the Argonne National Laboratory study were able to trace the movement of water from the Indiana Harbor Canal to the City of Chicago's South Water Filtration Plant. Significantly higher levels of dysprosium and lower levels of samarium were detected in samples from the SWFP's shore water intake relative to samples from the offshore intake. The pattern in trace element levels at the Chicago South Water Filtration Plant were interpreted to represent flow partitioning due to density differences. The oil and dysprosium that were spread over the Canal remained at the surface of Lake Michigan and were blown towards the shore by prevailing winds. The Canal water tagged with samarium however, descended as a plume below the surface of Lake Michigan and was carried toward the offshore intake by the prevailing current (Harrison and others, 1977).

The researchers in the Argonne Laboratory study used results from the tracer study to model the possible effects pollution in the Indiana Harbor Canal could have on municipal water supplies. The results of the tracer experiments were modeled with data relating to water temperature, wind direction, precipitation and lake currents. It was concluded that pollutants from the Indiana Harbor Canal could have detrimental effects on water quality at the Chicago municipal intakes under the following conditions: 1) An extended period (24 hours or more) of wind from the northwest which creates a flow reversal in the Indiana Harbor Canal; 2) A 3.0 inch (7.6 cm) 24-hour rainfall; 3) At least 24 hours of wind from southerly quadrants to facilitate discharge from the Canal into Lake Michigan. Because of the limited precipitation and wind data however, the return interval for this combination of meteorological events could not be calculated (Harrison and others, 1977).

Because the Lake Michigan Region is one of the most populated and industrialized areas in Indiana, it is possible that water quality in Lake Michigan is affected by various anthropogenic factors. Constituents from human sources may enter Lake Michigan through tributary streams such as the Grand Calumet River, Burns Ditch, and Trail Creek. Chemicals may also enter Lake Michigan from smokestacks, internal combustion engines, and other sources of atmospheric pollution (Indiana State Board of Health, 1982; Indiana Department of Environmental Management, 1991).

Possible evidence of human-induced changes in the chemistry of Lake Michigan has been detected by the

Indiana State Board of Health. Although few violations of applicable water-quality standards were detected in the ISBH data set (Indiana Stream Pollution Control Board, 1984), the ISBH noted that levels of dissolved solids, phenols, cyanide, nutrients and metals were consistently higher in samples collected in and around the Indiana Harbor Canal than elsewhere in the study area. High levels of sulfate, chloride and nutrients were also detected in samples collected offshore of urban areas, especially northern Lake County and Michigan City. The ISBH also made comparisons between data collected during their study and earlier Lake Michigan water-quality data. These comparisons indicated that sulfate, chloride and nutrient levels were higher in the ISBH data relative to the earlier samples. (Indiana State Board of Health, 1982).

Any effects human activities may have on water quality in Lake Michigan will be determined by pollution control technology, land-use management, environmental planning, and other factors. Protecting and maintaining water quality in Lake Michigan is an integral part of current environmental planning efforts in northwestern Indiana. A discussion of water-quality protection and remediation in the entire Lake Michigan Region is presented in the section entitled **Current water-quality management efforts**.

Sources of Lake Michigan water-quality data

The IDEM monitors water quality in southern Lake Michigan by analyzing raw-water samples collected monthly at 5 municipal water intakes (figure 41 and table 17). Selected data from these monitoring stations are used in this report to analyze water quality in the Indiana portion of Lake Michigan. Parameters examined consist of dissolved oxygen, sulfate, chloride, phosphorus, specific conductance (at 25°C), iron, copper, combined nitrate and nitrate (measured as equivalent nitrogen), and cyanide.

Because of variations in sampling practices at the IDEM monitoring-stations, the parameters examined were collected over varying time periods. Most of the parameters were measured in samples collected monthly over a 10-year period from 1982 to 1992. Specific conductance levels, however, were not recorded from samples collected after the spring of 1990, so specific conductance data were analyzed over an 8-year period (1982-90). Dissolved oxygen levels were measured over different time periods at the different monitoring station, and have only been taken at irregular intervals since 1976. The most consistent period of dissolved oxygen measurements was from 1971 to 1976, when DO levels were recorded at regular monthly or bimonthly intervals at all of the Lake Michigan monitoring stations.

Analysis of water-quality in Lake Michigan

Water quality in Lake Michigan can be evaluated by comparing the median levels of different constituents against established legal standards or suggested concentration limits. In this study, the median levels of the constituents under consideration are evaluated relative to established maximum contaminant levels (MCLs) or secondary maximum contaminant levels (SMCLs). Listings of MCLs and SMCLs for several inorganic constituents are presented in table and appendix 6. The water-quality data from Lake Michigan can also be compared to state regulations (table 16) in order to determine compliance with limits established for the Lake's designated uses.

Comparisons of the box plots developed from Lake Michigan water-quality data (figure 47) indicates that the median levels of sulfate, chloride, and specific conductance are approximately equal among the different monitoring stations. The lack of obvious variations in the median levels of these parameters, however, may not be representative of Lake Michigan in Indiana as a whole. The municipal intakes used as sampling stations all draw water from offshore locations. Water-quality at offshore locations may not be influenced by wastewater discharges, runoff from the shoreline, tributary streams, and seasonal thermal-segregation to the same extent as near-shore samples. Differences in the levels of some ions between samples collected at near-shore and deep-water locations of Lake Michigan in Indiana have been observed in previous studies (Harrison and others, 1977; Indiana State Board of Health, 1982).

In general, few violations of applicable water-quality standards are observed in the Lake Michigan data set. No specific conductance levels above the 1200 µmhos/cm industrial-use limit (table 16) were recorded in any of the Lake Michigan samples. All chloride measurements are less than the 250 mg/L SMCL for this constituent, and violations of the state's monthly limit on chloride levels in Lake Michigan (15 mg/L) occur in less than 5 percent of all samples. All sulfate levels in the Lake Michigan samples are also below the established SMCL. However, sulfate concentrations above the state's monthly average criteria (26 mg/L) are observed in approximately 8 percent (Gary municipal intake) to 25 percent (Whiting municipal intake) of samples.

Median hardness levels also appear to be consistent among samples collected at the Lake Michigan monitoring stations (figure 47). For descriptive purposes, hardness levels in the Lake Michigan samples can be compared to the hardness classification scale presented by Durfor and Becker (1964) described on page 166 of this report. Hardness levels in over 97 percent of the samples are less than 180 mg/L as $CaCO_3$, and fewer than 1 percent of all samples contain hardness levels below 120 mg/L as $CaCO_3$. This range would probably characterize Lake Michigan as "hard water" in the classification system presented by Durfor and Becker.

Because phosphate is an essential nutrient for algae and aquatic plants, excessive amounts of this ion in a lake may promote nuisance algae growth or *eutrophication*. It is therefore, generally desirable to limit phosphate levels in lakes used by humans, and the state of Indiana has established a limit of 0.04 mg/L (daily maximum) for total phosphorous in the Indiana portion of Lake Michigan. Phosphate levels above this limit however, are observed in some samples from Lake Michigan (figure 47). The data set collected from the Hammond municipal water intake (monitoring station LM H) contained the highest percentage (23 percent) of samples with phosphate concentrations above the 0.04 mg/L level. The lowest percentage (7.4 percent) of phosphate levels above the limit for Lake Michigan is observed in samples collected at the Whiting municipal intake (monitoring station LM W).

Measurements of total iron levels are available for water samples collected at the Whiting municipal intake (monitoring station LM W) and the Michigan City municipal intake (monitoring station LM M) (figure 47). Median iron levels are slightly higher (by 0.03 mg/L) in the data set from the Whiting municipal intake. Violations of the 0.3 mg/L SMCL for iron are observed in approximately 22 percent of samples collected at the Michigan City intake and approximately 27 percent of samples collected at the Whiting municipal intake.

Median monthly dissolved oxygen concentrations were calculated using available DO measurements collected during 1971-75. Graphs of these median monthly values at three monitoring stations (figure 48) may indicate that DO levels in Lake Michigan are inversely proportional to ambient temperatures. Median dissolved oxygen concentrations are generally higher during the winter and early spring relative to the summer months. The median dissolved-oxygen levels during this period did not decrease below the 7.0 mg/L minimum DO level established for Lake Michigan (table 16). Furthermore, DO concentrations in the Lake Michigan data collected by the Indiana State Board of Health (1982), were at or near saturation levels in almost all samples.

Similar median levels of combined nitrate + nitrite concentrations are observed among the five monitoring stations (figure 47). No violations of the state's limit for combined NO_3+NO_2 (10 mg/L) are detected in any of the samples from Lake Michigan in Indiana. Box plots for total cyanide could not be constructed because over 90 percent of all measurements are equal to or below the 0.005 mg/L reporting limit for this constituent. Cyanide levels above the 0.2 mg/L MCL are not observed in any of the samples. Violations of either the AAC (0.0052 mg/L) or the CAC (0.022 mg/L) for cyanide are observed in less than 3 percent of all samples.

Analyses of trace metal concentrations and bacteria counts in samples collected from the Lake Michigan monitoring stations during 1988-1989 are reviewed by the IDEM ([1990]). Violations of the applicable standards for lead, cadmium and E. coli bacteria are observed in less than 10 percent of the 1988-89 samples. Violations of the chronic aquatic criteria for copper are detected in 95 percent of samples from the Gary intake and 20 percent of samples from the East Chicago municipal intake collected during 1988-89. However, no copper concentrations above the CAC for this metal are detected in samples from the other Lake Michigan monitoring stations during 1988-1989. Because high copper levels are not observed throughout Lake Michigan in Indiana, the high copper levels in the Gary and East Chicago samples may be a result of copper contamination from the water intake system.

Although few E. coli bacteria violations are observed in data from the offshore municipal water intakes, more violations are observed in data collected by Indiana Dunes National Lakeshore personnel for near-shore sites. When E. coli counts from near-shore sampling exceed values for full-body contact recreation, beach closings are initiated at some beaches along the Lake Michigan coastline.

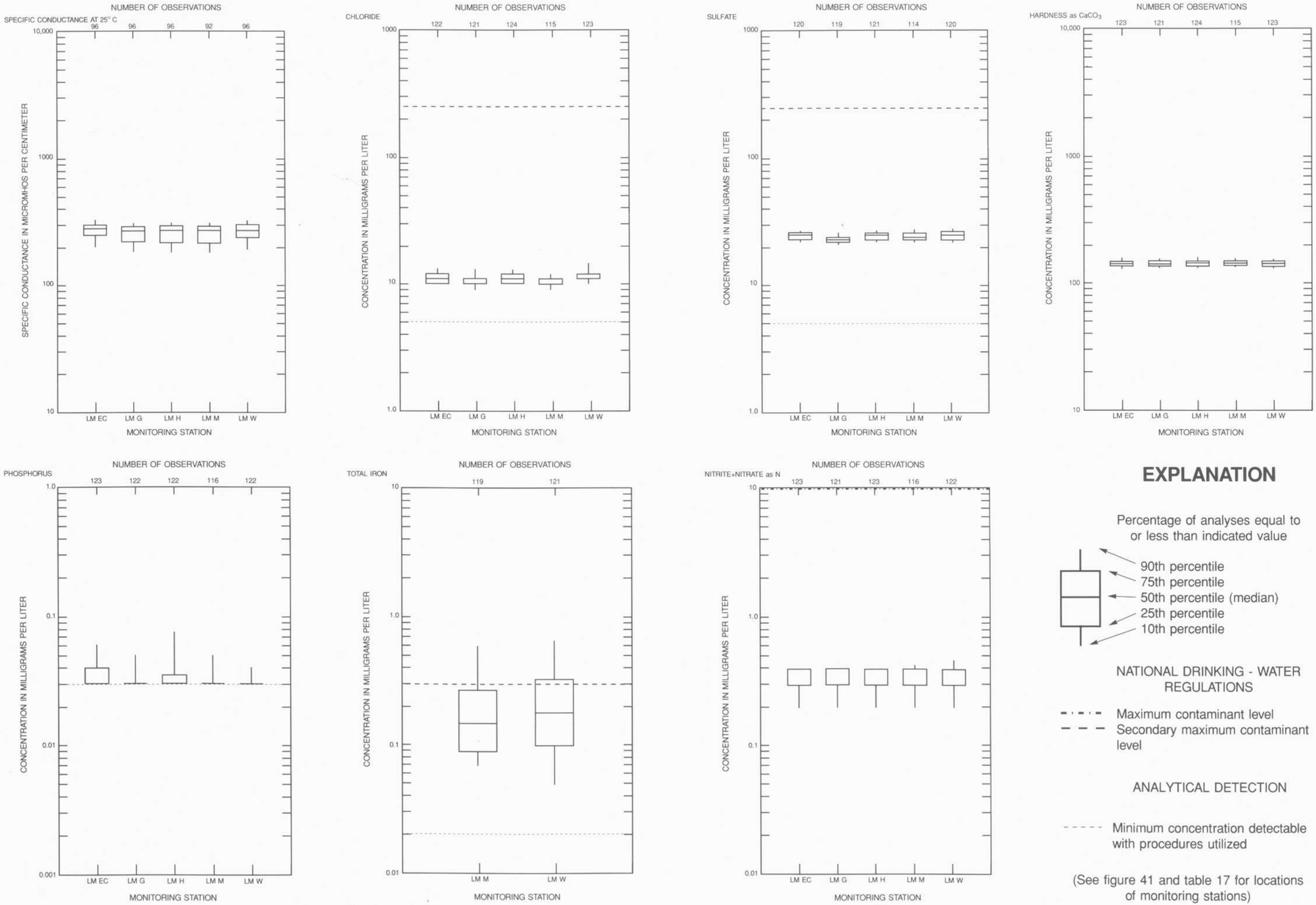

Figure 47. Statistical summary of selected water-quality constituents for selected Lake Michigan monitoring stations.

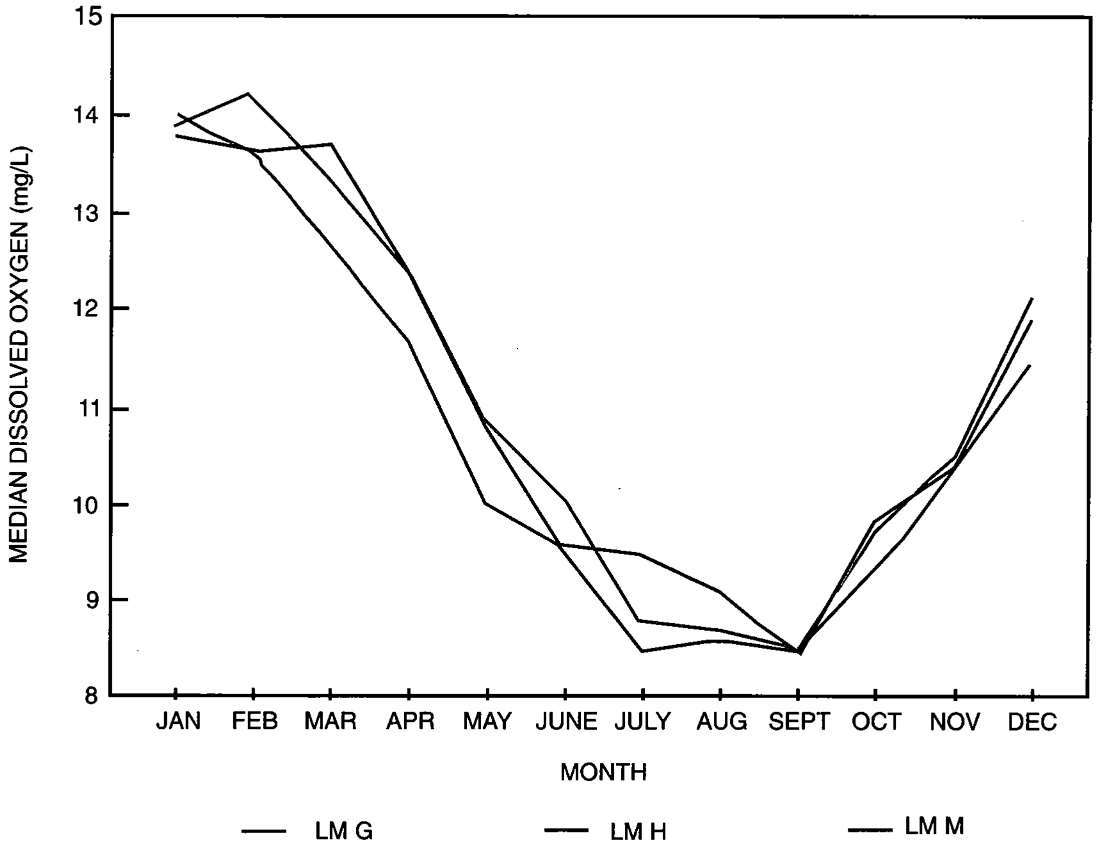

Figure 48. Median monthly dissolved oxygen values for selected Lake Michigan monitoring stations

Other lakes

Sources of lake-quality data

In 1970 the Indiana State Board of Health began a formal lake studies program for public freshwater lakes and reservoirs in the state. By 1975, essentially every public lake and reservoir had been sampled for physical, chemical and biological data. The goal of the sampling, now coordinated by the IDEM, was to generate a database from which a classification system could be developed for comparing lake quality and establishing a priority system for lake management and restoration. The IDEM uses 10 *trophic* parameters to derive a composite numerical index scaled from 0 (least eutrophic) to 75 (most eutrophic), which in turn defines a generic four-tiered classification of lakes. The lakes are further grouped by *morphometric* and trophic similarity into seven major lake management categories. Five of the selected Region lakes and reservoirs in table 10 have been placed in the IDEM's Indiana Lake Classification System and Management Plan.

Through the Clean Lakes Program, which is administered cooperatively by the USEPA and the State of Indiana (IDEM), many of Indiana's larger lakes have been resampled in recent years by the School of Public and Environmental Affairs (SPEA) at Indiana University. The Clean Lakes Program, which provides funds for studies and management activities on publicly-owned freshwater lakes, seeks to encourage participation at the local level to refine and implement plans outlined in the IDEM's Indiana Lake Classification System and Management Plan. The primary purpose of recent sampling activities was to detect apparent lake-quality trends by comparing trophic index numbers determined in the mid-1970s with those determined more recently.

Although none of the lakes monitored through the SPEA program are in the Lake Michigan Region, two

Recently-introduced aquatic species in the Great Lakes

The term "exotic" is often used in reference to species of plants or animals that have been introduced into habitats where they are not considered indigenous. In the aquatic environment, an exotic species may be transported inadvertently between water bodies by currents, commercial ships, pleasure boats or migrating animals. If environmental conditions in the new habitat are hostile towards the transported organism, the organism will probably die in the new surroundings. However, if an exotic species is placed in a lake or stream with an abundant food supply, sufficient dissolved oxygen levels, the proper temperature regime, and no natural predators, it may be able to survive and reproduce in its new environment.

The sudden introduction of an exotic species of plant or animal into a lake or stream can have adverse effects on the entire aquatic ecosystem. Although some introduced species have proven to be harmless to their new habitats, others have caused significant disruptions of existing ecological relationships. Exotic species may displace or otherwise decrease the population of other organisms through predation, competition for food resources, or destruction of habitat. The displacement of other organisms by exotic species can result in decreased biological diversity in an ecosystem and a loss of desirable species, such as game fish.

Many of the exotic species which now inhabit the Great Lakes were inadvertently introduced by anthropogenic activities. Certain non-indigenous species were able to enter the Upper Great Lakes (Lake Superior, Lake Huron and Lake Michigan) through connecting channels between the Great Lakes. However, the majority of non-indigenous species entered the Great Lakes through the release of ballast water from vessels entering the St. Lawrence Seaway. Exotic species may have also been introduced inadvertently to the Great Lakes Basin as domestic plants or pets (Michigan Department of Natural Resources, 1993).

Probably one of the best known exotic species in the Great Lakes is the sea lamprey. This predatory, eel-like fish is native to coastal regions of the Atlantic Ocean. The lamprey probably gained access to the Great Lakes through the Welland Canal between Lake Erie and Lake Ontario around 1921 (Minnesota Department of Natural Resources, 1992). The lamprey obtains nourishment by sucking the blood and bodily fluids from other fish species. It is estimated that an adult lamprey can kill 40 pounds of fish in 12 to 20 months. (Michigan Department of Natural Resources, 1993). Predation by the sea lamprey was an important factor in the decline of the whitefish and trout fisheries in Lake Michigan during the 1950s.

The ruffe is a small (rarely growing above 5 or 6 inches length) fish native to central and eastern Europe. This member of the perch family was introduced, probably through ship ballast water, to the Duluth, Minnesota area of Lake Superior about 1985. Ruffe are characterized by sharp spines on their gill covers, dorsal fins, and anal fins which protect them from predators. The ruffe feeds on fish eggs, and it competes with other fish species for habitat. The adaptability and high reproductive rate of the ruffe may allow this fish to displace native fish species in the Great Lakes (Minnesota Department of Natural Resources, 1992; Michigan Department of Natural Resources, 1993).

Although the ruffe has not been observed outside Lake Superior at present, it could be transported inadvertently to other areas of the Great Lakes. Spread of the ruffe could thus, become a potential threat to biological diversity and to sport or commercial fishing in the Great Lakes. It is difficult to estimate what effects the ruffe could have on the ecosystem of Lake Michigan in Indiana; however, some insights may be gained from previous incidents in which ruffe were introduced into a new habitat. In the St. Louis River near Duluth, populations of perch and emerald shiners have been observed to decline as the population of ruffe increases. Furthermore, invading ruffe have displaced native perch and whitefish populations in some Scottish and Russian lakes (Minnesota Department of Natural Resources, 1992).

Another recently-introduced species in the Great Lakes Basin is the spiny water flea. This animal is a small (usually less than 0.5 inch length) crustacean characterized by a long, barbed, tail-spine. Native to Great Britain and Northern Europe, the spiny water flea was first detected in Lake Huron in 1984 and has since spread throughout the Great Lakes and other inland waters (Minnesota Department of Natural Resources, 1992). The spiny water flea consumes zooplankton, an important component of the diets of many young fish. The long, barbed tail of the spiny water flea makes it difficult for small fish to consume. However, larger fish in Lake Michigan do prey on the spiny water flea. The spiny water flea

Clean Lakes projects are currently being developed for Wolf Lake and George Lake at Hammond. As part of the program, the Hammond Parks Department has been funded to develop a Watershed Management Plan for each lake. In addition to the Clean Lakes Program in Indiana, a similar grant has been funded by the Illinois EPA for Wolf Lake, since a portion of Wolf Lake resides in Illinois. The Illinois Water Survey is conducting technical studies which include bathymetric surveys, water-quality sampling, and investigations to determine ground-water and surface-water interaction. The one-year water-quality sampling phase has been completed and the hydrologic studies are still in progress. A final report by the Illinois Water Survey should be complete by the end of 1994 or early 1995.

During 1989, a statewide citizen Volunteer Monitoring Program was also established as a part of the Clean Lakes Program. Citizen volunteers were equipped and trained to measure Secci disk transparencies at their lakes as a low-cost, high-volume lake monitoring tool. None of the lakes monitored in this volunteer program are located in the Region.

The only lake besides Lake Michigan which is part of the IDEM fixed-station water-quality monitoring network (table 18 and figure 41) is Wolf Lake. Sampling at the Wolf Lake station near the Indiana/Illinois state boundary has been occurring since 1966. Samples are analyzed for physical parameters, chemical constituents, and the abundance of fecal coliform. Sampling of more recent years at Wolf Lake and all other has been observed in the southern part of Lake Michigan, but does not appear to have adversely affected fishing in southern Lake Michigan as of this writing (Michigan Department of Natural Resources, 1993; Todd Pederson, Indiana-Illinois Sea Grant, personal communication, 1994).

The zebra mussel is a small (generally less than 2 inches) freshwater mollusk native to the Caspian Sea Region which has become an ecological concern since being unintentionally released into North American waters. These clam-like mussels apparently entered the Great Lakes ecosystem in 1985 or 1986, when ships discharged ballast water contaminated with zebra mussel larvae into Lake St. Clair near Detroit, Michigan. Since its arrival in North America, the zebra mussel has spread to parts of all the Great Lakes, the Mississippi River and other inland waters. Zebra mussels probably reached the Indiana coast of Lake Michigan during 1989 or 1990 (Todd Pederson, Illinois-Indiana Sea Grant Extension Program, personal communication, 1994; Snyder, 1990).

The rapid spread of zebra mussels in the Great Lakes can be attributed to this organism's tolerance of various environmental conditions, and its reproductive and developmental cycles. A female zebra mussel may produce as many as 1 million eggs in a single year. These eggs can hatch free-swimming, microscopic larvae called veligers which may be carried long distances by prevailing currents or in the ballast water of ships. Within 1 to 3 weeks of hatching, the surviving veligers attach to a solid substrate and begin growing a shell. A veliger may develop into a mature zebra mussel capable of reproduction within a year of hatching.

Adult zebra mussels generally live in colonies that form on hard substrates wherever dissolved oxygen and food are available and currents do not exceed 6 feet per second. Colonies of zebra mussels are thus, rarely found in wave-washed zones, except in sheltered niches and crevices. The colonies are often characterized by a high number of individual zebra mussels assembled in a small area. For example, it is estimated some zebra mussel colonies in Lake Erie contain over 30,000 and up to 70,000 organisms per square meter (Snyder, 1990; Minnesota Department of Natural Resources, 1992).

Like certain other species of mollusk, zebra mussels feed by filtering algae and plankton from the water column. An adult zebra mussel may filter up to 1 liter of water per day; thus, colonies containing thousands of zebra mussels may remove much of the algae from a water body, and leave an insufficient food supply for other aquatic organisms. Uneaten plankton and algae are bound to mucous and ejected from the zebra mussel as pellets called pseudofeces. Plankton bound up as pseudofeces is unavailable for fish and other aquatic organisms. Furthermore, laboratory studies indicate that the *biochemical oxygen demand* associated with the decay of pseudofeces may cause decreases in dissolved oxygen and pH levels around zebra mussel colonies. It is possible that the low DO and acidic conditions associated with pseudofeces decay may be detrimental to the eggs of game fish species such as walleye, white bass and smallmouth bass (Snyder, 1990).

The zebra mussel invasion may also affect water supply and recreational activities in the Great Lakes. The zebra mussel's requirement of a hard substrate for anchorage makes industrial and municipal water intakes susceptible to clogging by zebra mussel colonies. Reduced pumping capacities and occasional shutdowns of some water intakes on Lake Erie have been attributed to zebra mussel infestation. Recreational activities can also be affected when zebra mussels colonize docks, breakwaters, boat hulls, and the cooling-water intakes of boat engines. Beaches may also be adversely affected by the zebra mussel, because deposits of hard, sharp-edge zebra mussel shells may be washed ashore during periods of high wave activity. Extensive deposits of such shells were observed on bathing beaches along Lake Erie during the fall of 1989. The U.S. Fish and Wildlife Service estimates that the economic costs of the zebra mussel invasion may reach 5 billion dollars over the next decade (Snyder, 1990; Michigan Department of Natural Resources, 1993).

Numerous other exotic species have been detected in Lake Michigan and other Great Lakes. In the future, some of these exotic species may displace certain indigenous plants and animals in the Great Lakes Basin. Additional exotic animal species of concern include the rusty crayfish, and various fish species such as the goby, the common carp, and the white perch. Aquatic-plant species which have recently been introduced to the Great Lakes Basin include the purple loosestrife, the flowering rush, and the eurasian watermilfoil. These exotic plants could possibly displace aquatic and wetland plant species which provide food, cover or nesting sites for various animals (Minnesota Department of Natural Resources, 1992; Michigan Department of Natural Resources, 1993).

stations within the network includes analyses of many more constituents than that of earlier years. Selected water-quality parameters from the Wolf Lake monitoring station are discussed on page 143.

The IDEM also samples fish tissue and sediments to assess the extent of contamination by toxic and *bioconcentration* substances in lakes and reservoirs having high recreational use or a potential for contamination (Indiana Department of Environmental Management, [1994?]). George Lake at Hammond, Lake George at Hobart, Wolf Lake, and Marquette Park Lagoon are part of the fish tissue and sediment monitoring program in the Lake Michigan Region.

Another lake-quality management program which includes limited water-quality sampling is the lake-enhancement program. Administered by the IDNR Division of Soil Conservation, the lake-enhancement program provides technical and financial help to control sediment input and associated nutrient problems in public-access lakes. At the present time, there are no lake enhancement projects in the Lake Michigan Region.

Other state programs monitor lake quality for public health, recreational, or fisheries management purposes. The IDNR has a policy of having E. coli sampling performed in water on properties which have state-operated public beaches, including Lake Michigan at Dunes State Park, to determine violations of standards for swimming and wading. Sampling results are generally reported to the Division of Engineering. The IDNR

Division of Fish and Wildlife conducts lake surveys in which physical, chemical and fish community data form the basis for fisheries management recommendations. In the Lake Michigan Region, lake surveys and other fisheries projects have been conducted on four of the lakes on the selected list of lakes in table 10: Wolf Lake, George Lake at Hammond, Lake George at Hobart, and Hog Lake. In addition, the following lakes of greater than 25 acres also have been sampled: Marquette Park Lagoon, Grand Boulevard Park Lake, Kennedy Park Oxbow, and Hobart Township Park (Rosser) Lake. The Division of Fish and Wildlife also conducts aquatic weed control and fish restoration projects to improve game fishing and enhance the recreational value of selected lakes.

On the federal level, the U.S. Environmental Protection Agency (USEPA) conducted a National Eutrophication Survey in 1973 and 1974 in which 27 Indiana lakes and reservoirs were seasonally sampled. The Agency then funded Purdue University to resurvey 15 of these lakes in 1977 to determine changes in trophic condition. None of the lakes surveyed in the national study are located in the Lake Michigan Region (Spacie and Bell, 1980; and U.S. Environmental Protection Agency, 1976a).

A cooperative project between IDNR and IDEM, utilizing USEPA non-point source pollution control funds (Section 319 of the Clean Water Act), has recently been undertaken for Wolf Lake. The project has three aspects: a lake sediment sampling program designed to detect unpermitted wastewater discharges into the stormwater collection system; an Urban Water Conservation Specialist to train and educate; and a training program in water-pollution case development for conservation officers.

The National Biological Survey has recently begun to sample the Marquette Park Lagoons. A total of eight sites were sampled during 1994 including analyses of conventional parameters and nutrients. In addition, aquatic toxicity testing was performed and assessments were made of contaminants of water and sediments. Plant, macroinvertebrate, and fish distribution were also determined.

Assessment of lake quality

The five major lakes and reservoirs of the Lake Michigan Region from table 10 which are included in the Indiana Lake Classification System range widely in water-quality characteristics, lake *morphometry*, and management needs. Two of the lakes are of either low (Class 1) or moderate (Class 2) eutrophy, Hog and Swede lakes, respectively, and rarely have water quality problems that impair attainable lake uses. Two of the lakes in the region, Wolf Lake and Lake George at Hobart, are highly productive (Class 3). These lakes usually support periodic algal blooms and growth of aquatic weeds which impair one or more lake uses.

One of the lakes (table 10) in the region, George Lake at Hammond, is assigned a Class 4 status in the IDEM's Lake Classification System. Class 4 lakes are generally small, shallow, natural water bodies that are in an advanced state of senescence. They are often nearly filled with aquatic weeds and organic sediments, and frequently are on their way to becoming a swamp, bog, or marsh. Water quality in these remnant lakes may be good, but the majority of Class 4 lakes are not large enough or deep enough for swimming, water skiing, boating, or building sites. The most common uses of Class 4 lakes are hunting, fishing, trapping, and wildlife habitat.

Although table 10 lists only one Class 4 lake, the Marquette Park Lagoons have also been placed in the IDEM classification system as trophic class 4 lakes. Smaller lakes of all classes may also exist in the region.

In 1986, IDEM biologists conducted a limnological study of the Marquette Park Lagoons. Low levels of total phosphorous and total nitrogen were measured in the east lagoon, and green species of plankton were dominant. The west lagoon was characterized by higher levels of phosphorous and nitrogen, and a higher percentage of blue-green algae species relative to the east lagoon. PCBs were detected in the tissues of some fish specimens from the Marquette Park Lagoons, but not at levels exceeding the Food and Drug Administration's *action level* for total PCBs (Indiana Department of Environmental Management, 1991).

Results of fish surveys of natural and man-made lakes provide an additional source of information on water quality of lakes in the Region. Some of the surveys include direct water-quality measurements, while others may have observations concerning water quality. The numbers, type, and size of fish recorded in the survey may also provide insight into the overall water quality of the lake. Good water quality in a lake can result in a full array of size and age classes of fish. In addition, many of the lakes have multiple-year surveys which may provide insight into changes in the lake through time. The surveys also include recommendations for improvement of water quality and fish populations.

Only the fisheries surveys of lakes having more than 25 acres were reviewed for this report. These include Hog Lake, Wolf Lake, Lake George at Hammond, Lake George at Hobart, Marquette Park Lagoons, Hobart Township (Rosser Park) Lake, Grand Boulevard Park, and Kennedy Park Oxbow. Summaries of the fisheries surveys may be found in appendix 8, and physical descriptions of these lakes may be found in the Surface Water Hydrology, Lakes Section of this report.

Wolf Lake

The IDEM maintains an active water-quality monitoring station along the southern shores of Wolf Lake (figure 41 and table 17). Data collected at this monitoring station are used in this report to estimate the average levels and variability in concentrations of certain parameters in Wolf Lake. Violations of specific water-quality standards (appendix 6 and table 16), were also analyzed when detected in the data. All data utilized in this analysis were collected on an approximately monthly basis from 1982 to 1992, unless otherwise noted. Summary statistics for some of the parameters collected at the Wolf Lake monitoring station are presented in appendix 7.

Because dissolved oxygen (DO) can be a significant factor in supporting a viable community of organisms, DO levels in samples from Wolf Lake were analyzed and compared to Indiana DO standards established for aquatic-life uses (table 17). None of the Wolf Lake samples contained DO levels below the minimum DO criteria for aquatic-life use (4.0 mg/L). Furthermore, time trends in the data may indicate that higher monthly-average DO levels are generally observed in samples collected from Wolf Lake during late fall and winter than during summer. This possible seasonal pattern in Wolf Lake DO levels may reflect differences in oxygen solubility due to variations in ambient temperatures.

The median pH level of the samples collected from Wolf Lake is approximately 8.2 standard units. This median level may indicate that waters from Wolf Lake are generally within the basic range of the pH scale. A pH range of 6.0 to 9.0 is considered ideal for waters used as aquatic habitats (table 17). No pH measurements below the lower limit of this range, which would indicate excessive acidity, are observed in any of the samples from the Wolf Lake monitoring station. However, slightly over 2 percent of all samples, contained pH levels which exceed the upper limit for aquatic-life use.

Monthly measurements of E. coli bacteria levels in samples collected from Wolf Lake between 1988 and 1992 were analyzed for this report. Approximately 81 percent of all samples from the Wolf Lake monitoring station contained E. coli levels equal to or below 10 organisms per 100 ml. The highest single measurement in any of the samples from Wolf Lake equaled 140 organisms per 100 ml. This highest single-sample level does not exceed the recreational-use limit on E. coli in a single sample (235 organisms per 100 ml) but is however, above the limit for the 30-day average E. coli level (125 organisms per 100 ml).

Total phosphorous and nitrate+nitrite concentrations of 0.03 mg/L and 0.3 mg/L, respectively, may be sufficient to initiate nuisance growths of algae (U.S. Department of Health, Education and Welfare, 1965). Concentrations of these nutrients above levels which may promote algae growth are observed in some water samples from Wolf Lake. Phosphate concentrations exceed 0.03 mg/L in approximately 57 percent of the samples from Wolf Lake, and almost 15 percent of the Wolf Lake samples contain combined nitrate+nitrite concentrations higher than 0.3 mg/L. Furthermore, total nitrogen levels as high as 3400 mg/kg have been observed in some Wolf Lake sediment samples (Indiana Department of Environmental Management, [1988a]).

Measurements of copper, lead and mercury levels in some recent samples from Wolf Lake were analyzed in an attempt to quantify the occurrence of these trace metals in the lake. A total of nine samples collected over the period from December 1988 to October 1991 were available for analysis. Concentrations of copper and lead exceed their detection limits (0.004 mg/L for copper and 0.006 mg/L for lead) in three samples and one sample, respectively. The highest mercury concentration in the examined data equals 0.0038 mg/L, which is almost twice the established MCL for mercury. This violation of the mercury MCL occurs in a sample collected in December of 1988. Mercury levels above the detection limit for this metal (0.0001 mg/L) were not observed in the remaining 8 samples.