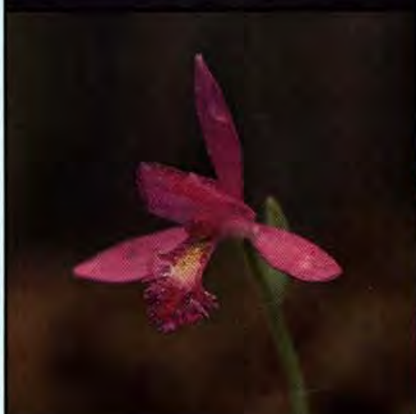
WATER RESOURCE AVAILABILITY IN THE LAKE MICHIGAN REGION, INDIANA



STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

1994

WATER RESOURCE AVAILABILITY IN THE LAKE MICHIGAN REGION, INDIANA

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Water Resource Assessment 94-4

Printed By Authority of the State of Indiana
Indianapolis, Indiana: 1994

STATE OF INDIANA
Evan Bayh, Governor

DEPARTMENT OF NATURAL RESOURCES
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Compilation and development of the final report was the primary responsibility of the Basin Studies Section of the Planning Branch

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MAJOR ACRONYMS AND ABBREVIATIONS

DOW	Division of Water
IDEM	Indiana Department of Environmental Management
IDNR	Indiana Department of Natural Resources
IGS	Indiana Geological Survey
IJC	International Joint Commission
ISBH/ISDH	Indiana State Board of Health/Indiana State Department of Health
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
USDA	U.S. Department of Agriculture
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
USACE	U.S. Army Corps of Engineers

bg	billion gallons
cfs	cubic feet per second
°F	degrees Fahrenheit
I.C.	Indiana Code
m.s.l.	mean sea level
gpd	gallons per day
gpm	gallons per minute
MCL	maximum contaminant level
mg	million gallons
mgd	million gallons per day
mg/L	milligrams per liter
ml	milliliter
SMCL	secondary maximum contaminant level
sq. mi.	square miles

SELECTED CONVERSION FACTORS

Multiply	By	To obtain
	AREA	
Acres	43,560	Square feet
	0.001562	Square miles
	VOLUME	
Acre-feet	0.3259	Million gallons
	43,560	Cubic feet
	FLOW	
Cubic feet per second	0.646317	Million gallons per day
Gallons per minute	0.002228	Cubic feet per second
Gallons per minute	0.0014	Million gallons per day

WATER RESOURCE AVAILABILITY IN THE LAKE MICHIGAN REGION, INDIANA

INTRODUCTION

Water is a vital resource which greatly influences Indiana's socio-economic development. Ground-water and surface-water supplies serve a diversity of human needs, ranging from non-withdrawal uses such as instream recreation to large water withdrawals for public supply, industry, power generation and agriculture. Demands on the water resource are expected to increase as Indiana's economy and population continue to grow. Effective management of the water resource is possible only through a continuing assessment of the interactions between water availability and use.

BACKGROUND AND APPROACH

Issues concerning water supply and use in Indiana historically have been addressed on a case-by-case basis. The need for a comprehensive approach to conservation and management of Indiana's water resource led to the 1983 enactment of the Water Resource Management Act (I.C. 13-2-6.1).

Under this legislative mandate, the Natural Resources Commission must 1) conduct a continuing assessment of water resource availability, 2) conduct and maintain an inventory of significant withdrawals of surface water and ground water, and 3) plan for the development and conservation of the water resource for beneficial uses.

The legislation further mandates the continuing investigation of 1) low stream-flow characteristics, 2) water use projections, 3) the capabilities of streams and aquifers to support various uses, and 4) the potential for alternative water supply development.

The Indiana Department of Natural Resources, Division of Water, serving as the commission's technical staff, is achieving these legislative directives through ongoing investigations of water resource availability, water use, and conflicts involving limited water supply or competing uses.

Although conflicts between supply and demand typically are of a local nature, ongoing assessments of water availability and use are being conducted on a regional scale using the 12 water management basins designated by the Natural Resources Commission (figure 1).

A drainage basin, or watershed, is defined by the land surface divide that separates surface-water runoff between two adjoining regions (figure 2). A basin encompasses all of the land that eventually drains to a common river.

One disadvantage of using a drainage divide as the boundary of a water management unit is the potential oversight of factors that influence water resource issues but are located geographically outside of the basin. On the other hand, the basin approach allows local conditions or problems to be evaluated as parts of a unified hydrologic system. This integrated approach to a basin's water resource stems primarily from a recognition of the interrelated elements of the hydrologic cycle (figure 2), a continual exchange of water between the atmosphere and earth.

A comprehensive assessment of a basin's water resource requires an understanding of the socioeconomic setting, physical environment and hydrologic regime (figure 3). The complex interactions among these natural and manmade factors define the availability of a suitable water supply, which subsequently influences urban and industrial expansion, economic and agricultural development, and population growth. The water availability reports prepared by the Division of Water address these interactions in an attempt to comprehensively assess the water resource and its potential for further development.

PURPOSE AND SCOPE

This report describes the availability, distribution, quality and use of surface water and ground water in the

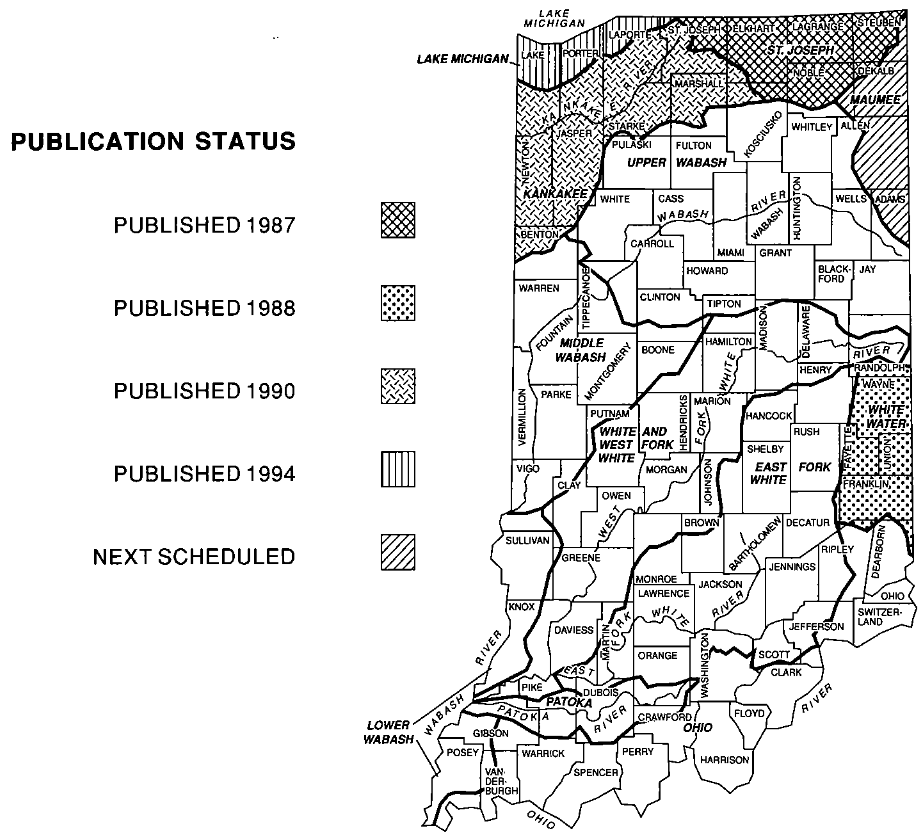


Figure 1. Location of Indiana water management basins and status of water availability reports

Lake Michigan Region, Indiana (figure 4). The fourth in a series of 12 regional investigations (figure 1), the report is intended to provide background hydrologic information for persons interested in managing or developing the region's water resource.

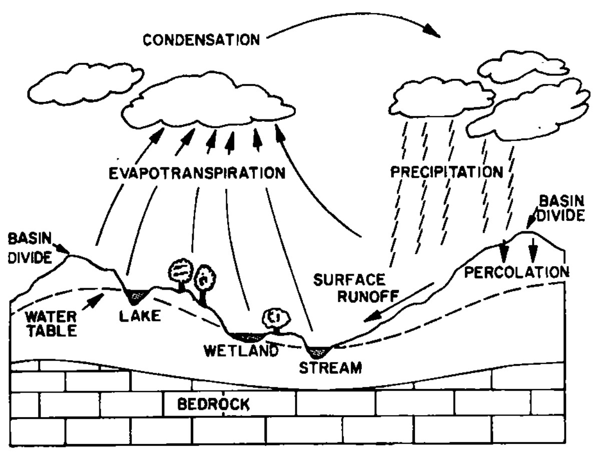
The Lake Michigan Region in Indiana is predominantly urban and is one of the state's most heavily populated and industrialized areas. It has been described as the area having the greatest concentration of iron and steel mills and electric-generating facilities in the world. The Region also maintains one of the largest refineries in the United States. The highly developed industrial/urban complex is served by major transportation networks including rail systems, interstate and local highways, and the St. Lawrence inland water navigation system. Yet, the Region also contains hundreds of acres of natural areas including wetland, woodland, and dune and swale ecosystems.

The eastern shore of the Lake Michigan Region, where the Indiana Dunes State Park and Indiana Dunes National Lakeshore have preserved much of the dune and wetland areas, provides a sharp contrast to the western urban/industrial complex.

Four Indiana counties lie partly within the Lake Michigan Region (table 1). The largest city within the Region is Gary, in Lake County. Other major population centers, including Hammond and East Chicago, coalesce with Gary to form a nearly continuous urban environment along the western shore of Lake Michigan.

The study region is bounded on the north by Lake Michigan and the Michigan state line; on the west by the Illinois state line; and on the south by the crest of the Valparaiso Moraine (figure 4). About 2 percent of Indiana's land area lies within the Lake Michigan Region.

The Lake Michigan Region, as defined in this study, encompasses a total of approximately 604 sq. mi.



Water that falls to the earth as precipitation follows many paths on its way back to the atmosphere. Precipitated water may be intercepted and taken up by plants; it may infiltrate the soil; it may be stored in small depressions, wetlands and lakes; or it may flow over the land surface to a nearby stream channel.

Some of the water used by plants returns to the atmosphere through the process of transpiration. Some of the water in streams, lakes and soils returns to the atmosphere through the process of evaporation.

Precipitated water that is not taken up by plants, evaporated, or stored in upper portions of the ground surface can percolate through open spaces in soil and rock formations to become ground water. A portion of the slowly moving ground water eventually returns to the surface as seepage to springs, lakes, wetlands and rivers. Some of the discharged water is evaporated from the surface to re-enter the atmosphere, and the hydrologic cycle continues.

Figure 2. Major components of Hydrologic cycle

(square miles) of land in northwest Indiana and approximately 241 sq. mi. of Lake Michigan. The Region, as it exists today, forms a portion of two separate major drainage basins. Of the total area in the Region, about 81 percent (489 sq. mi.) is drained by streams that flow directly into the Indiana portion of Lake Michigan. The remaining 115 sq. mi. or 19 percent is drained by streams that flow either into the state of Illinois or Michigan.

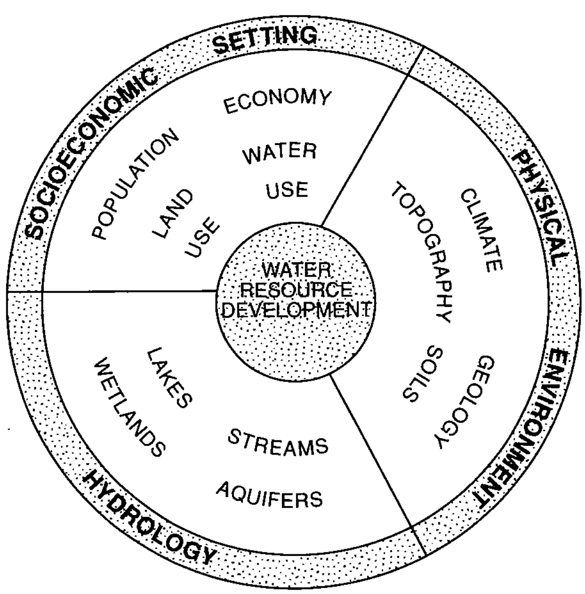


Figure 3. Factors influencing water availability

Most of the streamflow leaving the Region to enter the state of Michigan eventually reaches Lake Michigan. However, little if any, of the streamflow leaving the Region to enter the state of Illinois reaches Lake Michigan. The latter travels through the Mississippi River Basin and into the Gulf of Mexico (figure 4).

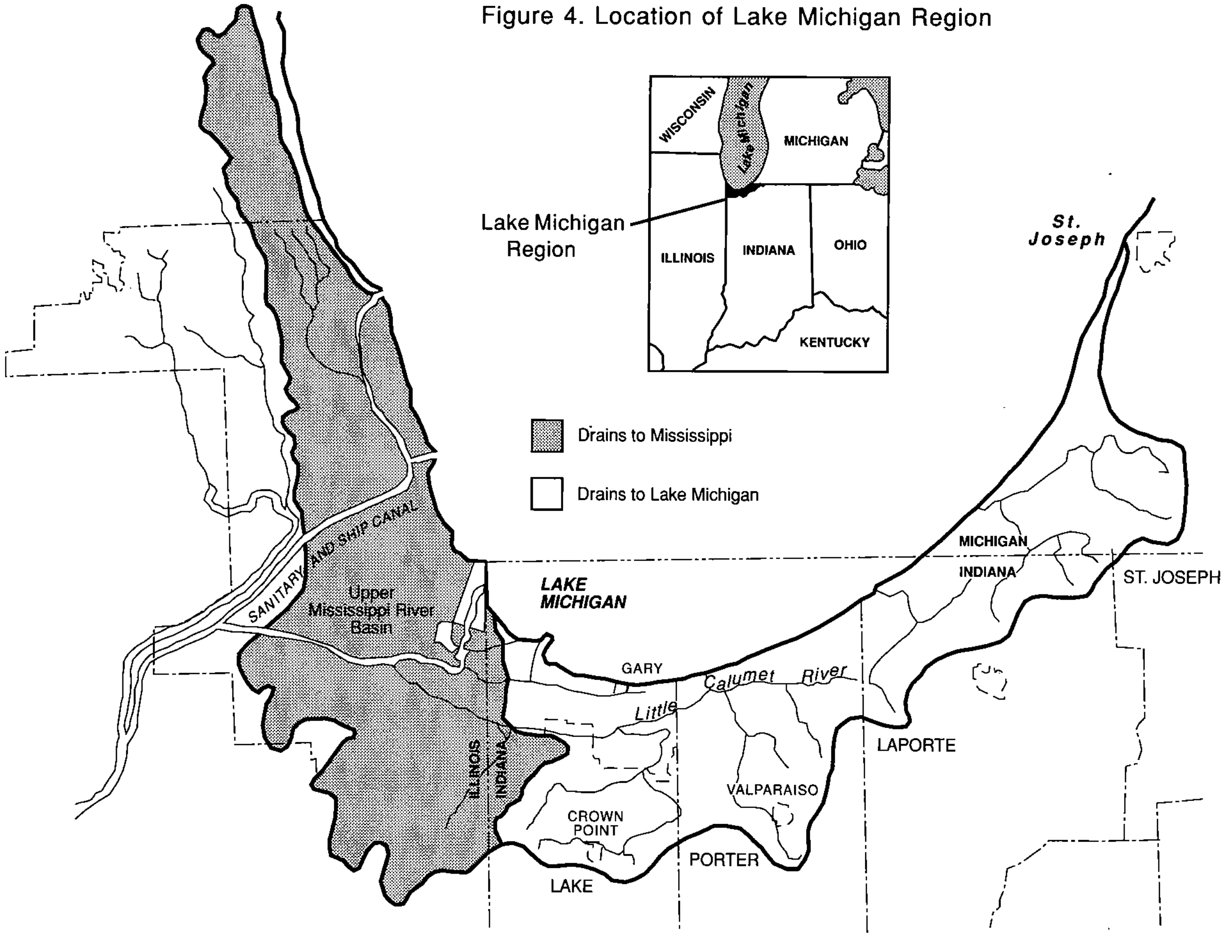
Streams of the Region include the Little Calumet, Grand Calumet, Galena, Trail Creek and an extensive network of smaller tributary streams and ditches. Surface drainage within the Lake Michigan Region is quite complex. The natural hydrology has been altered considerably because of modification of the landscape, urbanization and industrializaton of the Region.

Although the Lake Michigan Region drainage system covers parts of two drainage basins in three states, this report examines only the Indiana portion unless otherwise indicated. In general, discussions apply to in-basin portions of Lake, Porter and LaPorte Counties, which constitute 99.5 percent of the study area (figure 4, table 1).

Unless otherwise noted, data in this report are compiled only for areas lying within the study boundary. However, some economic, land use and agricultural information are for entire counties.

The information presented in this report should be suitable as a comprehensive reference source for public and private interests including governmental, agricultural, commercial, industrial, and recreational. However, the report is not intended for evaluating site-specific water resource development projects. Persons involved in such projects should contact the Division

Figure 4. Location of Lake Michigan Region



of Water for further information.

The contents of the report follow the generalized scheme shown in figure 3. An overview of the population, economy, land use, and categories of water use is followed by a discussion of climate, geology and soils. The report then describes the Region's surface-water and ground-water hydrology, including water quality. The final section of the report summarizes current and potential water use, and examines areas of past or potential conflicts between water demand and available water supply.

Because the report is written for a wide spectrum of readers, key technical words within the text are italicized the first time they appear, and where appropriate thereafter. Brief definitions are given in the glossary. An appendix includes data tabulations and illustrations which supplement the information found within the body of the report.

Water-use information presented in this report was derived from data compiled by the Division of Water on a continuing basis. Water-well records and other data on file at the division were used to define the hydrogeologic conditions of the basin.

Field investigations conducted by the Division of Water and the Indiana Geological Survey between 1986 and 1988 provided additional data on the geology and ground-water quality of the basin. A series of gamma-ray logs and test borings in areas of sparse geologic data were conducted in order to better define the Region's geology and the hydraulic characteristics of surficial materials. The collection and analysis of 25 water-well samples yielded information on ambient ground-water quality throughout the study region.

The remainder of the information in this report was derived, summarized or interpreted from data, maps and technical reports by various state and federal

Table 1. Area of Indiana counties within the Lake Michigan Region

County	Total area (sq mi)	In-region area (sq mi)	Percent of total region area
Lake	501	266	44.0
LaPorte	600	138	22.9
Porter	419	197	32.6
St. Joseph	459	3	0.5
Total	1979	604	100

agencies. Specific sources of data are referenced within the report. A list of selected references is included at the end of the report.

PREVIOUS INVESTIGATIONS

Because published and unpublished documents relating to the Lake Michigan Region in Indiana and Illinois are so numerous, only the primary sources used to prepare this report are discussed below. These primary documents and other major references are cited at the end of the report. Additional sources of information are listed within these cited references.

The first attempt in the Region to systematically collect and record all available information on the water resource in Lake and Porter Counties was published by the Lake-Porter Regional Transportation and Planning Commission (1970, revised in 1971). The water resource inventory includes summaries of water uses and sources, water quality programs and sampling results, summaries and outlines of related planning studies, and an extensive bibliography. The Northwest Indiana Regional Planning Commission (1976) prepared a regional plan for Northwest Indiana which includes a description of the region's water resource, population and economic base and sets forth a comprehensive plan for future development. Major components of the plan are land use, housing, and economic development. The Great Lakes Basin Commission (GLBC) in 1975 and 1976 published a Great Lakes Framework Study which encompassed the Lake Michigan Region. The GLBC study includes a framework study report, 25 appendix volumes and an environmental impact statement. The framework study was developed to provide an information base, identify problems, and determine future needs for the Great Lakes Basin; it includes surveys of the physical, biological, social and political resources which make up the Great Lakes Basin. A report by the Governor's Water Resources Study Commission (1980) assessed various aspects of water availability and use for 18 planning and development regions in the state of Indiana. The Lake Michigan Region lies primarily in one of these planning and development regions. Topics addressed in the 1980 report include flood hazard mitigation, land use, soil erosion, sedimentation, water supply, water quality, drainage, irrigation, fish and wildlife habitat, and outdoor recreation.

The geology and ground-water resources of several Indiana counties lying wholly or partly within the Region are addressed in a series of reports by the Indiana Department of Natural Resources and the U.S. Geological Survey (Rosenshein, 1961, 1962, 1963; Rosenshein and Hunn, 1962a, 1968a, 1968b). Maps and reports by the Indiana Geological Survey describe the surficial and bedrock geology of northwestern Indiana (Wayne 1956,1958,1963; Pinsak and Shaver, 1964; Lineback, 1970; Schneider and Keller, 1970; Doheny and others, 1975; Gray, 1982, 1983, 1989; Droste and Shaver, 1982, 1983; Shaver and others, 1986; Gray and others, 1987; Thompson, 1987). Various aspects of geology which are important to environmental planning were presented by Hartke and others (1975) for Lake and Porter Counties and by Hill and others (1979) for LaPorte County. A regional ground-water assessment was compiled by the Northwestern Indiana Regional Planning Commission (1981).

The U.S. Geological Survey (USGS) and the National Parks Service have been studying the hydrology and hydrochemistry of Indiana Dunes since 1973. The first study of the National Lakeshore was a general assessment of both surface- and ground-water quality throughout the Lakeshore (Arihood, 1975). A more detailed study of surface-water quality, of both biological and chemical characteristics, was done by Hardy (1984). Much of the USGS work was done in the area around Cowles Bog National Natural Landmark, a 56-acre tract at the western end of the Great Marsh. Several studies were initiated to assess the potential for changes in the water table and ground-water quality caused by seepage from fly-ash settling ponds and from dewatering for excavation (Marie, 1976; Meyer and Tucci, 1979; and Gillies and Lapham, 1980; Hardy, 1981; Cohen and Shedlock, 1986; Wilcox and others, 1986; and Shedlock and others, 1987). In 1988, Banaszak and Fenelon discussed water quality in a thin water-table aquifer adjacent to Lake Michigan within a highly industrialized region of Indiana, and Watson and Fenelon described the geohydrology of the same aquifer. A preliminary analysis of the shallow ground-water system in the vicinity of the Grand Calumet River/Indiana Harbor Canal was provided by Watson and others (1989). In 1992, the geohydrology and hydrochemistry of the unconsolidated aquifer system at the Indiana Dunes National Lakeshore and the surrounding area are described by Shedlock and others, and the geohydrology and water quality of the Calumet Aquifer in the vicinity of the Grand Calumet River/ Indiana Harbor Canal are discussed by Fenelon and Watson (1993).

The quality of the environment in the heavily industrialized Northwest Indiana has been the focus of a number of studies and planning efforts over the past several decades. Summary tables and a brief description of major environmental studies and sampling projects are presented by the Indiana Department of Environmental Management (IDEM), 1988b. The IDEM report also includes an extensive bibliography and a detailed description of known contamination sites and potential contamination sources.

The U.S. Environmental Protection Agency (US EPA) has funded a number of initiatives to identify, understand, and mitigate environmental problems in the region. One initiative was a four-phase ground-water strategy study for Lake and Porter counties prepared by the Indiana State Board of Health (1983b). A Master Plan for Improving Water Quality in the Grand Calumet River and Indiana Harbor Canal was developed by the U.S. EPA (1985a). More recent initiatives include: a Northwest Indiana Environmental Action Plan (IDEM, 1987); a draft Northwest Indiana Environmental Action Plan/Area of Concern Remedial Action Plan, IDEM (1988b); the Stage One-Remedial Action Plan (RAP) for the Indiana Harbor and Canal, the Grand Calumet River, and the Near-shore Lake Michigan, IDEM (1991); and the Stage Two- RAP: Water Quality Component (1993).

The surface-water hydrology of the Region has been addressed primarily by the U.S. Army Corps of Engineers (USACE) and the Indiana Department of Natural Resources (IDNR), especially in regard to acute flooding problems in the Region. In 1948, the U.S. Army Corps of Engineers was directed by Congress to study the flooding problems along the Little Calumet River drainage system. A report by the USACE in 1965 identifies areas subject to flooding along the Little Calumet River and its tributaries. The IDNR contracted with Horner and Shifrin (1968) to provide discharge hydrographs at various points along the Little Calumet River and its tributaries in Indiana and to also include information on the low flow, flow duration and flood frequency characteristics of the Little Calumet River and its tributaries. The IDNR (1971a) published a summary report on hydrologic data for the Little Calumet River and tributarties for use in flood plain management. In 1973, the U.S. Army Corps of Engineers published a series of reports describing flood-plain information on numerous streams and ditches including Deep River, Turkey Creek, Hart Ditch, and Cady Marsh Ditch. An engineer's report and final environmental impact statement were also prepared by the USACE in 1973 which defined Little Calumet flood control options; supplemental information was added in 1984. The Little Calumet River Basin Commission (1976) published a summary of publications and studies related to flooding along the Little Calumet River.

Crawford and Wangsness (1987) define the stream-flow and water quality of the Grand Calumet River in Lake County, Indiana and Cook County, Illinois during October 1984.

The Chicago and Calumet Rivers were diverted from the Lake Michigan watershed by the construction of the Sanitary and Ship Canal (Main Canal) in 1900 and the Calumet-Sag Channel in 1922. Cooley, (1913) prepared an early brief of facts and issues concerning the diversion of waters of the Great Lakes. The Chicago Diversion resulted in numerous legal actions, the earliest which culminated in the Supreme Court decision-Sanitary District of Chicago v United States, 161 U.S.405 (1925) which allowed the Secretary of War to issue diversion permits. Keifer and Associates (1978) performed a study to determine flows crossing the Lake Michigan diversion boundary line at the Grand Calumet River in Hammond, Indiana and the Little Calumet River at Munster, Indiana. An evaluation of flow measurements and accounting methods for the Lake Michigan diversion was prepared by Harza Engineering Company in 1981. A manual of procedures for Lake Michigan diversion accounting was prepared by the Northeastern Illinois Planning Commission (1985). The latter publication also has a bibliography of legal actions related to the Chicago diversion. Espey and others (1987) prepared, for the U.S. Army Corps of Engineers, the findings of a committee for review of diversion flow measurements and accounting procedures for the Lake Michigan Diversion. The Espey publication includes a narrative on the history of the diversion, including a discussion on the most recent U.S. Supreme Court amendment (1980) to the diversion permit.

As a result of high water levels on the Great Lakes in the 1950's, the U.S. House of Representatives requested the U.S. Army Corps of Engineers (1965c) to determine the feasibility of measures to prevent the recurrence of damages related to high lake levels. Extremely high lake levels recurring in the early 1970's generated additional concern. A report was presented to the International Joint Commission (IJC) by the International Great Lakes Levels Board (1973) concerning potential changes in regulation plans at existing regulatory sites on the lakes as a means of alleviating problems caused by high lake levels. The Great Lakes Basin Commission in their Great Lakes Basin Framework Study, devoted an appendix to discussion of Great Lakes levels and flows (1975b). In 1981, the International Great Lakes Diversion and Consumptive Use Study Board examined effects of consumptive use and diversions on water levels and flows of the Great Lakes Basin. Record high lake levels occurring in 1985 and 1986 resulted in a series of studies and publications concerning Great Lakes water levels. Bixby (1985) prepared, for the Center for the Great Lakes, an overview of Great Lakes Water levels. The U.S. Army Corps of Engineers (1985) prepared a publication about Great Lakes water level facts. Briefings were held by the Corps and the International Joint Commission (1985) with Senators and representatives of the Great Lakes basin states concerning water levels of the lakes. The Great Lakes Commission (1986) published a report concerning water level changes and factors influencing the Great Lakes. A recent investigation has been undertaken by the International Great Lakes Levels Board-International Joint Commission at the request of the United States and Canadian governments to examine and report on methods of alleviating the adverse consequences of fluctuating water levels in the Great Lakes-St. Lawrence River Basin using the most up-to-date techniques and information. Phase I of the IJC investigation, a progress report, was completed in 1989. Phase II, which produced a final recommendations document, was completed in 1993.

Shoreline erosion in the Indiana Coastal Zone has been addressed primarily by the Indiana Department of Natural Resources and the U.S. Army Corps of Engineers. A fairly comprehensive summary of studies preceeding 1979 was prepared by the Indiana Department of Natural Resources (1979b). More recent studies include U.S Army Corps of Engineers (1982), Davis and others (1981), Wood and Davis (1986), and Wood and others (1988).

ACKNOWLEDGEMENTS

The following divisions of the Indiana Department of Natural Resources (IDNR) provided valuable data and assistance during the preparation of this report: Engineering, Fish and Wildlife, Forestry, Nature Preserves, Soil Conservation, State Parks, Outdoor Recreation and Geological Survey (now part of Indiana University). The following organizations also made significant contributions: Indiana Department of Environmental Management; Indiana State Department of Health; Indiana Department of Highways; Indiana State Library (Indiana Division, Government Documents, Data Center); Purdue University (Department of Agronomy); Indiana University (School of Public and Environmental Affairs, Indiana Business Research Center); Illinois Department of Energy and Natural Resources (Water Survey, Geological Survey); National Oceanic and Atmospheric Administration (National Weather Service); U.S. Department of Interior (Fish and Wildlife Service, Geological Survey); U.S. Environmental Protection Agency (Region 5); and U.S. Department of Agriculture (Soil Conservation Service, Agricultural Stabilization and Conservation Service).

The authors of this report thank residents of the Lake Michigan Region for their cooperation during a 1987 ground-water sampling project. In addition, well-drilling contractors contributed water-well records and cooperated with a gamma-ray logging project.

The authors extend their appreciation to technical and support staff of the Division of Water, especially Steve Davis, the Lake Michigan Specialist, for his contribution to the chapter on Coastal Environment. The project manager extends special appreciation to new staff member Surender Sayini and to former staff members of the Basin Studies Section: Rajindra Gosine, Kimberly A. Wade, Cynthia J. Clendenon, and Richard F. Geekie for the invaluable contributions they made to the study. Information specialist Eddie Reynolds prepared the layout and camera-ready copy for the report.

SOCIOECONOMIC SETTING

The demand for water in the Lake Michigan Region is directly linked to the area's population, economy and land use. Industrial processes create the greatest total demand for water in the Region. Water requirements also are high for energy production. Moreover, large quantities of water are needed in and near highly-populated urban centers for public supply. In rural areas, water is needed primarily for domestic and agricultural uses.

POPULATION

In 1990, the estimated population of the Lake Michigan Region (607,424) constituted nearly 11 percent of Indiana's total population (5,544,159). The in-basin portions of Lake, LaPorte and Porter Counties each had at least 65,000 residents in 1990, with Lake County accounting for almost 72 percent of the Region's population.

About 86 percent of the Region's total population in 1990 lived in urban areas of at least 2,500 persons. Fifteen of the 21 urban areas in the Region had population totals of 10,000 persons or greater. Gary and Hammond, the Region's largest cities, had populations of 116,646 and 84,236, respectively. The remainder of the Region's residents in 1990 lived in rural areas, which are defined by the U.S. Bureau of the Census as non-urban farm and non-farm areas of less than 2,500 persons.

Historic and projected population

Historic and projected population totals for in-basin portions of the four counties comprising the Lake Michigan Region are presented in appendix 1. The appendix also includes population values for entire counties and for urban areas within the Region. In-basin population values were derived by using county,

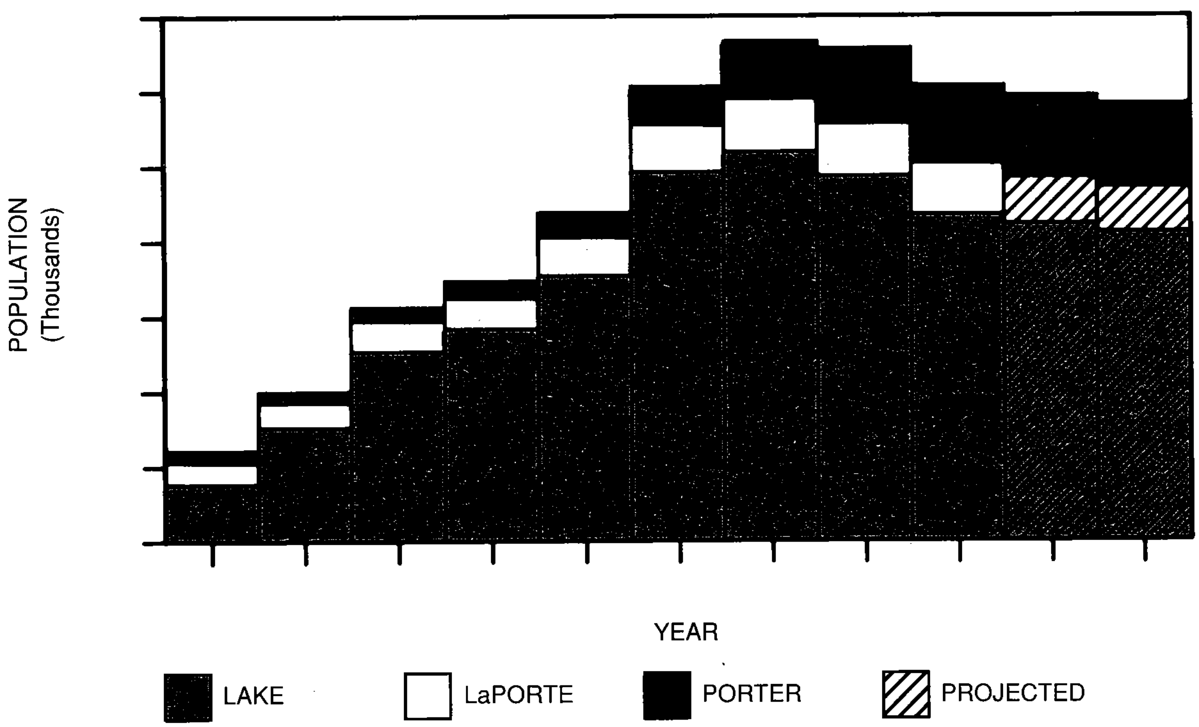


Figure 5. Historic and projected in-basin population of the three most populous counties

township, and urban area U.S. Bureau of Census data. Figure 5 illustrates the historic and projected population changes for the in-basin portions of the Region's three most populous counties Lake, LaPorte, and Porter. These three counties comprise 99.98 percent of the population for the Region.

Since 1910, there has been a 5-fold increase in total population for the Lake Michigan Region (figure 5 and appendix 1). The most rapid increases in population for the Region occurred during the 1950's and 1960's. After reaching a peak in the early 1970's, the total population in the Region began to decline and is expected to continue to decline for the next two decades. Of the three most populous counties in the Region, only Porter County has a population which continues to grow, while Lake County experiences the greatest decline in population (10 percent) since 1980. The primary loss of population in the Region has been in the urban areas in northern Lake County (appendix 1). Of the 21 urban areas in the Region, more than one-half of the towns or cities have experienced population declines since 1980, with New Chicago, Gary and East Chicago experiencing the greatest percentage of decline in population. Schererville, St. John, Dyer and Valparaiso had the greatest percentage increases in population for the same time period. Figure 6 illustrates the historic and projected population changes for selected cities.

The contrasting projections for communities within Lake County primarily reflect the southward shift of

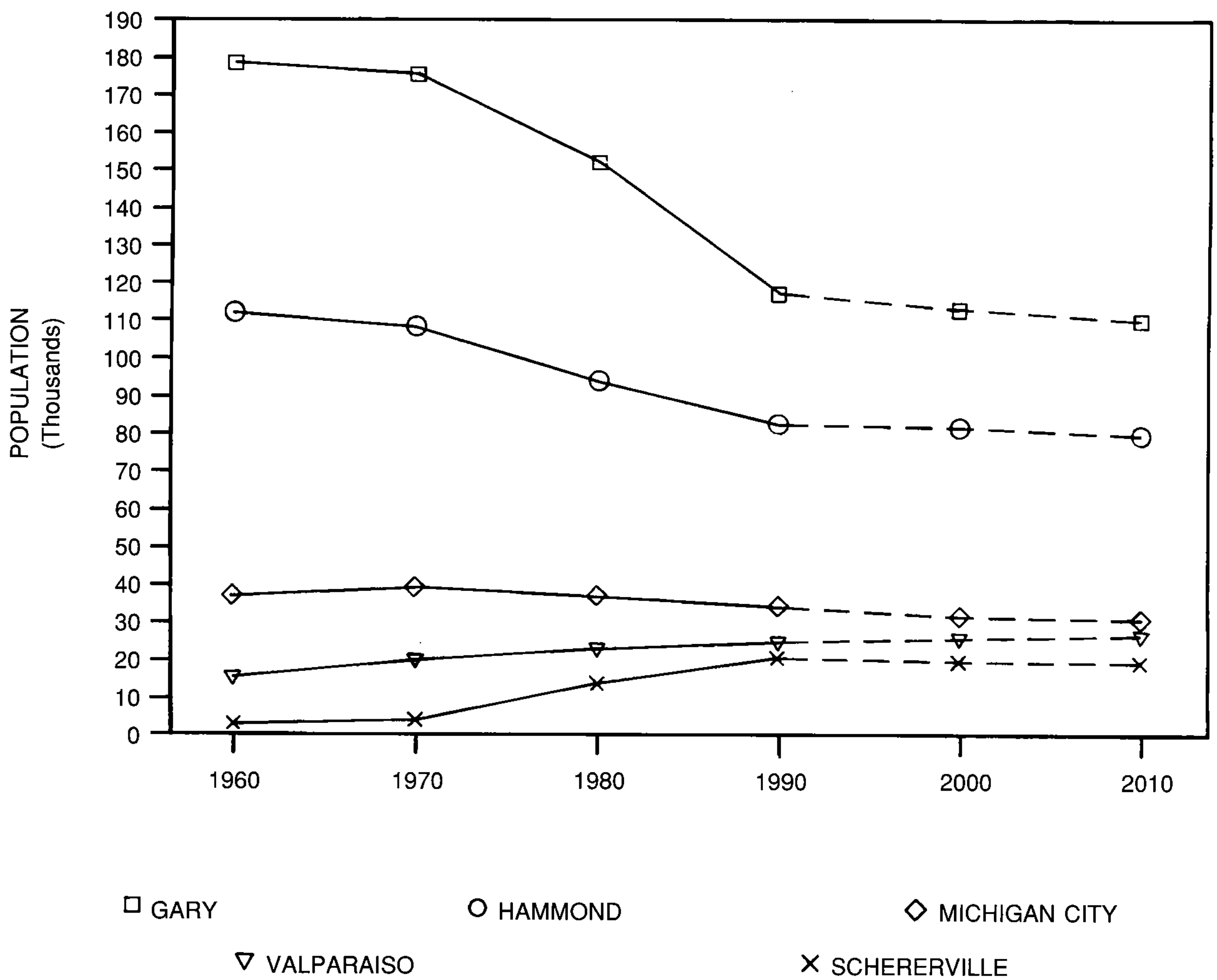


Figure 6. Recent and projected population of selected cities and towns

population from highly urbanized areas near Lake Michigan to urban and suburban areas lying near the southern boundary of the Lake Michigan Region.

ECONOMY

Economic activity within the Lake Michigan Region is an important factor determining water use because different types of industry have specific water resource requirements. In turn, the availability of water resources partially determines the type of industries that can be located in an area.

The lakeshore areas of the Lake Michigan Region form one of the largest industrial and commercial complexes in the world. The lake provides a plentiful supply of water and invaluable transportation for this industrial complex.

Lake Michigan is also part of the St. Lawrence navigation system, one of the most important inland waterway systems in the world. Four deep-draft commercial harbors in the Lake Michigan Region of Indiana provide access to this waterway: Indiana Harbor, Gary Harbor, Buffington Harbor and Burns International Harbor.

The following discussion on the economy of Lake, LaPorte and Porter Counties is based on data that were obtained from a computerized database (STATIS) which is maintained by the Indiana Business Research Center, Indiana University. The economic data refer to entire counties, and thus include areas lying outside the Lake Michigan Region.

Unemployment rates in Lake, LaPorte and Porter Counties were above the state average for most of the 1980's (figure 7). During the decade, unemployment rates in the Lake Michigan Region were highest in Lake County, peaking at 16.3 percent in 1982. LaPorte and Porter Counties experienced peak unemployment during 1983 when the rates were about 14.8 percent in both counties (figure 7). Toward the end of the 1980's unemployment rates were above the state average in Lake and LaPorte Counties but were below the state average in Porter County.

During the 1980's, the estimated per capita income in the Lake Michigan Region was highest in Porter County, staying above the state average during the entire decade (figure 8). Per capita income in Lake and LaPorte Counties was above the state average during the early 1980's. However, from 1984 to 1989 per capita income in Lake County was lower than the state

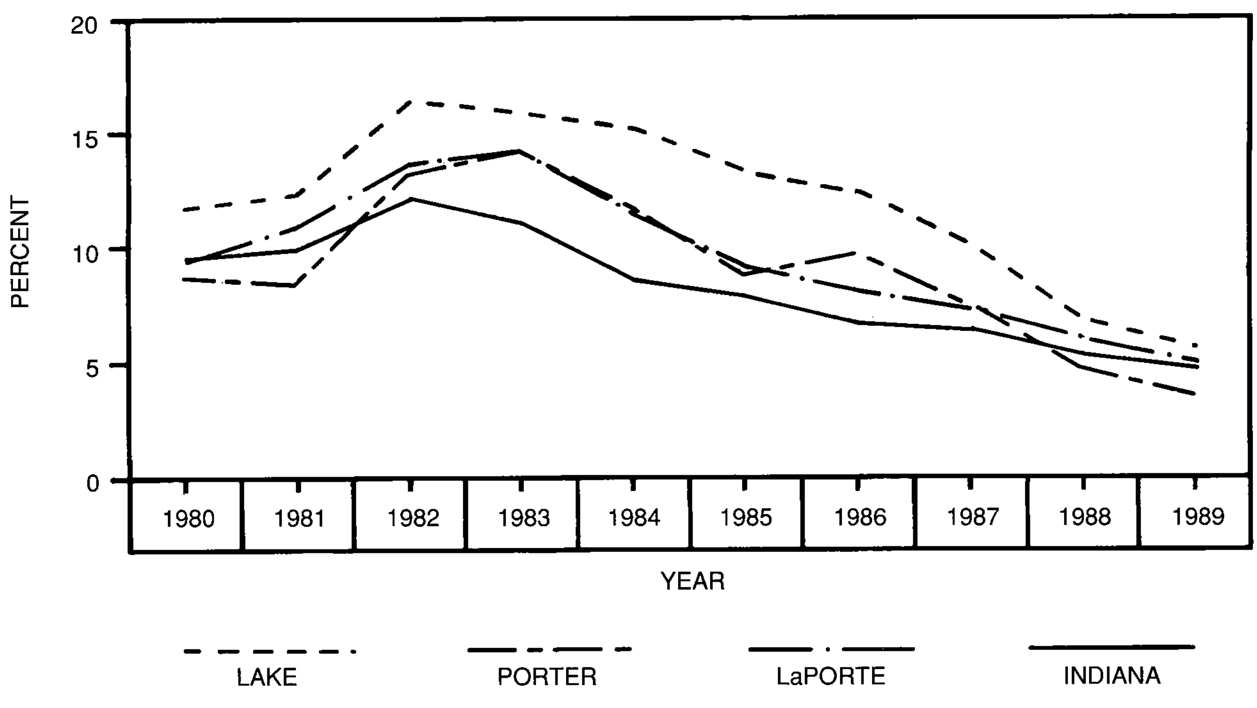


Figure 7. Unemployment rate

average, whereas income in LaPorte County was very close to the state average (figure 8).

Employment and earnings by industry in Lake, LaPorte and Porter Counties are based to a large extent on manufacturing, trade, services and government (figure 9). In 1988, these economic sectors employed more than 253,000 people or about 81 percent of the total workforce, and had a total payroll of $5.9 billion or almost 81 percent of the total earnings in the three counties (figure 9).

Manufacturing had the largest payroll among the economic sectors of Lake, LaPorte and Porter Counties during the period 1980-88 (figure 9). In 1988, the manufacturing sector employed only 22.4 percent of the total workforce, but had a payroll of about 36 percent of total earnings in the three counties (figure 9).

Steel manufacturing plants which dominate the industrial complex of the Lake Michigan Region utilize inexpensive and abundant surface water from Lake Michigan. Many of the steel mills in Lake and Porter Counties are operated by four of the nation's largest steel makers: Bethlehem Steel Corporation, Inland Steel Company, LTV Steel Company and the USS Division of USX. A $100 million steel finishing mill is being built by the Beta Steel Corporation at Burns International Harbor, and if it is successful, a second production facility will be built on an adjacent parcel of land (Indiana Port Commission, 1990b).

Indiana is currently the leading steel-producing state in the country with more than 20 percent of the nation's production in 1988. Although employment has stabilized in the steel industry, the installation of labor-saving machinery in the steel plants has resulted in an increase in steel production over the last few years.

The service and trade sectors of the economy of Lake, LaPorte and Porter Counties have experienced steady growth in employment and earnings since 1984 (figure 9). Since 1986, the service sector has had the largest workforce among the economic sectors in the combined area of Lake, LaPorte and Porter Counties. The shifting or restructuring of the regional economy from a manufacturing base to a service and trade base is the result of expansion in transfer economy (relief, pensions and social security payments), health care, personal care, financial services, legal services and insurance, many of which are financed from external sources (Singer, 1989)

In addition, retail trade and service expansion along U.S. Highway 30 in Lake and Porter Counties are drawing shoppers from a large geographic area. The lakeshore community of Michigan City, the retail hub of LaPorte County, continues to attract numerous shoppers from the eastern part of the Lake Michigan Region. Investments in restaurants, retail shops and

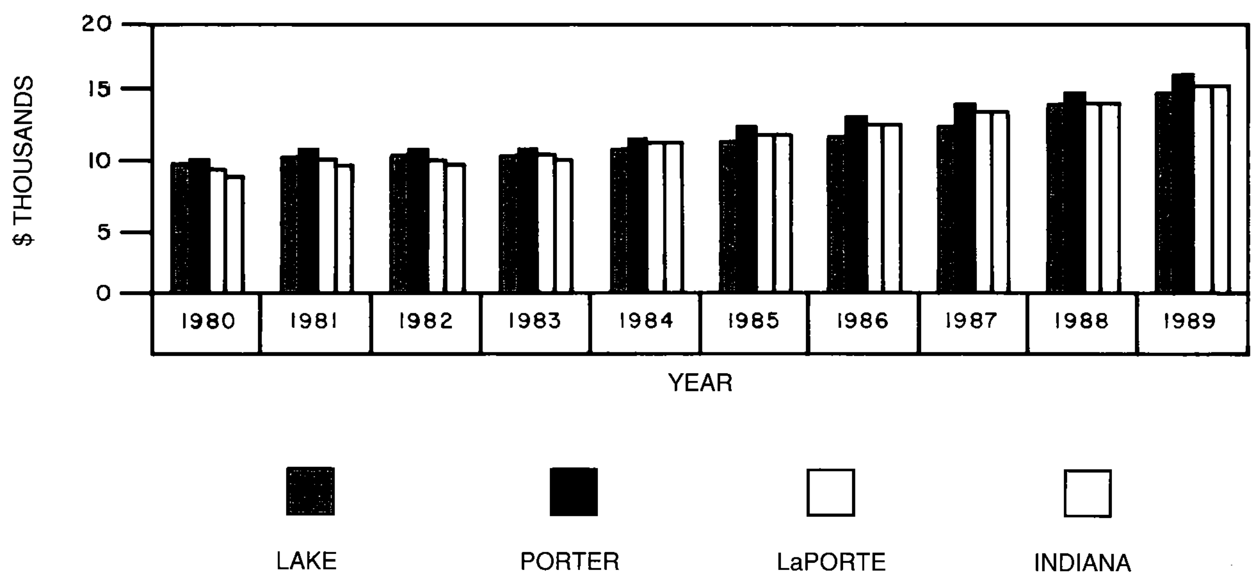


Figure 8. Per capita income

recreational facilities in the tourist areas of northern LaPorte County and the marina districts in Lake, LaPorte, and Porter Counties are expected to stimulate local economic growth. Like the regional trade and service industries, government activities are also concentrated in the urban areas.

The transportation network in the Lake Michigan Region is vital to the economic sectors of the Region. Harbors in the Lake Michigan Region link Indiana to other ports in the Great Lakes and the world. Cargo shipped through the ports in the Lake Michigan Region includes coal/coke, iron ore, steel and steel related products, fertilizer, grain, salt, limestone and petroleum. Burns International Harbor handled more than 8.6 million tons of cargo in 1989, which accounted for more than $46 million in sales and purchases. Counties in northern, central, and even southern Indiana (figure 10) benefit directly or indirectly from Burns International Harbor (Indiana Port Commission, 1990a).

The major industries and communities within the Lake Michigan Region are linked together by the Chicago South Shore and South Bend Railroad, Interstates 80/90 and 94, and U.S. Highways 12, 20 and 30. Studies by the Northern Indiana Commuter Transportation District (NICTD) show that the South Shore trains helped Indiana residents bring in $120 million a year in wages and salaries (in 1987 dollars) from jobs in Chicago (Smerk, 1990).

The smaller economic sectors of Lake, LaPorte and Porter Counties include construction, finance, agriculture, agricultural services, and mining. However, these economic sectors may be important to individual communities that lie within the Region. In 1988 agriculture in Lake, LaPorte and Porter Counties employed about 0.3 percent of the total workforce and had almost one percent of the total earnings, despite being the predominant land use in Lake, LaPorte and Porter Counties and in the Lake Michigan Region.

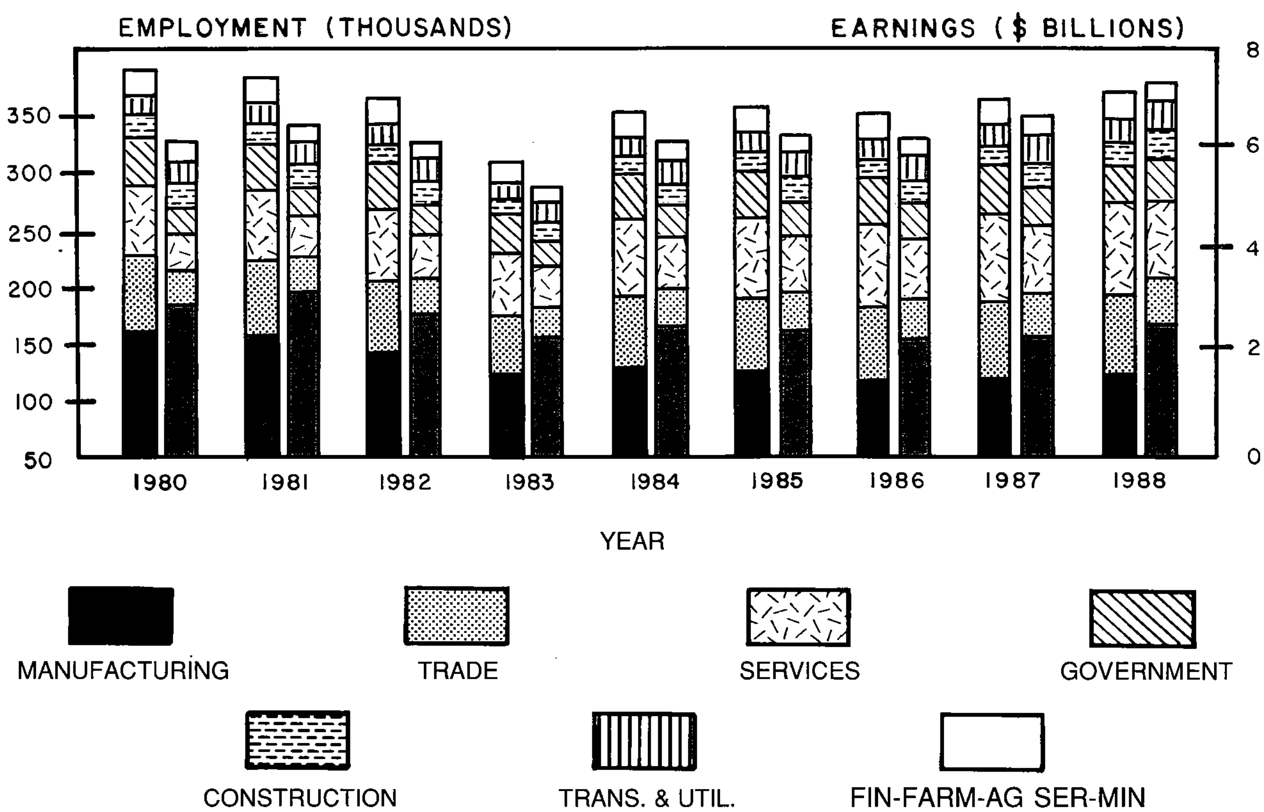


Figure 9. Employment and earnings

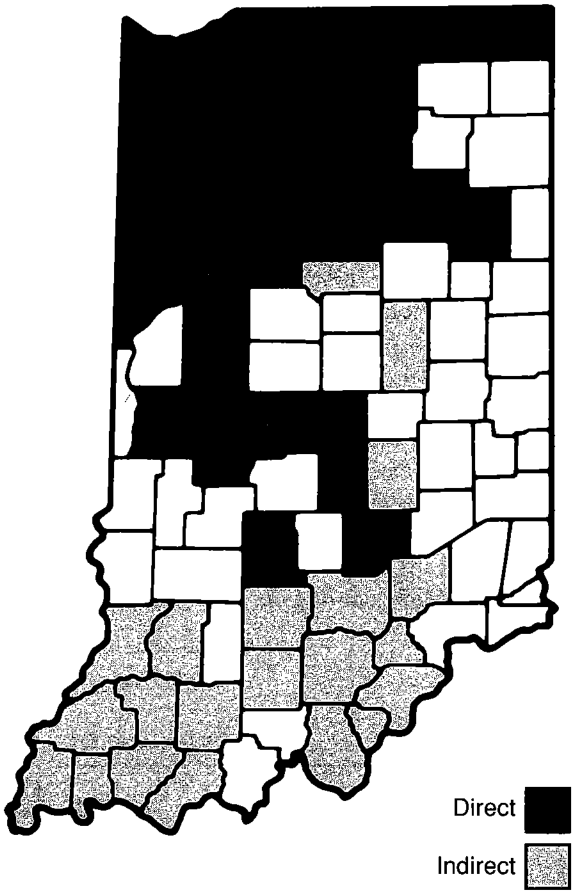


Figure 10. Counties which benefit directly or indirectly from Burns International Harbor in 1989
(adapted from Indiana Port Commission, 1989)

LAND USE

The landscape of the Lake Michigan Region today bears little resemblance to the natural landscape of presettlement times. Until the early 1800's, most of the area north of the Valparaiso Moraine was covered by a vast marsh and wooded swamp. Many areas in the Region were characterized by prairie grasses, and oak *savannas*, with hardwood forests common on the *morainal* uplands.

The current landscape of the Lake Michigan Region is dominated by urban and industrial areas in northern Lake County, and agricultural land in LaPorte and Porter Counties. Remnants of the natural prairie and wetland landscape occur only in isolated parcels in the Region. The Indiana Dunes National Lakeshore and the Indiana Dunes State Park in northern LaPorte and Porter Counties contain the largest expanse of natural forest in the Lake Michigan Region.

The U.S. Geological Survey has produced a series of land-use and land-cover maps by using aerial photographs and other remotely sensed data (Anderson and others, 1976). Land use refers to man's activities which are directly related to the land. Land cover describes the vegetation, water, natural surface and artificial constructions at the land surface (U.S. Geological Survey, 1982). It should be noted that only urban areas, bodies of water, gravel pits and certain agricultural areas of at least 10 acres are mapped. For other land use categories, the minimum mapping unit is 40 acres.

Figure 11 was produced from digital files of the U.S. Geological Survey land-use and land-cover maps using ARC/INFO geographic information system. The date of the aerial photography for the Lake Michigan Region was 1979. Land uses in the Region were grouped into five general categories for illustrative purposes. Tabular data of acreage for each general category and numerous subcategories were also generated from the digital files (appendix 2).

Figure 11 provides a general picture of land use for the Region. Higher resolution data on different types of land use may be obtained from other federal, state and local agencies.

In the Lake Michigan Region, agricultural land constitutes almost one-half of the land. Urban or built-up land accounts for about 29 percent of the Region's land area; forest land for about 17 percent; and water, wetlands and barren land for the remaining 5 percent.

Agricultural land

The U.S. Bureau of the Census compiles and publishes land use data for agricultural land, which is designated as "land in farms". A farm is defined by the bureau as any place from which the sale of agricultural products normally amounts to at least $1,000 during the census year.

Of the five agricultural land use categories defined by the bureau, the following four are mutually exclusive: cropland, woodland, other land, and land set aside in federal farm programs. The fifth category, total pastureland, is the sum of cropland, woodland, and other land used for pasture or grazing.

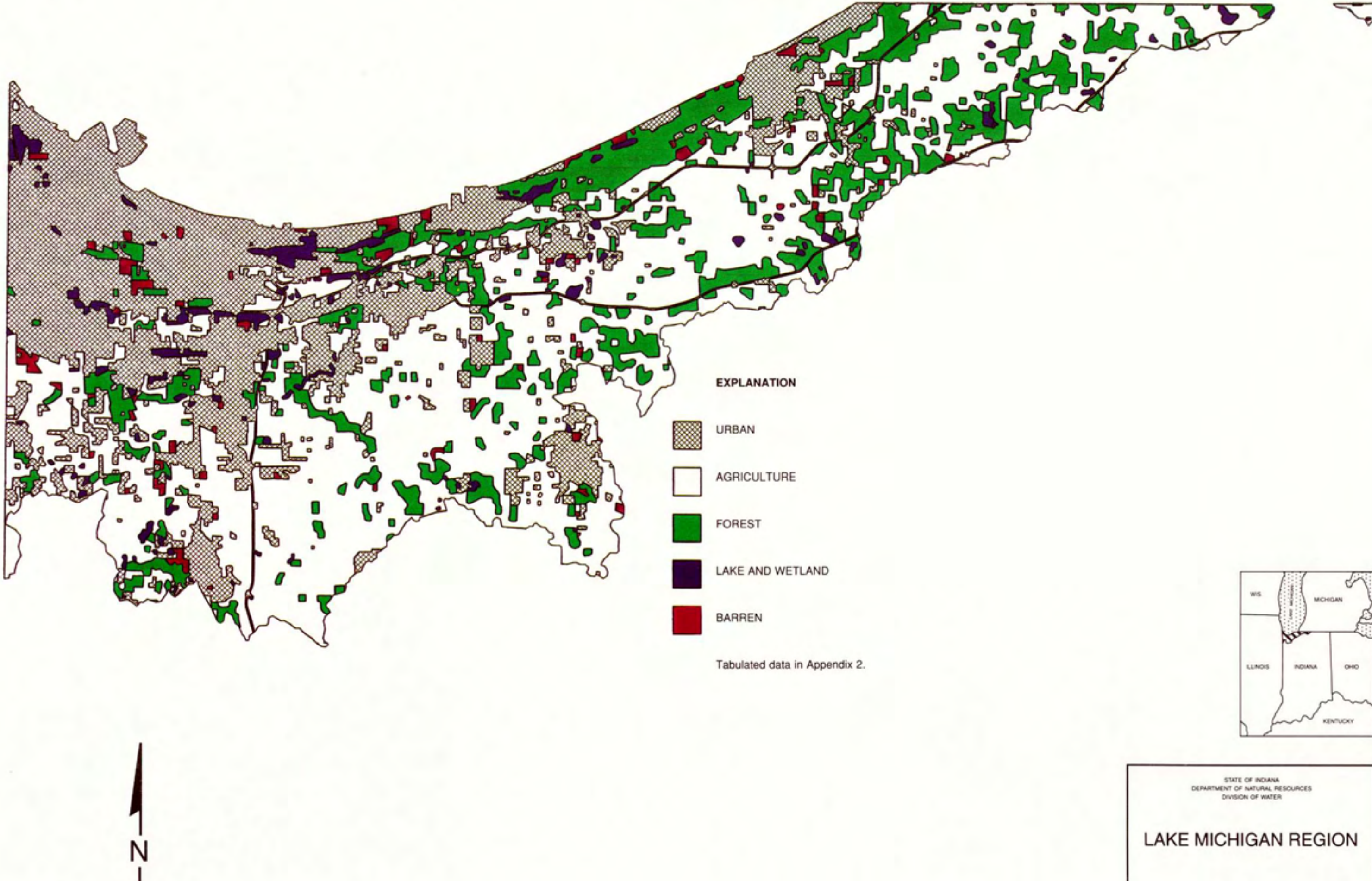


Figure 11. Land use and land cover
(adapted from U.S.G.S., 1982)

Agricultural statistics published by the U.S. Bureau of the Census are available on a county basis, and thus include areas lying outside the Lake Michigan Region boundary. However, the data available for the three major counties lying partially within the Lake Michigan Region nonetheless provide a general overview of agricultural land use.

Table 2 presents county data for the three major land uses on farmland. Cropland accounts for an average of about 90 percent of total farmland in Lake, LaPorte and Porter Counties. Most of the cropland in the Region is classified as harvested cropland, which includes not only land for field crops but also for orchards, vineyards, nurseries and greenhouses. Some small tracts of cropland are used for pasture, grazing, cultivated summer fallow, idle cropland or soil improvement crops. During the 10-year period 1978-87, cropland acreage showed a net increase in Lake County, but a decrease in LaPorte and Porter Counties.

Woodland accounts for an average of about 4 percent of all farmland in Lake, LaPorte and Porter Counties (table 2). Most woodland is used for woodlots, timber production and Christmas tree production.

Farmland designated as "other land" (table 2) constitutes about 6 percent of all farmland, and includes primarily land in house and barn lots, ponds, roads and wasteland. Only small tracts are used solely for pasture or are considered barren land. It should be noted that some of the barren land and land in lots or roads which the U.S. Bureau of the Census considers as agricultural land may be classified and mapped as barren, nonagricultural land by the U.S. Geological Survey.

Land used solely for pasture decreased in most of the counties that comprise the Lake Michigan Region during the period 1978-87. Land set aside in federal farm programs probably has increased since the establishment of the Conservation Reserve Program, which was created following enactment of the 1985 Food Security Act.

Other land

Urban or built-up areas occupy about 29 percent of the land area in the Lake Michigan Region (figure 11). Most of the urban land is concentrated in the northwestern part of the Region. The built-up areas near the shoreline of Lake Michigan form an almost continuous complex across northern Lake County and northwestern Porter County.

Other large tracts of built-up lands in the Lake Michigan Region are found in and near the communities of Crown Point in Lake County, Michigan City in LaPorte County, and Valparaiso, Portage, Chesterton, Burns Harbor and Ogden Dunes in Porter County.

Forest land, about 17 percent of the land in the Lake Michigan Region, generally occurs as small parcels scattered among cropland (figure 11). The predominant forest types in the Region are oak-hickory, elm-ash-soft maple, maple-beech, and cherry-ash-yellow poplar (Smith and Golditz, 1988).

The largest tracts of forested land are located just

Table 2. Selected land use data for farmland

{Values are for entire counties.}

Total area: Acreages are from county land areas listed in Marcus (1985).

Land in farms, total cropland, total woodland, other land: Upper numbers are for 1987 (U.S. Bureau of the Census, 1989); lower numbers are for 1978 (U.S. Bureau of the Census, 1984a).

County	Total area (acres)	Land in farms		Total cropland		Total woodland		Other land	
		Acres	Percent of total area	Acres	Percent of farmland	Acres	Percent of farmland	Acres	Percent of farmland
Lake	320,640	145,566 146,177	45	133,998 130,919	92	4,826 4,561	3	6,742 10,697	5
LaPorte	384,000	258,506 276,416	67	230,944 239,903	89	13,011 16,375	5	14,551 20,138	6
Porter	268,160	162,544 170,470	61	147,170 150,786	90	6,233 9,031	4	9,141 10,653	6

south of the Lake Michigan shoreline, particularly within the Indiana Dunes National Lakeshore and Indiana Dunes State Park. It should be noted that forest on these properties and other parts of the Region may also be classified as forested wetlands by the U.S. Fish and Wildlife Service.

Data on timberland are available on a county basis from the U. S. Forest Service (Smith and Golitz, 1988). Timberland is defined as commercial forest land producing or capable of producing crops of industrial wood and not withdrawn from timber utilization.

Table 3 presents timberland data for Lake, LaPorte and Porter Counties. Because the tabulated values include not only forest land held for non-agricultural uses but also woodland in farms, there is some overlap between timberland values in table 2 and total woodland values in table 3.

The area of timberland reported in the U. S. Forest Service's 1986 inventory is greater than the area reported in a 1967 inventory (Smith and Golditz,1988). One factor in timberland acreage increase may be procedural changes between the two surveys, including the reclassification as forest land of some areas previously classified as range, pasture and other land (U.S. Department of Agriculture, 1989). The large increase in LaPorte County, and to a lesser extent Lake and Porter Counties, may reflect both changes in agricultural land use within the Kankakee River Basin to the south, and increases in timberland near the Lake Michigan shoreline.

Wetlands, and areas categorized by the U.S. Geological Survey as water, including lakes, reservoirs and rivers, and barren land account for less than 5 percent of the land area in the Region (figure 11). However, the figure is not appropriate for all purposes because agencies may use significantly different classification schemes for wetlands.

Some areas mapped as cropland in figure 11 may be classified by the U.S. Fish and Wildlife Service as wetlands. Other areas mapped as forested wetlands may be classified by the U.S. Forest Service as riparian forest, or by the U.S. Bureau of the Census as wooded farmland. A discussion of wetlands and wetland classification used by the U.S. Fish and Wildlife Service is found in the **Surface Water Hydrology** chapter of this report under the subheading **Wetlands**. A discussion of the major lakes is found in the **Surface Water Hydrology** chapter of this report under the subheading **Lakes**.

Table 3. Area of timberland

{Values, for entire counties, are from a 1986 inventory report by Smith and Golitz, 1988.}

County	Acres	Percent of county area
Lake	17,800	6
LaPorte	41,700	11
Porter	30,600	11

WATER USE OVERVIEW

The demand for water in the Lake Michigan Region is influenced by a variety of factors including the level of urban and industrial development, the physical environment, and the hydrologic systems. A brief overview of current water use in the Region is presented below as a prelude to discussions of climate, geology, soils and hydrology. Details of current and projected water use are presented in the last chapter of this report.

Withdrawal uses

Withdrawals involve the physical removal of water from its surface-water or ground-water source, and conveyance to its place of use. The water withdrawn can be used in either a consumptive or non-consumptive manner.

Water applied for irrigation, incorporated into a manufactured product, lost to evapotranspiration, or otherwise removed from the immediate water supply is considered to be consumed if it is unavailable for reuse in a short period of time. Other applications, such as public water supply, energy production and many industrial uses, typically return most of the withdrawn water to the surface-water or ground-water systems.

Water-use data in Indiana historically has been obtained by combining limited data for public water supplies with various estimation techniques and voluntary responses to mailed questionnaires. Recent water-use summaries include those by the Indiana Department of Natural Resources (1982a, 1982b) and Solley and others (1983, 1988).

Since 1985, annual water-use data for large withdrawal facilities in Indiana have been compiled as mandated in the 1983 Water Resource Management

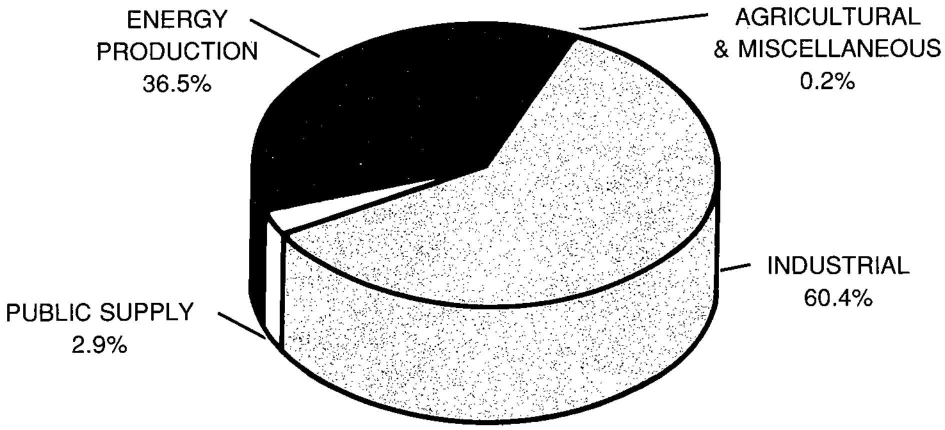


Figure 12. Percentage of registered water use by category
(Total 1990 Registered water use averaged 3089 million gallons per day)

Act (I.C. 13-2-6.1). This legislation requires owners of significant water withdrawal facilities to register these facilities and report annual water use to the Natural Resources Commission through the Indiana Department of Natural Resources, Division of Water. Significant water withdrawal facilities are defined as facilities capable of withdrawing at least 100,000 gallons per day of surface water, ground water, or surface water and ground water combined.

Reported water use for registered facilities typically is determined by metering devices, the multiplication of pump capacity and total time of pumpage, or by other methods approved by the Division of Water. Total non-registered water withdrawals generally are estimated using approximated values for population and per capita water use.

Although water withdrawals from a single well or surface-water intake may serve several purposes, each registered water withdrawal facility is grouped by the Division of Water into one of the following six categories: industrial, energy production, public supply, rural, agricultural, and miscellaneous. These categories differ slightly from those used in the 1980 report by the Governor's Water Resources Study Commission.

Facilities capable of withdrawing less than 100,000 gallons of water per day are not required to be registered with the Division of Water or to be monitored for annual pumpage. However, some types of non-registered facilities can create a large aggregate demand for water. It is estimated that non-registered facilities in the Lake Michigan Region withdrew approximately 2.4 billion gallons of water in 1990.

Registered withdrawals in the Lake Michigan Region totaled almost 1128 billion gallons during 1990. More than 99.8 percent of the withdrawals by the 80 facilities in the Region were used for industrial, energy production and public supply purposes (figure 12).

Industrial self-supplied water uses accounted for about 60 percent (682 billion gallons) of the total registered water use in the Lake Michigan Region in 1990 (figure 12). The 19 significant water withdrawal facilities used for industrial supplies represent about 24 percent of all registered facilities in the Region.

Energy production was the second highest water-use category in the Lake Michigan Region (figure 12). The four facilities grouped into this category withdrew about 412 billion gallons of water from Lake Michigan, or more than 36 percent of the total water withdrawals in the Region.

Public supply water-use was less than 3 percent of the total water use in the Lake Michigan Region (figure 12). The 25 facilities grouped into the public supply category withdrew more than 32 billion gallons of water. Surface water from Lake Michigan is the primary public supply source for communities in the northern parts of the Region, and ground water is the predominant public supply source for the communities in the interior parts of the Region.

About 14 percent of the Region's residents obtain their water from non-registered, privately owned domestic wells rather than from public supply systems. Non-registered, domestic self-supplied withdrawals account for about 0.2 percent (2.4 billion gallons) of all water withdrawals.

There were no registered rural withdrawal facilities in the Lake Michigan Region. Water withdrawals by fish hatcheries and large-scale livestock operations are categorized as rural usage.

Registered water withdrawals for agricultural and miscellaneous purposes constituted approximately 0.2 percent of the total water withdrawals in the Lake Michigan Region. However, the number of facilities grouped into either category represent 40 percent of all registered facilities in the Lake Michigan Region.

Instream uses

Instream uses are defined as non-withdrawal uses taking place within a stream, lake or reservoir. Instream uses in Lake Michigan, the primary surface-water body in northwestern Indiana, and the surface drainage networks primarily include commercial transportation, recreation activities, fish and wetland flora and fauna habitat, and waste assimilation.

Commercial transportation in the northern parts of Lake, LaPorte and Porter Counties is enhanced by the linkage of canals, waterways and dredged channels to Lake Michigan. Several harbors along Indiana's shoreline of the lake serve as transportation hubs for both regional and global cargo.

Water-based recreation activities, which include fishing, swimming, boating (including motorboating and sailing), and water skiing also occur on Lake Michigan. Hunting, camping, nature study, birdwatching, photography, walking, jogging, running and bicycling are among the activities that are strongly associated with or enhanced by the presence of water.

Popular recreation opportunities available at both the Indiana Dunes National Lakeshore and the Indiana Dunes State Park include camping, hiking, swimming, fishing and nature study. Activities permitted at the Langelutting Conservation Area in Porter County and the Galena Conservation Area in LaPorte County include fishing, hiking and nature study.

Water-dependent wildlife habitat in the Lake Michigan Region is composed primarily of the wetlands that lie between the relict dune and beach ridges in northern Lake, LaPorte and Porter Counties. Furbearers, wood ducks, waterfowl and deer are common in these areas.

Many of the wetlands in the Region have been drained or filled as a consequence of development, but some high-quality wetlands still remain as remnants of former wetland complexes. Exotic species of flora can be studied at Pinhook Bog in northwestern LaPorte County and Great Marsh (including Cowles Bog) in northern Porter County. In addition to these wetland areas, there are presently eight nature preserves in the Lake Michigan Region that are managed by the state. The conservation of these areas is discussed in the **Surface-Water Hydrology** chapter of this report under the subheading **Wetlands.**

Fisheries are present in the streams and lakes in the Lake Michigan Region. Because the type of fish population found in streams and lakes largely depend on ambient water quality, fisheries are summarized in the **Surface-Water Hydrology** chapter of this report in the section entitled **Surface-Water Quality.**

The treated effluents of waste-water treatment plants in the Lake Michigan Region are discharged directly into Trail Creek, the Grand Calumet River, the Little Calumet River and some of its tributaries. Wastewater discharges are discussed in the **Surface-Water Quality** section of this report.

PHYSICAL ENVIRONMENT

Climate, geology and soils affect the availability of surface-water and ground-water resources. Climatic factors largely determine the amount of available precipitation in the Region. Geologic and soil factors determine the proportion of precipitation which runs off the land to become surface water, as opposed to that which infiltrates the soil and *percolates* through underlying materials to become ground water. Geology and soils also determine surface drainage characteristics, the vulnerability of *aquifers* to contamination, and the limits of ground-water development.

CLIMATE

Water availability and use in the Lake Michigan Region is directly linked to the regional climate, which is the long-term composite of daily weather events. The climate of the Region is broadly classified as temperate continental, which describes areas located in the interior of a large continent and characterized by warm summers, cool winters, and the absence of a pronounced dry season. The continentality is partially modified near Lake Michigan, where the climate can take on semi-marine characteristics when *air masses* that have passed southward over the lake move inland.

Precipitation and temperature throughout the Region vary considerably on a daily, seasonal and yearly basis. This variability is primarily the result of interactions between tropical and polar air masses, the passage of low-pressure systems, and the shifting location of the jet stream, a powerful air current about 6 miles above the land surface. Localized weather modifications attributable to the presence of Lake Michigan and the Gary-South Chicago metropolis are superimposed on this regional variability.

Sources of climatic data

Most climatic data for Indiana are collected and analyzed by the National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA). The agency gathers data from more than 100 Indiana stations belonging to one or more of three networks (climatic, hydrologic or agricultural).

Temperature and precipitation data from the **climatic** network primarily are intended to represent long-term conditions over large areas of uniform terrain and climate. Rainfall-intensity data collected from the **hydrologic** network of recording precipitation gages are used for river forecasting, flood forecasting and related planning purposes. (About two-thirds of these recording gages are co-located with non-recording gages belonging to the climatic network.) Data on precipitation, air and soil temperature, relative humidity and other parameters are collected at agricultural stations. All but two of these **agricultural** stations also belong to the climatic or hydrologic networks, or both.

At most NWS stations, precipitation and/or temperature data are collected once daily by observers who typically are employed by water utilities, wastewater facilities, industries, municipalities or agribusiness. More detailed meteorological data are collected at four 24-hour NWS offices (including an office at South Bend) and at the Midwest Agricultural Weather Service Center at Purdue University.

Figure 13 shows the location of official NWS stations in or adjacent to the Lake Michigan Region in Indiana. Table 4 presents selected information for these stations and additional stations located within 8 miles of the Region boundary. The 8-mile limit was selected primarily for convenience rather than meteorological considerations.

Climatic stations in and near the Illinois and Michigan portions of the Region are not listed in table 4 or shown in figure 13. However, precipitation and temperature data are available for several stations in Berrien County, Michigan and Cook County, Illinois, including the NWS forecast office at Chicago's O'Hare International Airport.

An array of climatic data and climate-related data products for Indiana is available from NOAA's National Climatic Data Center in Asheville, North Carolina (Hatch, 1983). Climatic data also are available from the Midwestern Climate Center, a federally funded regional center housed at the Illinois State Water Survey in Champaign, Illinois. The center collects, analyzes and disseminates climatic data for nine midwestern states. Climatic summaries for stations in Berrien County, Michigan are available from the Michigan Department of Agriculture as part of a series of climatological publications (Michigan Department of Agriculture, 1989).

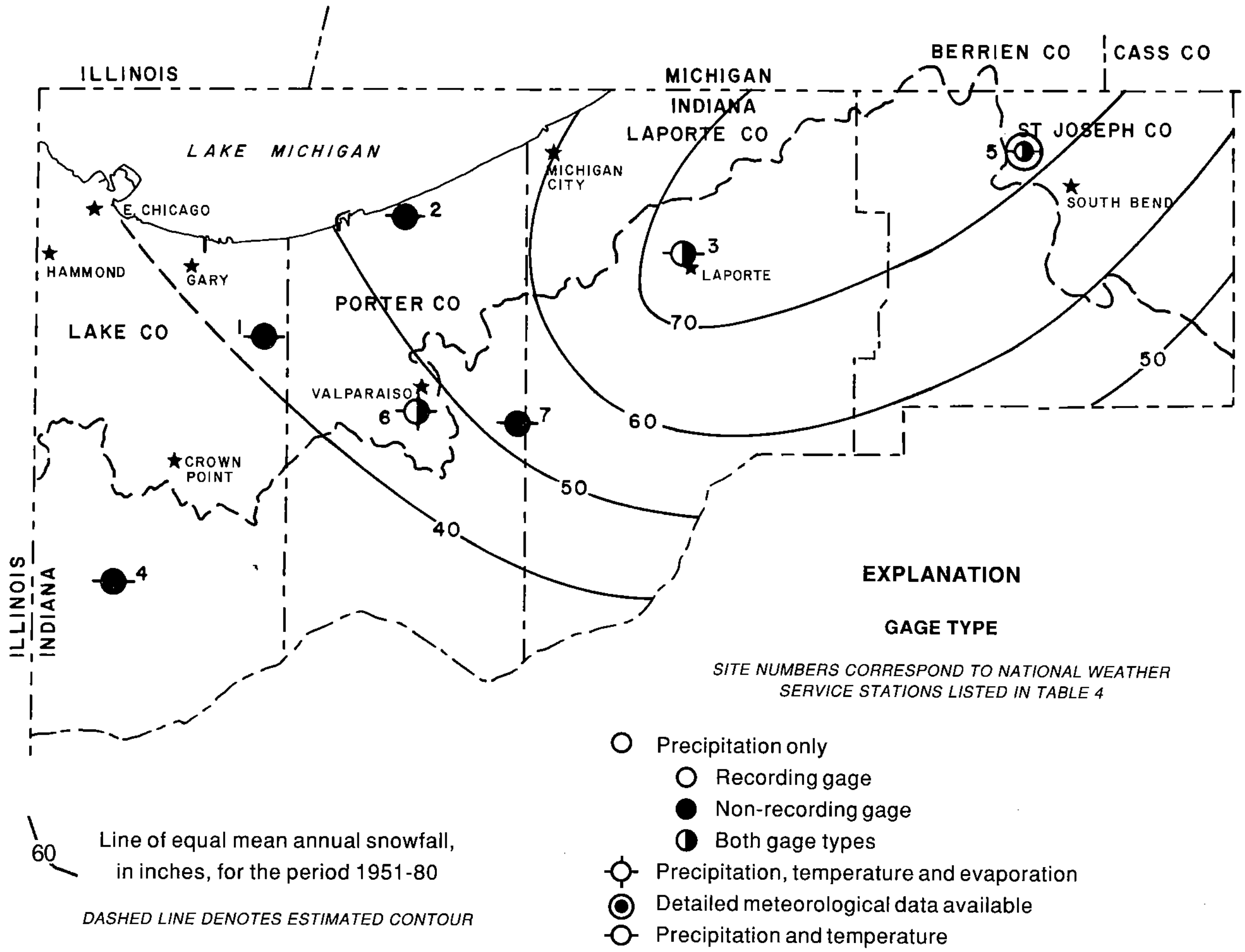


Figure 13. Location of National Weather Service stations and mean annual snowfall in and near the Lake Michigan Region

In the Indiana part of the Region, unpublished precipitation data are collected at the South Bend wastewater-treatment plant and at several unofficial NWS stations. Data from the unofficial stations are collected once daily by amateur-radio operators as part of a statewide volunteer network used to enhance the NWS river and flood forecasting program. Data from this network would be of limited use for most water management applications because the network is modified often and the data are filed only on a temporary basis.

The IDNR Division of Water operates a network of precipitation stations in Indiana, including a station in Merrillville in the Lake Michigan Region. Precipitation records from Merrillville are filed for an indefinite period at the division.

Climatic features

Although the climate of the Lake Michigan Region encompasses variations in wind, clouds, humidity, solar radiation and other elements, the following sections focus on variations in precipitation, temperature and *evapotranspiration*. Precipitation is the source of fresh water occurring on or below the land surface. Temperature defines the frost-free season, and largely controls the process of evapotranspiration, which accounts for about 70 percent of the average annual precipitation in northern Indiana.

In some regional overviews of climate, data are grouped and analyzed on the basis of geographic areas having homogeneous climate. The U.S. Department of Agriculture has divided Indiana into nine crop-reporting districts, which are identical to the nine climatic divisions defined by NOAA. In the following sections of this report, however, summaries of precipitation and temperature in the Lake Michigan Region are derived primarily from station data for Gary, Hobart, Ogden Dunes, and Valparaiso. Some data for LaPorte and South Bend also are included, because of the long data record and their proximity to the Region boundary.

Lake and urban effects

The presence of Lake Michigan produces unique climatic conditions in parts of northwestern Indiana, as described by Changnon (1968a), Changnon and Jones (1972), and Eichenlaub (1979). Although modifications of climate are most pronounced within a mile or two of the shore, several lake-effect features extend about 25 miles inland. This broad area of lake influence encompasses the entire Lake Michigan Region in Indiana.

In general, the Region can experience warmer falls, cooler springs, higher humidity, more frequent lakeshore fogs, increased winter cloudiness, and greater amounts of snow compared to nearby regions of similar latitude. The most critical factor producing these

Table 4. National Weather Service stations in and near the Lake Michigan Region

Map number: Station locations are shown in figure 13.

Station: Only active stations are tabulated. Historical data for discontinued stations in Indiana are available from Gary, Michigan City, and the University of Notre Dame.

Data network: A, climatological network; B, hydrologic network (National Weather Service); AG, agricultural network (Purdue University).

Data type: P, precipitation; T, temperature; E, evaporation and wind; S, soil temperature; D, detailed data on a variety of parameters.

Publication, ongoing: Precipitation and/or temperature data are published monthly and annually by the National Oceanic and Atmospheric Administration in the following reports- CD, *Climatological Data* (precipitation amounts are from non-recording gages); HP, *Hourly Precipitation Data* (precipitation amounts are from recording gages); LCD, *Local Climatological Data* (detailed data published).

Publication, periodic: Climatological summaries are published every 10 years, generally at the end of a 30-year period. Numbers refer to footnotes.

Period of record: Approximate total length of precipitation record, through 1980 inclusive. Years of record are taken from 1980 annual summaries of *Climatological Data* and Hourly Precipitation Data. Hourly precipitation data may not be available for all years of record at hydrologic (B) network stations.

Map no.	Station name	Data network	Data type	Publication		Period of record	
				Ongoing	Periodic	Years	Dates
1	Hobart	A	P,T	CD	*1,2,3*	61	1920-
2	Indiana Dunes National Lakeshore[4]	A	P,T	CD	*2,3*	29	1952-
3	LaPorte[5]	A,B	P,T	CD,HP	*1,2,3*	86	1895-
4	Lowell[5]	A	P,T	CD	—	18	1963-
5	South Bend NWSO[5,6]	A,B,AG	P,T,D	CD,HP,LCD	*2,7*	93	1888-
6	Valparaiso Waterworks	A,B	P,T,E	CD,HP	*2,3*	81	1900-
7	Wanatah[5]	A,AG	P,T,S	CD	—	20	1961-

1 National Oceanic and Atmospheric Administration, 1976.
2 ______1982a, 1983a.
3 ______1985.
4 Located at Ogden Dunes until May 1989.
5 Within 8 miles of Region boundary in Indiana.
6 NWSO, National Weather Service office.
7 National Oceanic and Atmospheric Administration, 1982b.

climate modifications is the slower change of the lake's water-surface temperature relative to the change of the adjacent land-surface temperature.

The slower change in water temperature tends to moderate extremes in air temperature, a feature which typically is ascribed to a semi-marine climate rather than a continental climate. Because the lake retains some of its summer warmth until midwinter, minimum air temperatures near the lake during fall and early winter are several degrees warmer than in areas farther south. Conversely, because the lake retains its winter chill long after the land has thawed, areas near the lake experience maximum springtime temperatures that are cooler than those expected for the given latitude.

Local lake breezes reaching a mile or two inland further moderate temperature extremes along the immediate lakeshore. For example, summer lake breezes can reduce maximum air temperatures along the lakeshore by several degrees, whereas land breezes help maintain warmer minimums.

Lake-induced changes in cloud cover are associated with changes in air temperature and humidity. A reduction in summer cloudiness may extend 20 miles inland when westerly winds blow across the lake and advect colder off-lake air onto the eastern shore (Changnon and Jones, 1972); however, summer clouds are most noticeably reduced over the lake and along the immediate lakeshore.

Lake-related increases in cloud cover are common throughout the Lake Michigan Region, especially during the fall and early winter when the lake is warm relative to land. Winter fog may form over the lake when cold air from the north initially contacts the warm water. As the air continues to pass southward over the lake, convection and turbulence transport the acquired moisture aloft to form clouds, rain or snow. Cloud and precipitation development may be further enhanced by the lack of winter icepack on most of the lake, except in nearshore and harbor areas.

As the warmed off-lake air reaches the shoreline, upward currents can become stronger because of the increased friction over land, thereby increasing the potential for cloud and snow development. An additional impetus may be provided by *orographic lifting* as the air ascends the elevated Valparaiso Moraine (figure 16), whose crest is as much as 300 feet higher than the lake surface. It also is possible that the additional warmth and the urban-related increases in ice-forming nuclei from the Chicago-Gary metropolis may help create or intensify downwind lake-effect snows (Eichenlaub, 1979).

Lake-effect snows of the Great Lakes region are unique because only a few areas of the world experience this *mesoscale* feature (Eichenlaub, 1979). In Indiana, lake-effect snows are most common in Lake, Porter, LaPorte and St. Joseph Counties.

North or northwest winds sweeping over Lake Michigan can acquire large amounts of warmth and moisture before crossing the downwind shoreline; consequently, the major snowbelt of southern Lake Michigan is located about 5 to 25 miles inland of the southeast shore. This snowbelt encompasses an area roughly bounded by Michigan City, LaPorte and South Bend, Indiana, and extends into Berrien County, Michigan (figure 13).

Annual snowfall in the snowbelt averages as much as 70 inches, which is twice the annual amount normally received elsewhere in northern Indiana. In some years, snowfall amounts may exceed 100 inches, largely due to the frequency of moderate to heavy lake-effect snows. Eichenlaub (1970) estimated that lake-effect snowfall accounts for 30 to 50 percent of the total snowfall in the Lake Michigan snowbelt.

The climate of the Lake Michigan Region is modified not only by the presence of Lake Michigan but also by the Chicago-Gary metropolis of northeast Illinois and northwest Indiana. In general, large cities and their environs experience higher average temperatures than rural areas, more clouds, haze, and local fog, and more summer convective storms. Many of these differences are due to the "heat island" effect of urban-industrial centers and the increased presence of atmospheric pollutants and particles which serve as nuclei for the formation of tiny water droplets and/or ice crystals. Reports by Changnon (1971, 1980a, 1980c), Huff and Changnon (1972, 1973), Lyons (1974), Changnon and Semonin (1978, 1979), and Changnon and others (1979a, 1979b) present the results of detailed climatic studies in the Chicago area.

Inadvertent weather modification by the Chicago-Gary metropolis has been cited as a possible cause of increased summer rainfall and severe storm events recorded at LaPorte from the mid-1930s to the mid-1960s (Changnon, 1968b, 1980b; Maxwell, 1975; Changnon and Huff, 1977; Clark, 1979). However, the validity of an urban-induced anomaly centered at or near LaPorte has been questioned by those who attributed the unusual precipitation record to poor gage exposure or observer error (Holzman and Thom, 1970;

Holzman, 1971a, 1971b; Machta and others, 1977). A water-resources report for the Kankakee River Basin (Indiana Department of Natural Resources, 1990) contains a summary of the rainfall anomaly.

Precipitation

Most precipitation in the Lake Michigan Region is derived from air masses that have passed over the Gulf of Mexico, although Lake Michigan can be the principal moisture source for some precipitation events, particularly snows. The geographic and temporal variability in precipitation is produced by daytime convection and the passage of frontal systems.

Most rainfall in late spring and throughout the summer is produced during localized thundershowers generated by the passage of cold fronts or by daytime convection. Local thunderstorms occasionally can become severe, and may be accompanied by strong winds, large hail, or frequent lightning. Funnel clouds, tornadoes, and offshore *waterspouts* are rare near Lake Michigan, perhaps because the relatively cool water of the lake has a stabilizing effect on atmospheric processes during spring and early summer.

Precipitation during spring and autumn, which typically is associated with the passage of frontal systems, often occurs in the form of slow, steady rains over large areas. One exception occurred on October 9-11, 1954, when heavy storms produced record-breaking rainfall at many locations in northwest Indiana, including Hobart, Valparaiso, and Ogden Dunes in the Lake Michigan Region (National Oceanic and Atmospheric Administration, 1985; Daniels and Hale, 1955; Huff and others, 1955).

Precipitation events typically are interspersed among several dry days and can vary widely in intensity and duration. Although daily normal values *interpolated* from monthly normals do not exhibit the daily random patterns, normals can be used to compute average precipitation for selected time intervals (National Oceanic and Atmospheric Administration, 1982b). Normal daily precipitation amounts calculated for South Bend range from 0.07 inch in February, the driest month, to 0.14 inch in April and June, the wettest months.

Monthly precipitation during the frost-free season commonly ranges from about 2 to 5 inches (see National Oceanic and Atmospheric Administration, 1985), but monthly extremes recorded in the Region range from trace amounts to about 14 inches. Normal seasonal precipitation at Gary, Hobart, Ogden Dunes, and Valparaiso averages 5.8 inches in winter, 10.1 inches in spring, 11.4 inches in summer, and 9.0 inches in fall (table 5). In general, total monthly rainfall amounts are greater and more variable during warm months than during cool months.

Normal annual precipitation at Gary, Hobart, Ogden Dunes and Valparaiso averages 36.2 inches for the period 1951-80 (see table 5). Total annual precipitation recorded for this period ranges from about 23 inches to nearly 50 inches.

Annual probability data (National Oceanic and Atmospheric Administration, 1983a) show that there is a 9-in-10 chance that the annual precipitation over a long period of time will average 28 inches or greater. There is only a 1-in-10 chance that the annual precipitation will average 44 inches or greater.

Annual snowfall is quite variable in the Region because of the lake effect. Annual averages range from about 35 inches near the Indiana-Illinois state line to about 70 inches in the lake-related snowbelt. The predominant snow season is from November to March, but snowfall has occurred as early as September and as late as May. On average, snowfall constitutes 10 percent of the annual precipitation in the Region's western portions, and 19 percent of the annual precipitation in the snowbelt.

Temperature

The normal annual temperature averages 50° F (degrees Fahrenheit) at Gary, Hobart, Ogden Dunes, and Valparaiso, and 49° F at South Bend, Indiana and Eau Claire, Michigan. Normal seasonal temperature in the Indiana part of the Region averages 49° F in spring, 72° F in summer, 54° F in autumn, and 27° F in winter (National Oceanic and Atmospheric Administration, 1982a).

Spring and autumn months generally are characterized by moderate temperatures, although brief periods of unusually cool or warm temperatures may occasionally occur. Summer months bring warm, humid conditions and occasional periods of oppressive heat. Winter months are characterized by short periods of extreme cold alternating with several days of milder temperatures.

January, the coldest month, has an average normal monthly temperature of 23° F and an average normal

Table 5. Normal monthly, seasonal and annual precipitation for the period 1951-80

{All values in inches; monthly data are from the National Oceanic and Atmospheric Administration, 1982a}

Month	Gary	Hobart	LaPorte[1]	Ogden Dunes	South Bend	Valparaiso
SPRING						
March	2.7	2.4	3.2	2.8	3.1	2.9
April	3.8	3.8	4.3	3.8	4.1	4.3
May	3.7	3.3	3.2	3.2	2.8	3.6
Seasonal	10.2	9.5	10.7	9.8	10.0	10.8
SUMMER						
June	3.8	3.8	4.2	4.0	3.9	4.1
July	3.8	3.8	4.5	3.8	3.7	4.0
August	3.6	3.5	4.1	3.4	3.9	4.0
Seasonal	11.2	11.1	12.8	11.2	11.5	12.1
AUTUMN						
September	3.4	3.5	3.8	3.4	3.2	3.7
October	2.9	2.9	3.8	3.1	3.2	3.4
November	2.3	2.4	2.8	2.3	2.8	2.6
Seasonal	8.6	8.8	10.4	8.8	9.2	9.7
WINTER						
December	2.4	2.2	3.1	2.4	3.0	2.6
January	1.7	1.7	2.4	2.0	2.5	2.0
February	1.4	1.5	2.2	1.6	2.0	1.6
Seasonal	5.5	5.4	7.7	6.0	7.5	6.2
ANNUAL	35.5	34.8	41.6	35.8	38.2	38.8

[1] Base data may be anomalous

daily minimum of 15° F. On average, about 3 or 4 days in January have minimum daily temperatures less than 0° F.

July, the warmest month, has an average normal monthly temperature of 73° F and an average normal daily maximum of 84° F. Maximum temperatures of at least 90° F typically occur on about 5 or 6 days.

The range in daily temperature is generally least in winter, and greatest in summer. The average difference between normal daily maximum and minimum temperatures in the Lake Michigan Region is 16° F in winter, 20° F in spring and fall, and 21° F in summer (table 6). Due to the moderating effect of Lake Michigan, these average temperature fluctuations are about 3 degrees less than average fluctuations elsewhere in northern Indiana.

According to comparisons of monthly and seasonal normal temperatures at climatic stations in and near the Lake Michigan Region (National Oceanic and Atmospheric Administration, 1982a), Hobart has the greatest average temperature fluctuations, and Gary has the least (table 6). A combination of the lake effect and urban-related heating probably explains the warmer average spring and summer minimums at Gary, whereas the lake effect probably is responsible for maintaining warmer average minimums during fall and winter at Ogden Dunes (table 6).

Because the presence of Lake Michigan reduces the risk of early fall frosts and unusually late spring frosts, the frost-free season within about 10 miles of the lakeshore generally is 2 to 3 weeks longer than the season elsewhere in northern Indiana. In the Lake Michigan Region, the frost-free season typically lasts from late April or early May to the middle of October.

Table 6. Normal seasonal maximum and minimum temperatures for the period 1951-80

{Values, in degrees F, are derived from monthly normals published by the National Oceanic and Atmospheric Administration, 1982a}

Station	Spring		Summer		Fall		Winter	
	max	min	max	min	max	min	max	min
Gary	57.5	39.2	81.9	62.1	62.9	44.6	33.9	18.7
Hobart	60.1	38.4	83.6	60.3	65.2	43.4	35.4	18.9
LaPorte	59.0	38.0	82.8	60.1	63.0	42.7	33.8	18.3
Ogden Dunes	58.1	38.5	81.9	61.3	63.6	44.9	34.4	19.7
South Bend	57.6	38.1	81.1	60.4	61.8	43.3	33.4	19.0
Valparaiso	59.1	37.9	81.8	59.6	63.2	42.6	34.0	17.9

The average number of consecutive frost-free days ranges from about 175 days near the lakeshore to about 165 days near the Region's southern boundary (National Oceanic and Atmospheric Administration, 1985). A season of this length is comparable to the season typically found in much of central and south-central Indiana; however, the season length near Lake Michigan changes rapidly within short distances, as opposed to a more gradual change in central and southern Indiana (Schaal and Newman, 1981).

The longer frost-free season, in combination with the moderate temperatures, higher humidity, rolling terrain, and loamy or clayey soils on and north of the Valparaiso Moraine produce an environment suitable for the growing of frost-sensitive fruit crops such as apples, pears, peaches, grapes and berries. Fruit production is especially common in northern LaPorte County, Indiana and in Berrien County, Michigan.

During the warm season when Lake Michigan is cool relative to land, local lake breezes may limit extremely high temperatures within a mile or two of the shore. Conversely, land breezes at night help maintain temperatures that are warmer than those farther inland; hence, 24-hour temperature averages are not significantly modified by local lake winds.

Extreme temperatures recorded in the Lake Michigan Region range from -23° F to 104° F for the period 1951-80. Very hot weather typically occurs when tropical air masses reach the region from the south without first passing over Lake Michigan. Record high temperatures occurred at several stations during the summer drought of 1988, when southerly winds predominated.

Winter cold snaps generally are less severe in the Lake Michigan Region than in other areas of northern Indiana, but northeast winds not moderated by the lake influence can occasionally bring extremely low temperatures.

Evapotranspiration

Precipitated water is being returned continually to the atmosphere as vapor through the processes of evaporation and plant *transpiration*. Measurements of evaporation from the water surface in a shallow, circular pan can be used to estimate the maximum water loss possible from shallow lakes or saturated soils.

Pan evaporation stations typically are operated between May and October. In general, evaporation pans are not operated between November and April because frequent ice cover would produce erroneous measurements.

At South Bend and Valparaiso, mean monthly pan evaporation during the frost-free season ranges from an average of about 6 inches in June and July to about 3 inches in October (table 7). Estimated monthly means of evaporation at South Bend show that nearly 25 percent of the annual total pan evaporation occurs during the 6-month winter period (Farnsworth and Thompson, 1982b).

A reasonable estimate of potential evapotranspiration can be obtained by multiplying total pan evaporation by a factor of 0.75 (see Farnsworth and Thompson, 1982a); hence, potential evapotranspiration at South Bend and Valparaiso averages about 30 inches. This amount is a generalized index of the maximum annual consumptive use of water by evaporation and transpiration.

Because the availability of moisture for evapotranspiration varies continually in time and space, actual evapotranspiration often occurs at less than the poten-

Table 7. Mean monthly pan evaporation at South Bend and Valparaiso

{Values, in inches, are from Farnsworth and Thompson (1982b) unless otherwise indicated.}

Month and season	South Bend, estimated (1956-70)	Valparaiso, measured (1960-79)
WARM SEASON		
May	5.63	5.38
June	6.73	6.14
July	6.64	5.94
August	5.93	4.92
September	4.26	3.23
October	3.17	2.95
Season total	32.36	28.56
COOL SEASON		
November	1.61	1.48[1]
December	0.88	0.93[1]
January	0.83	0.83[2]
February	1.00	1.00[2]
March	2.08	2.58[1]
April	3.80	3.84[1]
Season total	10.20	10.66
Annual total	42.56	39.22

[1] From Indiana Department of Natural Resources, 1988.
[2] Estimated values for South Bend; no measured data available.

tial rate. Studies in central Illinois revealed that average annual evapotranspiration is approximately 84 percent of the average annual potential evapotranspiration during years of normal or above-normal precipitation (Schicht and Walton, 1961). If annual potential evapotranspiration in the Lake Michigan is assumed to be 30 inches, then annual evapotranspiration is approximately 25 inches. An estimate of 25 to 26 inches for northwest Indiana was obtained by different methods by Jones (1966) and Newman (1981).

The loss of at least 25 inches (more than 70 percent) of the average annual precipitation to evaporative processes represents the single largest consumptive use of water in the Lake Michigan Region. Although the remaining 11 inches of water is considered adequate with respect to the Region's overall water budget, the spatial and temporal variability of rainfall from year to year and its uneven distribution during any given year can occasionally limit crops and water supplies.

Evapotranspiration during the summer months commonly exceeds total rainfall, producing a seasonal deficit in available precipitated water. During the winter, when precipitation far exceeds evapotranspiration, water supplies are replenished in the form of increased ground-water and surface-water levels and increased soil moisture.

The exact amount of evaporation from Lake Michigan is unknown; however, average annual evaporation has been estimated to be 30 inches (Richards and Irbe, 1969). More recent studies have involved modeling efforts for forecasting and simulation applications (Croley, 1989a, 1989b).

Climatic extremes

Extreme climatic events such as droughts and flood-producing storms are infrequent but can have far-reaching economic impacts. In the Lake Michigan Region, economic losses caused by flooding and high lake levels are most widespread in urban and residential areas.

Heavy rainstorms can be described statistically by rainfall frequency analysis. Three reports published by NOAA summarize rainfall-frequency data for selected durations from 5 minutes to 10 days and return periods from 1 to 100 years (Hershfield, 1961; U.S. Weather Bureau, 1957, 1964; National Oceanic and Atmospheric Administration, 1977). Other reports provide data on *probable maximum precipitation* (Schreiner and Riedel, 1978; Ho and Riedel, 1980) and rainfall intensity-duration-frequency (U.S. Weather Bureau, 1955). A report by the Indiana Department of Natural Resources (1982c) summarizes the NOAA data for Indiana and provides interpolated estimates of rainfall values.

The Midwestern Climate Center in Illinois has updated heavy-rainfall frequency values for midwestern states. The analyses, which utilize data from NWS stations, provide values on a more detailed scale than values published by NOAA. A preliminary report was available in early 1990 (J. Angel, Illinois State Water Survey, personal communication, 1990).

The term "drought" generally is associated with a sustained period of abnormally low water levels or moisture supply. Drought-severity indices may be based on cumulative precipitation deficits, reservoir storage, stream flows, ground-water levels, or other hydrologic factors relevant to water supply and agricultural activities.

Because drought-severity indices commonly are used to initiate drought-response activities such as water-conservation measures and financial assistance, it is crucial that the selected indices provide a representative assessment of drought conditions. Researchers at Purdue University are working cooperatively with the IDNR Division of Water to develop regional drought indicators for Indiana (Delleur and others, 1990).

A report by Fowler (1992) describes the effects of the 1988 drought on ground-water levels, stream flow, and reservoirs in Indiana. Reports by the former Indiana Drought Disaster Preparedness Committee (1977), the former Indiana Drought Advisory Committee (1988), and the Great Lakes Commission (1990) discuss drought preparedness and planning for Indiana. Reports by Changnon and others (1982), Changnon (1987), Easterling and Changnon (1987), and Changnon and Easterling (1989) are four among many publications by staff of the Illinois State Water Survey that address drought climatology, impacts and preparedness in Illinois, including the Chicago-Gary area.

GEOLOGY

Ground-water resources are strongly influenced by geology. Surficial geology greatly influences *topography* and soil development which, in turn, control runoff and *infiltration* of precipitation. Ground-water storage and rate of flow are controlled by the geology of the underlying unconsolidated and bedrock formations.

In northwestern Indiana, herein called the Lake Michigan Region, the most important *aquifers* consist of glacial, *glaciofluvial*, and *glaciolacustrine* deposits. These unconsolidated sediments were associated directly or indirectly with the advance and retreat of the Lake Michigan lobe of ice into and out of northwestern Indiana (figure 14).

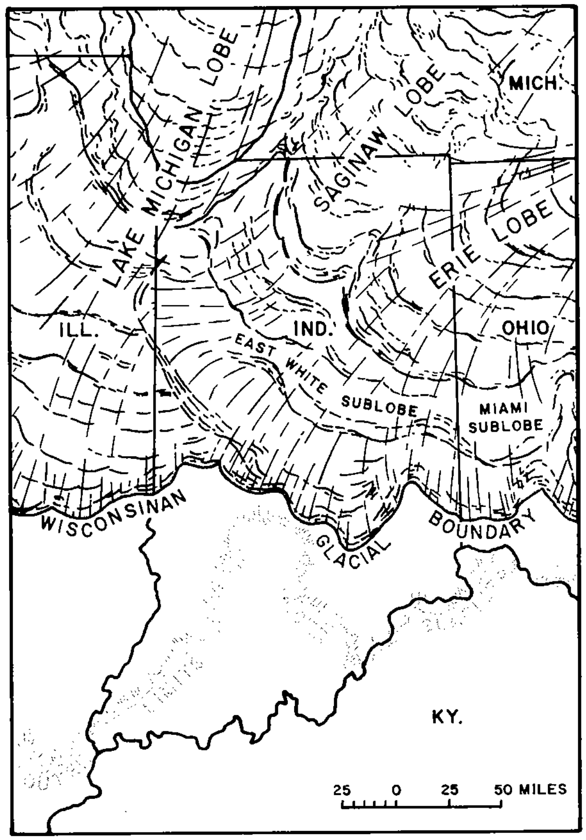


Figure 14. Extent of major ice lobes in Indiana during the Wisconsinan glaciation
(Adapted from Wayne, 1965)

Sources of geologic data

Hydrogeologic information for the Lake Michigan Region comes primarily from water-well records, an observation-well monitoring program, *lithologic* descriptions from oil- and gas-well records, engineering borings, *seismic* studies, *gamma-ray logs*, and local hydrogeologic projects.

Information on the shallow *aquifer systems* in the Lake Michigan Region comes mainly from water-well records. Approximately 4,500 water well records, kept on file at the Division of Water- Indiana Department of Natural Resources (IDNR), were analyzed for the ground-water assessment portion of this study. Since 1959, water-well drilling contractors have been required to submit to the IDNR a complete record of any water well drilled in the state.

Hydrogeologic information on the deep unconsolidated formations in the Lake Michigan Region was obtained during a cooperative drilling project that was conducted by the Division of Water and the Indiana Geological Survey (IGS) in 1987-88. This information was helpful in determining aquifer characteristics and the depositional history of the unconsolidated sedi-

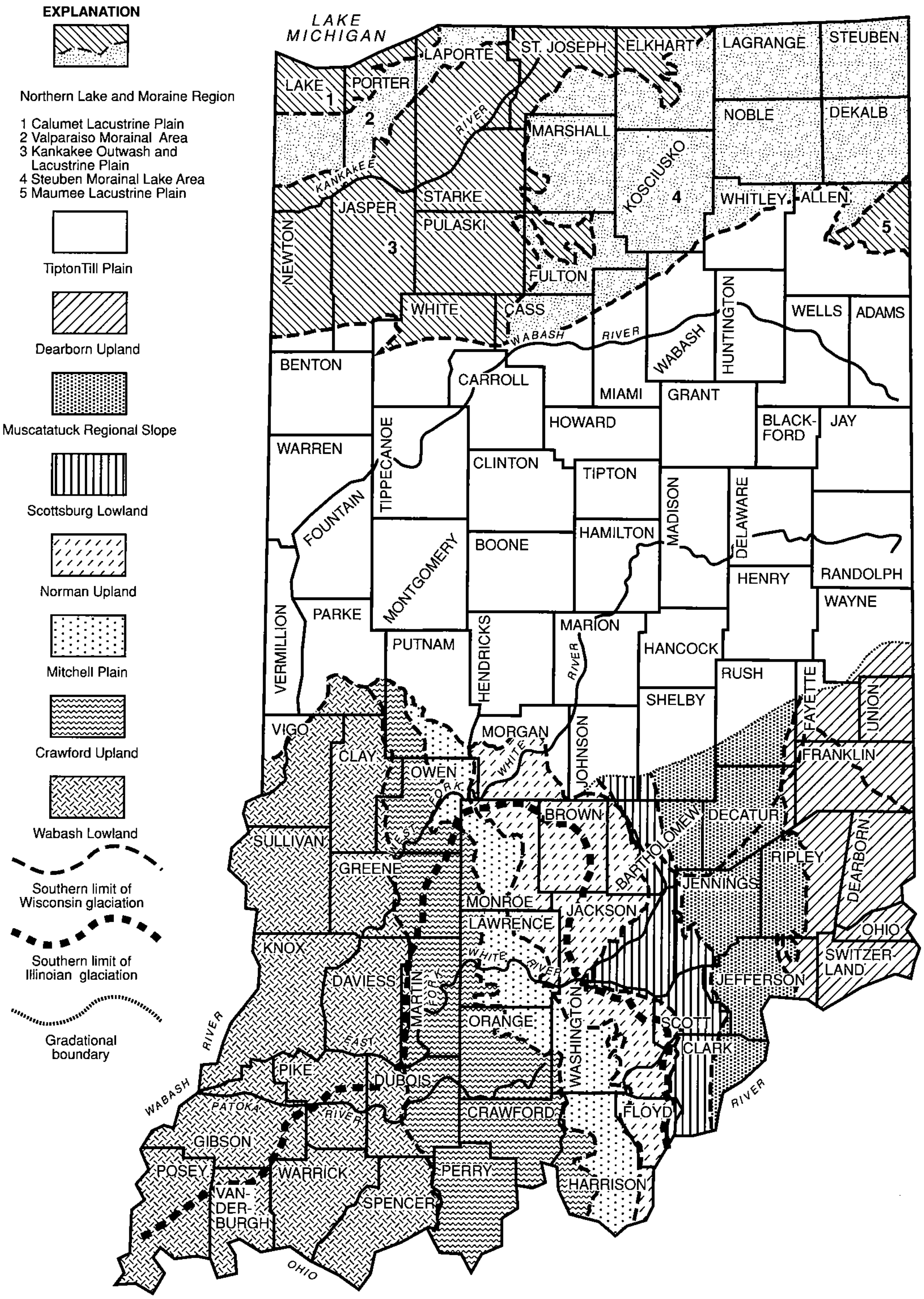


Figure 15. Physiographic regions of Indiana
(After Malott, 1922; modifed by Wayne)

ments in the region. Much of the interpretation of the glacial geology of the southern part of the Lake Michigan Region comes from an unpublished report by Bleuer and Fraser, Indiana Geological Survey.

Physiography

Malott (1922) divided Indiana into nine *physiographic regions* according to topography and the effect of glaciers on the landscape. The Lake Michigan Region lies within the extreme northwestern part of the Northern Lake and *Moraine* Region and includes the northern part of the **Valparaiso Morainal Area** and the entire **Calumet *Lacustrine* Plain** (figure 15).

The physiography of the southern part of the Lake Michigan Region is mostly the product of late Wisconsinan glacial advances of the Lake Michigan lobe. Subsequent retreat of the Lake Michigan lobe from the morainal area and development of ancestral Lake Michigan were responsible for most of the physiography in the northern part of the region.

The Valparaiso Morainal Area

The Valparaiso Morainal Area is comprised of the Valparaiso, Tinley and Lake Border Moraines (figure 16). These *end moraines* mark the limits of glacial advances by the Lake Michigan lobe during the late Wisconsinan glacial period.

The **Valparaiso Moraine** is the largest and oldest end moraine in the Lake Michigan Region. The crest of the moraine forms most of the drainage divide between the Kankakee River Basin to the south and the Lake Michigan Region to the north. A topographic sag near the town of Valparaiso in Porter County divides the moraine into two segments. Topographic expression and areal extent of both segments are distinctly asymmetrical.

The eastern segment of the Valparaiso Moraine is a ridge having maximum elevations which vary from about 850 feet (259 meters) to more than 950 feet (290 meters) above mean sea level (m.s.l.) near Springville in LaPorte County. The crest and northern slopes of the morainal ridge are underlain by a veneer of *debris-flow tills.* Numerous ice-block depressions called *kettle holes* are present in areas of rugged relief along the northern slopes of the moraine from Valparaiso to the Michigan state line. Large kettle depressions are presently occupied by lakes, and the smaller depressions are filled with a complex mix of sediment, including considerable amounts of *peat* and *muck.*

The western segment of the Valparaiso Moraine is comprised of two ridges capped by *basal tills.* The western segment of the moraine is much broader than the eastern segment, and maximum elevations seldom exceed 800 feet (244 meters) above m.s.l. The morainal surface is highly irregular and contains numerous basins of internal drainage and areas of irregular and deranged drainage patterns. Stream channels are flat-floored and deeply *incised* into the till surface. Evidence of *mass movements* from the margins into the axes of the channels suggest that the surficial till was deposited from thick ice that was drained by deep *englacial channels* or *tunnel valleys.*

The **Tinley Moraine** is the northernmost of the three morainal ridges in the western segment of the Valparaiso Morainal Area. The Tinley Moraine represents a re-advance of the Lake Michigan Lobe after it had retreated an unknown distance from the Valparaiso Moraine (Schneider, 1968). The Tinley Moraine generally trends eastward from the Indiana-Illinois state line near the town of St. John, through Lake County, and into western Porter County. The moraine has local relief of less than 50 feet (15 meters), but maximum elevations of the moraine exceed 730 feet (222 meters) above m.s.l. at its western edge and 700 feet (213 meters) above m.s.l. at its eastern edge.

A shallow trough lying between 690 and 700 feet (210 and 213 meters) above m.s.l. separates the Tinley Moraine from the Valparaiso Moraine. The trough is presently drained by West Creek in the extreme west-central part of Lake County and the upper reach of Deep River in central and east-central Lake County. Considerable deposits of peat, muck and organic-rich *colluvium* are found in ice-block depressions along the trough.

An upland *till plain* located north of the eastern extent of the Tinley Moraine (figure 17) probably represents the terminal zone of Tinley ice (Schneider, 1968). This upland probably joins northward with the Lake Border Moraine (Todd Thompson, Indiana Geological Survey, personal communication).

The **Lake Border Moraine** in the Lake Michigan Region is an end moraine complex of low relief that is located north of the eastern segment of the Valparaiso Moraine (figure 16). The Lake Border Moraine consists of several linear ridges that parallel the long axis of the moraine. In northwestern LaPorte County, the

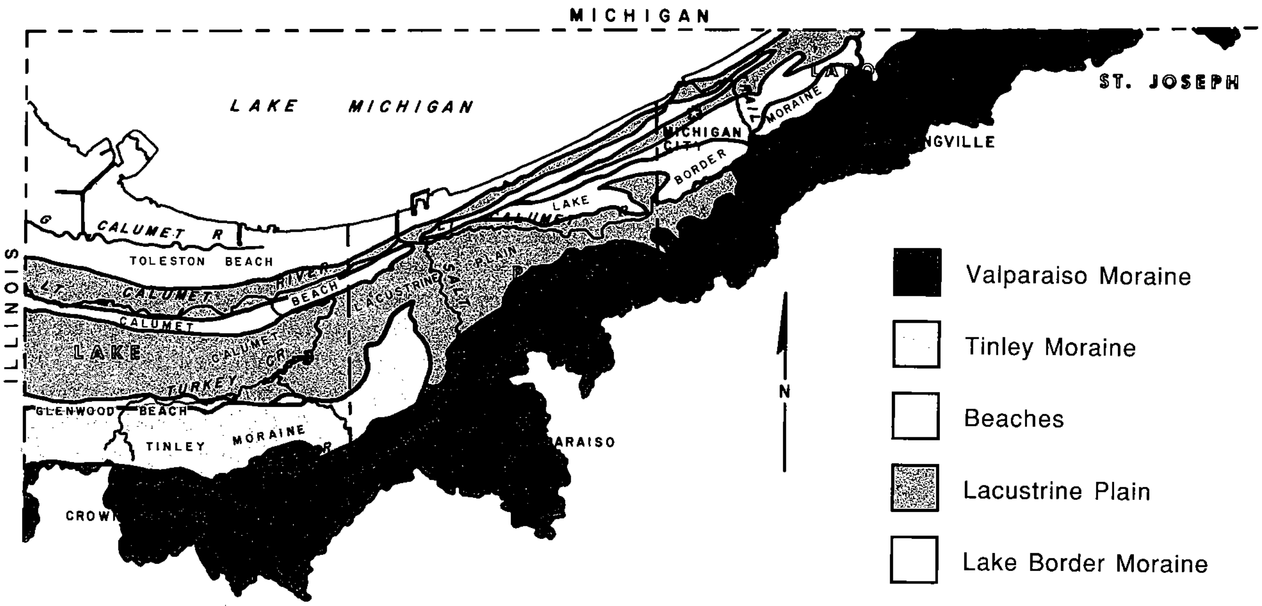


Figure 16. Major physiographic features

moraine is approximately 2.5 miles (4 kilometers) wide and ranges in elevation from 630 to 670 feet (192 to 204 meters) above m.s.l. Toward the west, the moraine thins to less than 0.25 mile (0.4 kilometers) in width and ranges in elevation from 650 to 690 feet (198 to 210 meters) above m.s.l. in north-central Porter County (Thompson, 1987).

The Calumet Lacustrine Plain

The Calumet Lacustrine Plain lies between the Valparaiso Morainal Area and Lake Michigan (figure 16). The plain ranges in elevation from about 580 feet (177 meters) at the present shoreline of Lake Michigan to as much as 760 feet (232 meters) above m.s.l. at dune-capped beach ridges. In the western part of the plain, the natural character of the landscape has been altered considerably as a result of industrialization and urbanization. The following description of the major physiographic features in the Calumet Lacustrine Plain is based on studies conducted primarily at the Indiana Dunes National Lakeshore and the Indiana Dunes State Park in the extreme northern part of Porter County. The natural physiography of the plain has remained relatively unaltered in these areas.

The predominant topographic expressions in the Calumet Lacustrine Plain are three *relict* dune-capped beach ridges separated by extensive interridge marshes. The relict beaches mark semi-stable shorelines of ancestral Lake Michigan during its late *Pleistocene* and *Holocene* history.

The **Glenwood Beach** is the highest dune and beach complex in the Lake Michigan Region. The relict beach is present as a discontinuous ridge on the lakeward slopes of the Lake Border and Tinley Moraines. The crest of the dune and beach complex has an average elevation of about 650 feet (198 meters) above m.s.l. However, the *foreshore* deposits, which represent the paleoshoreline, are present in places between 620 and 630 feet (189 to 192 meters) above m.s.l. (Thompson, 1987). The poorly-developed beach consists predominantly of dune sand capping till which suggest that the beach was probably covered by ice for most of the year.

The **Calumet Beach** is lakeward of the Glenwood Beach, but truncates the Glenwood Beach at the western tip of the Lake Border Moraine near the town of Tremont in Porter County. Dune-capped areas of the Calumet Beach have an average elevation of about 630 feet (192 meters) above m.s.l., and the foreshore deposits have an average elevation of 607 feet (185 meters) above m.s.l. (Thompson, 1987). Calumet deposits consist of *dune* sediments overlying beach and *nearshore sediments.*

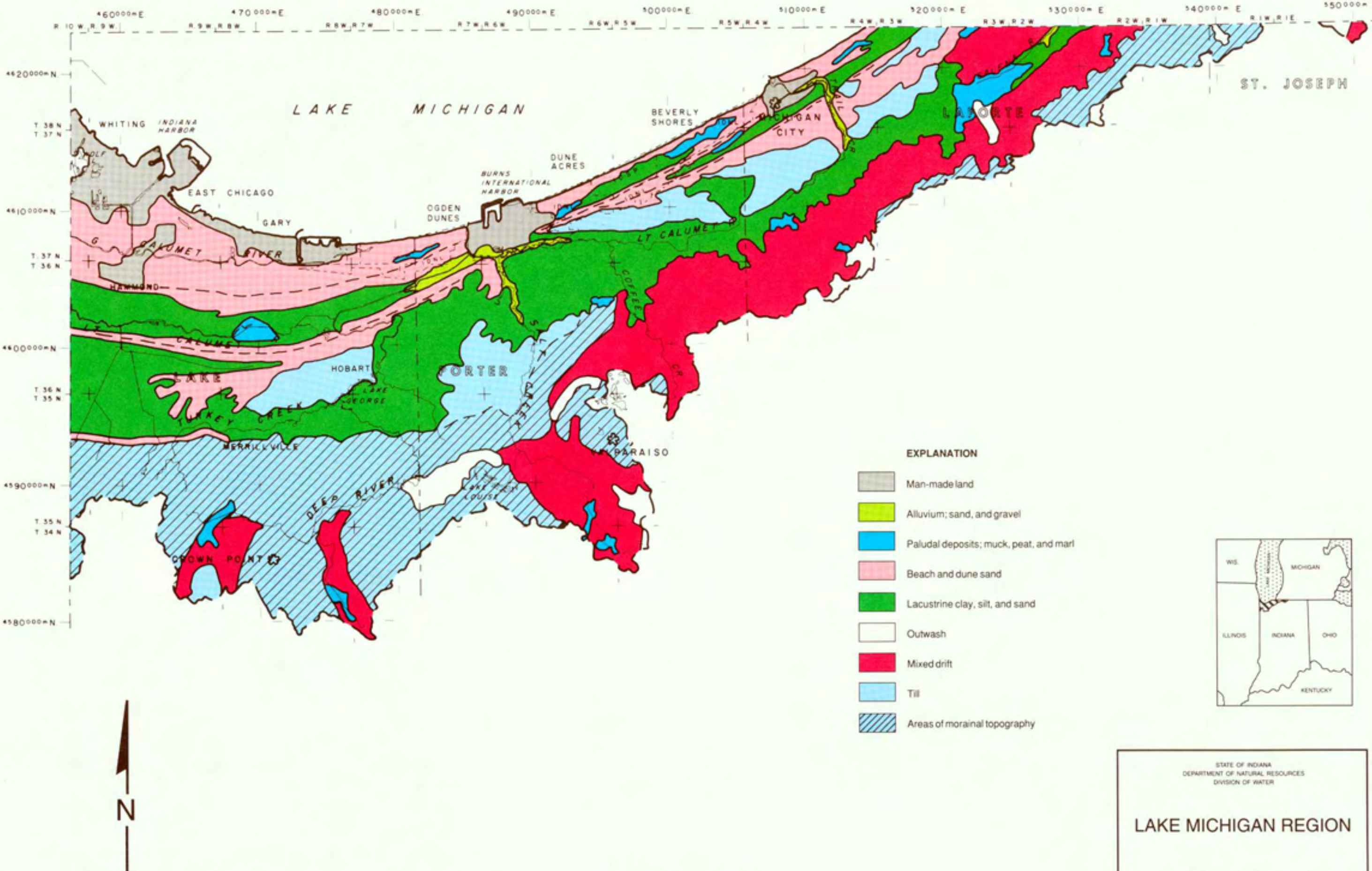


Figure 17. Surficial geology
(modified from Gray, 1989)

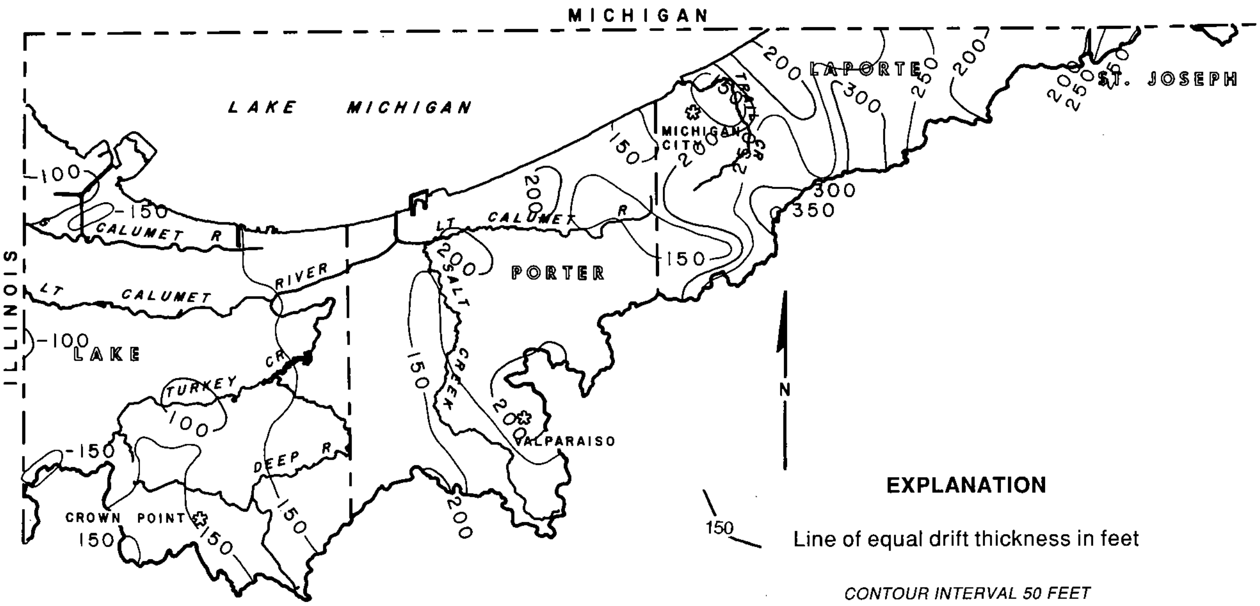


Figure 18. Thickness of unconsolidated deposits
(Adapted from Gray 1983)

The **Toleston Beach** is the youngest dune and beach complex in the Lake Michigan Region. The landward part of this complex consists of linear ridges of coalesced *parabolic* dunes separated by interdunal swamps, and the lakeward portion is comprised of large dome-shaped and small parabolic dunes (Thompson, 1987), as well as over 150 beach ridges in its western part. Elevations at the top of large domal dunes are as much as 750 feet (229 meters) above m.s.l. Foreshore, *upper shoreface* and *back-barrier* lacustrine deposits occur in the internal core of the complex. The top of the foreshore sequence of the Toleston Beach ranges from 597 to 603 feet (182 to 184 meters) above m.s.l. (Thompson, 1987). Modification of the Toleston Beach is still occurring in the eastern part of the Lake Michigan Region because of the reorientation of dominant wind direction across Lake Michigan.

Wetlands of considerable size are present in the interridge depressions in the eastern part of the Lake Michigan Region. An unnamed marsh lies between the Glenwood and the Calumet Beaches, and **Great Marsh**, which includes **Cowles Bog**, lies between the Calumet and the Toleston Beaches. *Palustrine* sediments are abundant in these interridge wetlands.

Areas of gentle relief in the Calumet Lacustrine Plain are capped by lacustrine and palustrine sediments (Gray, 1989). These areas are drained by sluggish rivers which empty into Lake Michigan. However, extensive *channelization* of the Little and Grand Calumet Rivers and industrialization in neighboring areas have altered the physiography and the hydrology of the Region.

Surficial geology

Surficial deposits overlie bedrock throughout the Lake Michigan Region. The deposits in the region are directly and indirectly related to the latest Wisconsinan glacial events of the Lake Michigan lobe.

The surficial deposits in the southern part of the Region are primarily the result of glacial processes, but the deposits in the northern part of the Region are the result of glacial, lacustrine, coastal and *eolian* sedimentation (figure 17). The unconsolidated deposits in the Lake Michigan Region ranges in thickness from about 100 feet (30 meters) to more than 350 feet (107 meters) (figure 18).

In general, the *stratigraphy* of surficial deposits controls the occurrence of ground water within the deposits. Important factors that control the hydraulic characteristics of an aquifer include grain size, grain shape, degree of sorting, and extent and arrangement of the deposits. The occurrence of these hydrogeologic elements in the surficial deposits of the Lake Michigan Region is the result of a complex interplay of depositional processes in various sedimentary environments.

Valparaiso Morainal Complex

The *lithofacies* of the Valparaiso and Tinley Moraines can be classified into five groups: 1) lacustrine muds, 2) *outwash* sands, 3) shale-rich gravels, 4) basal tills and 5) debris-flow tills. The vertical sequence of the deposits suggests that most of the complex was probably deposited during a time of ice advance.

Lacustrine muds, consisting of laminated silt, silty *loam*, and silty clay loam underlie the morainal complex in many places. These basal muds were probably deposited in a *proglacial* lake that covered almost the entire Kankakee River Basin. The lake formed when the Lake Michigan lobe retreated from a terminal position at the Iroquois Moraine south of the Region. The basal lacustrine muds are thickest beneath the western part of the Valparaiso morainal complex. Thin, less extensive sequences of lacustrine muds occur in the upper parts of the morainal complex. The muds, which are commonly interbedded with debris-flow tills or sand in abbreviated *deltaic sequences*, probably originated as *ice karst*, kettle holes or other irregular basins of internal drainage.

Medium-grained outwash sands overlie the basal lacustrine muds throughout most of the complex. The outwash sands were deposited by *meltwater* streams emanating from the Lake Michigan lobe. Thick outwash deposits occur as stacked channel fills with erosional *basal contacts* or as coarsening-upward deltaic sequences. The sand deposits form the Valparaiso Moraine *Aquifer system* and are extensive and thought to be continuous beneath most of the morainal complex. The outwash sands are generally thinner toward the west.

Black shale gravels are common in the Valparaiso morainal complex. The gravels are present in channel deposits throughout the central part of the morainal complex, and also make up a significant portion of the *outwash fan* toward the east. Thinning and fining-upward sequences in the channel deposits indicate channel abandonment, while thickening and coarsening-upward sequences indicate *progradation* of depositional lobes away from the advancing ice front. Gravels that were deposited outside of channels may be coarser-grained and thicker-bedded upward in the sequence.

Tills overlie most of the outwash sands in the Lake Michigan Region and extend to the surface. However, the thickness and texture of the surficial tills are not uniform across the morainal complex.

Thick basal tills cover the surface of the western segment of the Valparaiso morainal complex. The tills, mostly of clay loam texture, were deposited directly from ice as the Lake Michigan lobe overrode its outwash fan.

A **veneer of *debris-flow tills*** is present along the northern slopes and crest of the eastern part of the Valparaiso morainal complex indicating that glacial ice did not override the outwash fan in this area. The debris-flow tills are coarser grained than the basal tills to the west, and are usually in the form of silty loam and sandy silty loam. In a few places along the crest of the eastern part of the morainal complex, no tills are present and outwash deposits occur at the top of the sequence (figure 17).

The surface of the Valparaiso morainal complex contains isolated pockets of palustrine sediments (figure 17). The organic-rich sediments accumulated in *kettle holes* which are scattered throughout the morainal surface.

Lake Border Moraine

Surficial sediments of the Lake Border Moraine were deposited during the final glacial advances of the Lake Michigan Lobe. Thompson (1987) subdivided the deposits beneath the morainal surface into three *lithostratigraphic units*: 1) interbedded sand, gravel, clay and till, 2) till and glaciolacustrine clay capped by outwash sand and gravel, and 3) till.

Randomly **interbedded sand, gravel, clay and till** overlie shale and limestone bedrock in the northern part of the moraine. Lithologic variability, random distribution and poor preservation of the basal sediments prohibit interpretation of age and origin (Thompson, 1987).

Till and glaciolacustrine clay directly overlie the basal sediments of the Lake Border Moraine. Glaciolacustrine deposits predominate in the northward part of the unit, whereas tills are common in the central part of the unit (Thompson, 1987). The till and glaciolacustrine clay unit averages about 50 feet (15 meters) in thickness, and extends under Lake Michigan. Outwash sand and gravel overlie the glaciolacustrine clay and form the internal core of the morainal complex. The coarse-grained deposits commonly range in thickness from about 40 to 60 feet (12 to 18 meters). In some areas where the coarse-grained sediments are underlain by broken rock, local thickness of the sediments may exceed 150 feet (46 meters). Thick, localized accumulations of outwash material may indicate *tunnel valley fills* and/or isolated *outwash cones* at tunnel exits (Ned Bleuer, Indiana Geological Survey, personal communication).

A relatively impermeable **till** overlies the sandy core of the Lake Border Moraine and extends to the surface. The upper part of the till is yellow to brown but becomes blue-gray in the lower part. *Lenticular* bodies of sand and gravel, which probably formed as beach ridges, are present at the contact between the upper and lower parts of the till (Thompson, 1987). The surficial till of the Lake Border Moraine can be traced westward beneath the surficial sands of the Calumet Lacustrine Plain (Ned Bleuer, Indiana Geological Survey, personal communication).

Calumet Lacustrine Plain

Formation and development of the Calumet Lacustrine Plain began after the Lake Michigan lobe retreated northward from a terminal position at the Lake Border Moraine. The southern extent of the plain is marked by the Glenwood Beach, a discontinuous relict dune-capped beach ridge present along the northern slopes of the Lake Border and Tinley Moraines (figure 16). The deposits of the Calumet Lacustrine Plain can be subdivided into three lithostratigraphic units: 1) stratified lacustrine sand, silt and clay, 2) till and glaciolacustrine clay, and 3) lacustrine, dunal and coastal sands.

Stratified lacustrine sand, silt and clay overlie shale and limestone bedrock in the Calumet Lacustrine Plain. Gamma-ray logs of wells drilled in northern Lake and northwestern Porter Counties indicate the lacustrine sequence is generally upward-coarsening with intermixed silt and clay layers (Ned Bleuer, Indiana Geological Survey, unpublished data). This unit may be similar to the lowest unconsolidated unit of the Lake Border Moraine.

A relatively impermeable **till and glaciolacustrine clay** unit overlies the lacustrine sediments in the Calumet Lacustrine Plain. The unit consists predominantly of thick basal tills and thinner sequences of *ablation* tills. The unit exceeds 100 feet (30 meters) in thickness in many places.

Fine-grained lacustrine and dunal sands, and medium-grained coastal sands form most of the surficial deposits of the Calumet Lacustrine Plain. The lacustrine sands were deposited during the formation and development of ancestral Lake Michigan. Coastal and dunal sands comprise the relict beach ridges which mark the ancient shorelines of the lake. The surficial sand deposits of the Calumet Lacustrine Plain commonly range from about 30 to 50 feet (9 to 15 meters) in thickness, but can be much thicker along the dune-capped beach ridges.

Lacustrine clays and palustrine sediments are present at the surface in small areas throughout the plain (Gray, 1989). The lacustrine clays were deposited in the low-energy environments of ancestral Lake Michigan, and the palustrine sediments accumulated in basins of restricted or internal drainage and in poorly-drained interridge lowlands. Extensive accumulations of palustrine sediments which are found in Great Marsh, including Cowles Bog, are preserved in the Indiana Dunes National Lakeshore and the Indiana Dunes State Park. In the industrialized part of the Calumet Lacustrine Plain and lakeshore areas, slag and dunal sands were used to fill in the depressions and interridge lowlands, creating a relatively featureless plain.

Bedrock geology

Bedrock in the Lake Michigan Region consists of more than 4,000 feet of *sedimentary* rocks overlying a *granitic Precambrian basement.* The bedrock units consist primarily of sequences of **Cambrian** through **Mississippian** sandstone, limestone, dolomite and shale. In the Lake Michigan Region, bedrock is not exposed at the surface.

Regional bedrock structure in the Lake Michigan Region is controlled by two principal features: the **Kankakee Arch** to the southwest and the **Michigan Basin** to the northeast (figure 19). Sedimentary rocks dip away from the northern flank of the Kankakee Arch toward the Michigan Basin at an average rate of about 35 feet per mile (6.6 meters per kilometer) (Pinsak and Shaver, 1964). The gradient of the lower surface of the bedrock units is significantly higher than the gradient

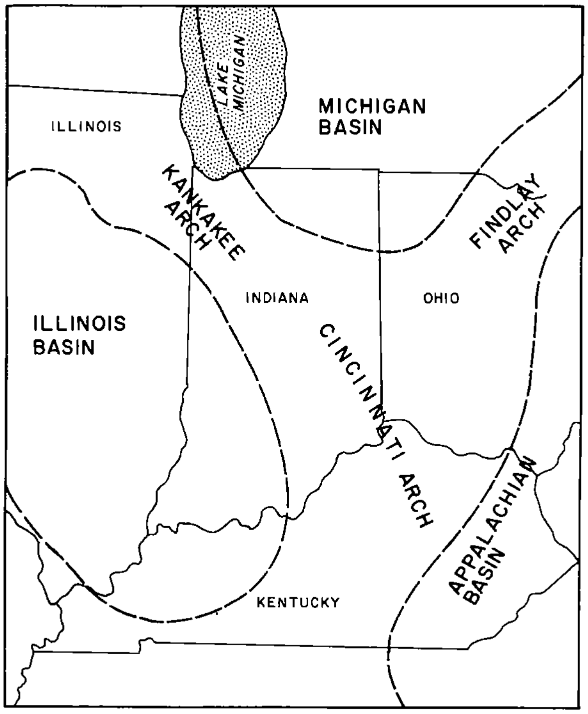


Figure 19. Regional bedrock structure

of the upper surface because the units thicken toward the Michigan Basin. Erosional truncation of bedrock along the Kankakee Arch has left Silurian rocks at the bedrock surface in western Lake County and progressively younger rocks toward the east.

Bedrock physiography

Bedrock relief in the Lake Michigan Region is probably the result of bedrock structure, lithology, differential erosion by streams and glaciers, and variations in the orientation and direction of glacial advances. The bedrock surface has greater relief in the eastern part of the Lake Michigan Region than in the western part of the region (figure 20).

Bedrock highs are present along the southern margin of the Lake Michigan Region. Maximum elevations developed on the bedrock surface range from about 575 feet (175 meters) above m.s.l. in southwestern Lake County to more than 675 feet (206 meters) above m.s.l. in east-central Porter County (figure 20). In most of the areas where maximum bedrock elevations exceed 600 feet (183 meters) above m.s.l., the Antrim and Ellsworth Shales form the bedrock surface (figures 20 and 21).

Major **bedrock valleys** in the Lake Michigan Region frequently originate near or beyond the southern margin of the Region and generally trend northward into Lake Michigan (figure 20). The bedrock valleys in northern Lake and northwestern Porter Counties are broad and have gently-sloping walls along most of their extent. These valleys are developed on rocks which range from Silurian carbonates to Mississippian shales (figures 20 and 21). In contrast, the deep bedrock valleys with steep walls in northeastern Porter and northern LaPorte Counties are developed on shales (figures 20 and 21).

The most prominent bedrock valley in the Lake Michigan Region is located in northern LaPorte County (figure 20). The valley begins in the vicinity of Pine Lake near the city of LaPorte and generally trends northward to the Michigan state line, where it is overlain by more than 250 feet (76 meters) of unconsolidated material (figure 18). Minimum elevations at the valley floor are less than 350 feet (107 meters) above m.s.l. in the northernmost reach (figure 20). Buried bedrock valleys sometimes contain thick coarse-grained deposits which can form aquifers.

Bedrock stratigraphy and lithology

Cambrian and Ordovician rocks form a large part of the Paleozoic sedimentary sequence in the Lake Michigan Region (appendix 3). However, these lower Paleozoic rocks are not present at the bedrock surface in the Region.

The **Cambrian** sequence in the Lake Michigan Region is comprised of thick sandstone units separated by carbonate, shale, and interbedded shale and carbonate units (appendix 3). The overlying rocks of lower Ordovician age are *conformable* with the upper Cambrian rocks where the stratigraphic sequence is preserved. However, in parts of northwestern Indiana, pre-middle Ordovician erosion has removed lower Ordovician rocks. The **Ordovician** sequence is not as thick as the Cambrian sequence, but consists of relatively thick carbonate units that are separated by a thin sandstone unit and capped by a shale unit (appendix 3).

Rocks at the bedrock surface in the Lake Michigan Region range from **Silurian** to **Mississippian** (figure 21). Detailed discussions on structure, stratigraphy and sedimentology of the rocks may be obtained from

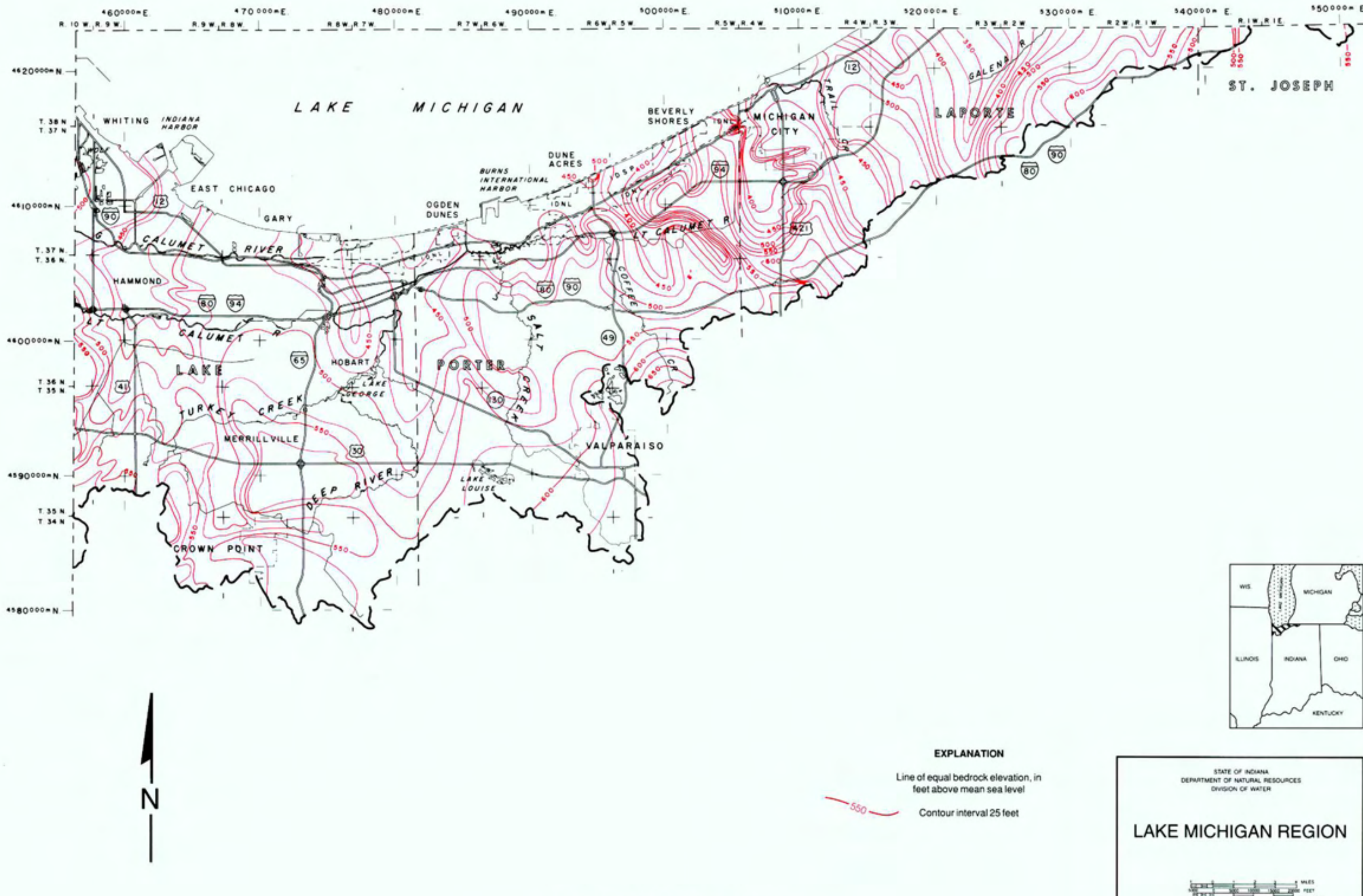


Figure 20. Bedrock topography

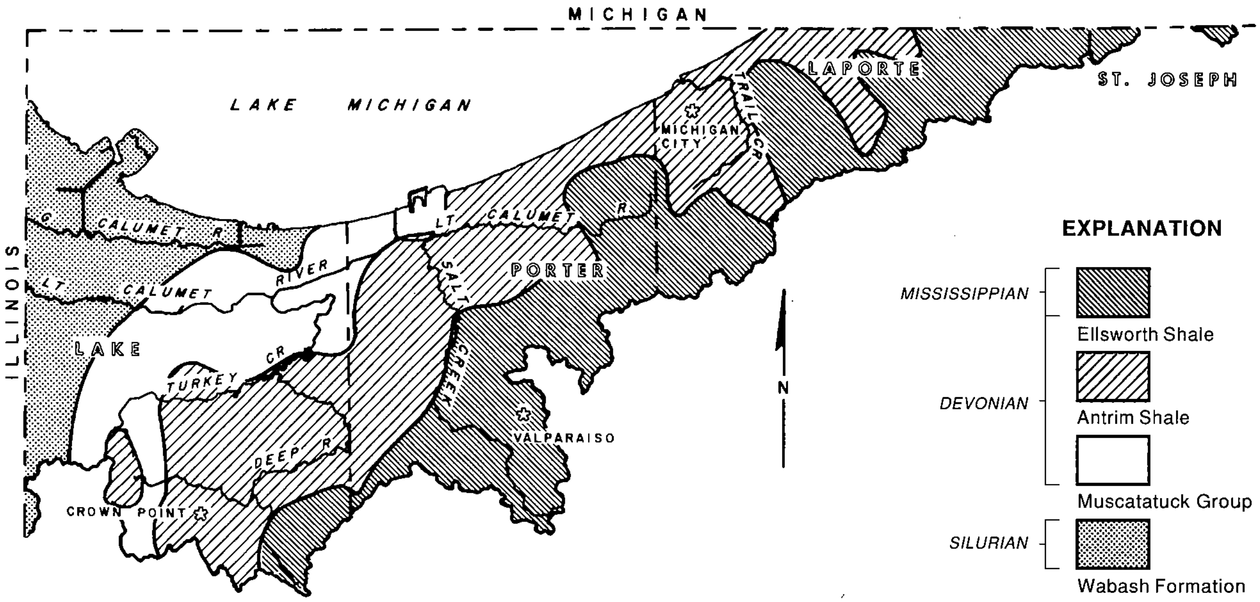


Figure 21. Bedrock geology
(Adapted from Gray and others, 1987)

Doheny and others (1975), Droste and Shaver (1982), and other references cited in the text.

Rocks of the **Silurian Wabash Formation** are the oldest rocks at the bedrock surface in the Lake Michigan Region. Wabash rocks consist of limestone, dolomitic limestone, dolomite and *argillaceous* dolomite. Depositional environments of the Wabash rocks include reef and inter-reef environments, although non-reef facies of the Wabash Formation exist (Droste and Shaver, 1982). The four principal lithologies of the Wabash Formation which are generally characteristic of the Mississinewa Shale Member, Liston Creek Limestone Member, Kokomo Limestone Member and the Huntington Lithofacies intergrade and replace one another spatially within the formation (Shaver and others, 1986). Pre-middle Devonian erosion truncated Wabash rocks differentially, more southward than northward and more eastward than westward (Droste and Shaver, 1982).

The **Devonian Muscatatuck Group** *unconformably* overlies Wabash rocks. The Muscatatuck Group, comprised of the Detroit River and Traverse Formations, occurs at the bedrock surface in the western part of the Lake Michigan Region (figure 21). Rocks of the Muscatatuck Group are predominantly limestone and dolomite, but evaporitic rocks are present in the upper and the lower sections of the Detroit River Formation. Common lithologies of Muscatatuck rocks are described by Shaver and others (1986).

The **Upper Devonian Antrim Shale** *paraconformably* overlies Muscatatuck rocks in the Lake Michigan Region. The Antrim Shale is exposed at the bedrock surface in east-central Lake County and the northern parts of Porter and LaPorte Counties (figure 21). The Antrim consists of brown to black non-*calcareous* shale; however, calcareous shale, limestone and sandstone are present in the lower part of the unit in some areas in LaPorte County (Shaver and others, 1986). The Antrim Shale is largely correlative with the **New Albany Shale** of the Illinois Basin.

The **Ellsworth Shale** ranges from **Upper Devonian** to **Lower Mississippian** in age and conformably overlies the Antrim Shale. The Ellsworth Shale can be found at the bedrock surface along the southern and southeastern margins of the Region in Porter and LaPorte Counties (figure 21). The Ellsworth is characterized by gray-green shale with limestone or dolomite lenses in the upper part and alternating beds of gray-green shale and brown-black shale in the lower part.

SOILS

Soil development is controlled to a large extent by climate, topography, biota, *parent material* and time. Surficial geology and physiography are important factors that influence soil texture. In the Lake Michigan Region, the distribution of the major soil types is closely related to the physiographic terrains of the Region: namely, clayey or loamy soils found in the Valparaiso Morainal Area, and sandy soils found in the Calumet Lacustrine Plain.

Soils on the end moraines of the Valparaiso Morainal Area (see figure 16) have been developed primarily in clay-rich glacial till. Loamy soils are more common in the eastern part of the morainal area, where stratified mixed drift of the Valparaiso Moraine are present in northern LaPorte County. The soils that are formed on morainal swells and slopes are well-drained, but the soils in plains, ice-block depressions and relict glacial drainageways are poorly-drained.

In the Calumet Lacustrine Plain, sandy soils occur on dune and beach complexes and on lacustrine and coastal deposits. The well-drained soils occur on the dune and beach ridges, whereas the poorly-drained soils are present in interridge depressions, drainageways and lake-plains.

Soil development in most of the Lake Michigan Region occurred under a cover of mixed hardwood forest; however, some soils in Lake and Porter County developed under prairie grasses (figure 22). Isolated pockets of organic soils have developed in areas of restricted or internal drainage. At several industrial and urban sites along the Lake Michigan shore, alteration of the landscape has resulted in substantially modified soil.

Soil data of major Region counties are presented in soil survey reports (Persinger, 1972; Furr, 1981 and 1982). Soil maps and related data found in these reports can be used for general planning purposes. The following discussions are based on generalized maps which provide an even broader overview of Region soils.

Soil associations and hydrologic soil groups

Soils can be classified according to similarities of parent materials, texture, *horizon* characteristics, topography, natural drainage, and special features. A soil series, the most common category used in county soil surveys, allows detailed evaluations of specific tracts of land. For generalized applications, however, a soil association is a commonly used category.

A soil association is a landscape having a distinctive pattern of soil series in relation to similar parent materials, landforms and slopes. Within a given soil association, each soil series occupies a characteristic position on one of three major landform types; namely, 1) hillslopes, swells, or depressions within broad uplands, 2) terraces, outwash plains, or lacustrine plains, and 3) floodplains or bottomlands (Galloway and Steinhardt, 1984).

A soil association is composed primarily of two to four major soils and a few minor soils, and is named for the major soils. The soils in one association may occur in another, but in a different pattern.

A total of 108 soil association were identified in a series of generalized county soil maps developed in 1970 by the U.S. Department of Agriculture's Soil Conservation Service and Purdue University's Agricultural Experiment Station. A few of the general soil maps were revised slightly when they were later printed with supplementary data tables and a user's guide in 1975 (U.S. Department of Agriculture, 1971; Galloway and others, [1975]).

In 1977, the Soil Conservation Service and Purdue University combined the 1971/1975 series of general soil maps to produce a 1:500,000-scale map of Indiana showing major soil associations on a broad basis. Figure 22, adapted from a 1982 revision of the state map (U.S. Department of Agriculture, 1982), shows the location of major soil associations in the Lake Michigan Region.

Figure 22 also shows the regions of similar parent materials into which the major associations are grouped. Figure 22 can be useful in relating Region soils to surficial geology, topography and vegetation types (see explanatory text accompanying figure 22). A report by Galloway and Steinhart (1984) discusses the influences of geology, physiography and climate on the formation of soil association, and summarizes the relations among associations occupying specific landscape positions.

Soil survey reports (referenced previously) contain detailed descriptions of soil properties that affect land use, and include tables which outline the potentials and limitations of individual soils for cultivated crops, woodland, urban and recreation uses. Although the map shown in figure 22 is too generalized for such detailed land-use planning, it can be used to compare the suitability of large areas for general land uses.

In addition to its utility in assessing general land uses, the map in figure 22 also can be helpful in examining, on a broad basis, the role of soils in the

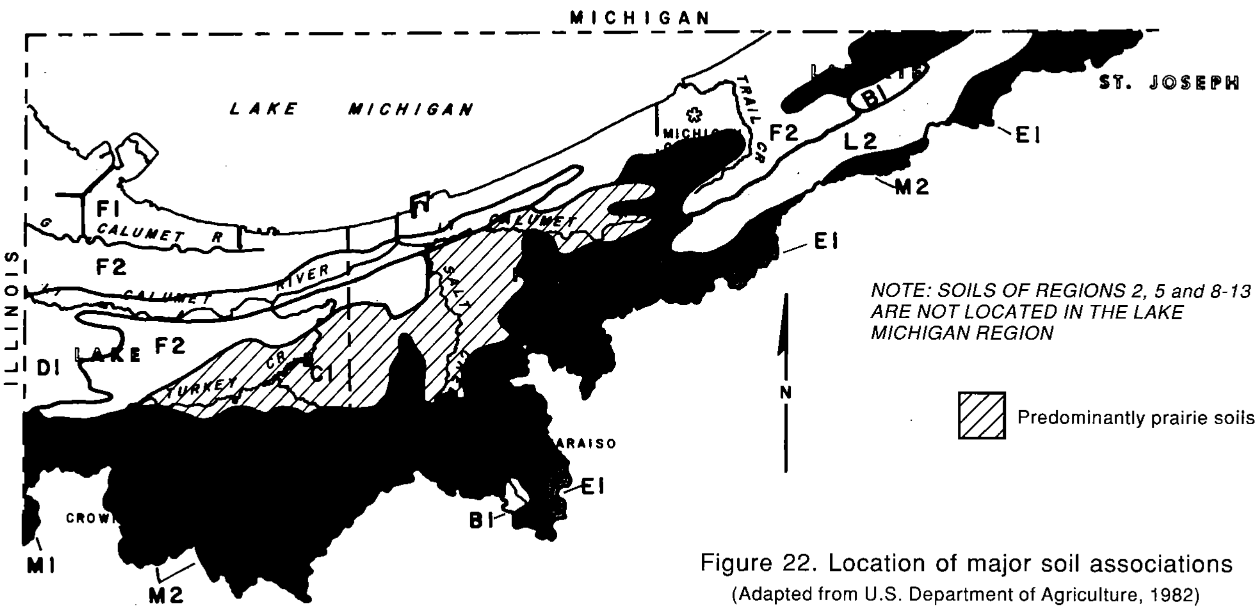


Figure 22. Location of major soil associations
(Adapted from U.S. Department of Agriculture, 1982)

REGION 1 - SOILS FORMED IN SANDY AND LOAMY LACUSTRINE AND EOLIAN SAND DEPOSITS

The nearly level, very poorly drained soils of the Houghton-Adrian association (B1) formed in organic materials deposited in ancient lakes, and developed under a cover of trees, shrubs and sedges. These soils frequently occur as small, scattered muck pockets; however, two mappable areas occur in the region. One is located in LaPorte County near the headwaters of the Galena River, the other is south of Valparaiso. Loamy soils in the Rensselaer-Darroch-Whitaker association (C1) predominate on the nearly level lacustrine plains of the Lake Michigan Region. The very poorly drained Rensselaer soils occur in swales and broad, flat areas. Somewhat poorly drained Whitaker and Darroch soils are found on convex swells in the lake plain. Whitaker and Rensselaer soils formed under a cover of mixed hardwoods, whereas Darroch soils developed under prairie grasses. Soils of the Milford-Bono-Rensselaer association (D1), located in the west central part of the region, are very poorly drained. The native vegetation was mainly water-tolerant mixed hardwood and grass species. The parent materials are calcareous, silty, clayey and loamy lacustrine deposits.

REGION 3 - SOILS FORMED IN ALLUVIAL AND OUTWASH DEPOSITS

Well-drained soils of the Tracy-Door-Lydick association (E1) occupy the pitted outwash fan which extends from eastern Porter County to northwest St. Joseph County. Only two small areas of this association occur near the southeastern boundary of the Lake Michigan Region. The parent materials are loamy and sandy outwash deposits that were high in sulfur-containing shale particles and which weathered to form acid soils. The native vegetation on Tracy soils was mainly oak; on Door it was prairie grasses; and on Lydick, it was a mixture of the two vegetation types. Tracy soils are found on 0 to 12 percent slopes. Lydick and Door soils are mainly on 0 to 2 percent slopes.

REGION 4 - SOILS FORMED IN EOLIAN DEPOSITS

At the south end of Lake Michigan Oakville-Adrian (F1) association soils are found on the high sand dunes and the lower sandy ridges and wet swales. Oakville soils, formed from dune sand or beach sand, are on dunes and beach ridges. Comprised of fine sand throughout, the Oakville soils are well-drained. Native vegetation was mainly oak trees. Adrian, a very poorly drained soil, formed in 16 to 50 inches of organic material over sands, is found in the swales between the ridges. Soils of the Plainfield-Maumee-Oshtemo association (F2) developed in *eolian* sands and sandy outwash deposits. Well-drained Plainfield soils have a fine sand texture throughout and typically are found on 2 to 12 percent slopes on sand dunes, where the native vegetation was mainly white and black oak. Very poorly drained Maumee soils, which are fine sand or loamy fine sand throughout, occupy the level, low-lying areas around the dunes. Oshtemo soils, located on outwash plains, are well drained and are comprised of loamy sands or sandy loams.

REGION 6 - SOILS FORMED IN LOAMY GLACIAL TILL

Well-drained soils of the Riddles-Tracy-Chelsea (L2) association are mainly found on 2 to 18 percent convex slopes of the Valparaiso Moraine in LaPorte County. Parent materials are glacial till and outwash and native vegetation was hardwood trees.

REGION 7- SOILS FORMED IN CLAYEY GLACIAL TILL

Soils of the Markham-Elliott-Pewamo (M1) and Morley-Blount-Pewamo (M2) associations are found on the Valparaiso Moraine in Lake, Porter and western LaPorte Counties. The parent material is calcareous silty clay loam or clay loam till. Soils of the Markham-Elliott-Pewamo association developed under prairie grasses, whereas soils of the Morley-Blount-Pewamo association formed under beech, oak and maple forests. Well-drained Markham and Morley soils are found on 2 to 12 percent slopes. The somewhat poorly drained Elliott and Blount soils occupy nearly level areas. Very poorly drained Pewamo soils are found in drainageways and swales.

generation of surface-water runoff. The Soil Conservation Service has classified soils into four hydrologic groups (A,B,C,D) according to the soil's ability to absorb rainfall and thereby reduce runoff. Classifying bare soils on the Region of their minimum *infiltration* rate, after an extended period of wetting, reflects the properties of both the surface and underlying soil horizons.

Soils in hydrologic group A have high infiltration rates even when thoroughly wetted, and consist chiefly of deep, well to excessively drained sands and gravels. These soils also have high *transmission* rates. Plainfield and Oakville soils, which are found on sand dunes and ridges just south of Lake Michigan (associations F1 and F2 in figure 22) and Chelsea (association L2) which is found on the Valparaiso Moraine in LaPorte County, are the major soils of the region which naturally fall into hydrologic soil group A. Maumee, Houghton and Adrian soils, found primarily in level, low-lying areas around dunes or river valleys (associations F2 and B1), may be classified into hydrologic soil group A after artificial drainage measures have improved their ability to absorb rainfall and reduce runoff.

Soils in hydrologic group B have moderate infiltration and transmission rates. Well-drained soils that typify this soil group include those that have formed in loamy glacial till of the Valparaiso Moraine in LaPorte County (L2). Other soils classified into hydrologic soil group B include those that formed on outwash-plain deposits, such as soils of the Tracy-Door-Lydick association (E1).

Soils in hydrologic group C have slow infiltration and transmission rates. These soils consist chiefly of soils with a layer that impedes downward movement of water, or soils having a moderately fine to fine texture. In the Lake Michigan Region, these soils are found primarily on the Valparaiso Moraine (associations M1 and M2), where soils have formed on clayey glacial till deposits in Lake and Porter Counties. Other areas of C-group soils are found on the nearly level lacustrine plains of the Region (association C1).

Soils in hydrologic group D have very slow rates of infiltration and transmission. In the Lake Michigan Region, this soil group consists chiefly of soils having a permanent high water table and/or organic materials, or soils having a clay layer at or near the surface. Undrained tracts dominated by Maumee, Houghton or Adrian, Bono or Milford soils (associations F2, B1, and D1, respectively) are included in this hydrologic soil group. Undrained depressional areas dominated by Pewamo soils also are classified in soil group D. Undrained Pewamo soils commonly are found in *swales* and drainageways on the Valparaiso Moraine (associations M1 and M2).

LAKE MICHIGAN AND ITS COAST IN INDIANA

Lake Michigan covers 234.5 square miles of the northwest corner of the state of Indiana, and 45 miles of its coast are also within the state boundaries. The Lake and its coast are encompassed within the Lake Michigan Region as defined in this report.

The present configuration of Lake Michigan and the other Great Lakes is mainly the result of erosion by continental glaciers during the Pleistocene Epoch. The glaciers gouged large depressions into the preglacial lowlands, removing layers of rock in many places. Water filled the large depressions during retreat of the ice sheets at the end of the Wisconsinan glacial period, thus forming the Great Lakes.

The physiography of the Lake Michigan drainage basin is the expression of surficial sediments deposited during the late Pleistocene and Holocene Epochs. Lake-bed deposits in the southern part of Lake Michigan, including the portion of the lake that lies within the state of Indiana, include sand near the shore, gravel from 50 to 100 feet deep, and mud in the deep parts (Great Lakes Basin Commission, 1976b).

Elongated sand dune ridges landward of the south shore of Lake Michigan represent late Pleistocene and Holocene shorelines of ancestral Lake Michigan. Three of the ridges are major dune and beach complexes which developed during periods of high semi-stable lake level.

Natural processes

Lake-level fluctuations

Fluctuations in Great Lakes water levels have occurred continually since the Great Lakes formed at the end of the Ice Age. A summary of the late Pleistocene and Holocene lake-level history in the Lake Michigan Basin is presented in the box on the next page. The level of each of the Great Lakes, including Lake Michigan, depends on the balance between the quantities of water received and the quantities of water removed. As the supply of water changes under natural outlet conditions in a lake, the lake-level and outflow adjust continually to restore a balance between the net supply of water to the lake and the outflow through its outlet.

Lake level records have been kept for Lake Michigan/Huron since 1860, at Harbor Beach, Michigan. The lowest monthly average lake level recorded during that time, 575.35 feet *International Great Lakes Datum* 1955 (576.05 IGLD 1985), occurred in March 1964. The highest monthly average lake level recorded, 581.94 feet IGLD 1955 (582.64 IGLD 1985) occurred in June 1886. This is a difference of 6.59 feet in water level since records have been kept.

In this century, the highest monthly average lake level recorded, 581.62 IGLD 1955 (582.32 IGLD 1985), occurred in October 1986. This century's instantaneous record high lake level, recorded at Calumet Harbor, Illinois was 582.76 IGLD 1955 (583.46 IGLD 1985) at 8:00 am on October 4, 1986.

Lake levels affect extent of flooding, shoreline erosion and shoreline property damage, wetland acreage, depth of navigation channels and hydroelectric power output.

There have been record water level lows for Lake Michigan and the other Great Lakes occurring in the 1920s, 1930s, and 1960s and record highs occurring in the 1950s, 1970s, and most recently, in 1985 and 1986. As a result of the high water levels of the 1950s, the U.S. House of Representatives requested that the U.S. Army Corps of Engineers determine the feasibility of measures to prevent the recurrence of damages. The Corps study (1965c) consisted of two phases: the first, to look at the advisability of adopting local projects for flood control at specific areas along U.S. shores and tributary streams of the Great Lakes to reduce damage due to water level fluctuations; the second, to examine the feasibility of lake-regulation measures to reduce damage. The Corps report contained recommendations regarding local shoreline protection projects but had no conclusions or recommendations on the second phase of the study. The study, however, provided information on various lake-regulation plans and associated cost.

Extremely high lake levels occurring again in the early 1970s generated a lot of concern. A report was presented to the International Joint Commission (IJC) by the International Great Lakes Levels Board (1973) concerning potential changes in lake-level regulation plans at existing regulatory sites on the lakes as a means

ANCESTRAL LAKE MICHIGAN

The complex history of ancestral Lake Michigan began during the late Wisconsinan deglaciation when the Lake Michigan ice lobe retreated a short distance from the Lake Border Moraine. Subsequent episodes of advance and retreat by the ice margin into and out of the north and central parts of the basin caused considerable changes in the water level and areal extent of ancestral Lake Michigan.

Evidence for major lake events in the Lake Michigan Basin comes from the extent and altitudes of wave-cut cliffs, beaches, spits and deltas, and from altitudes of abandoned lake outlets (Hansel and others, 1985). In addition, radiocarbon evidence has proved helpful in determining the timing of glacial and post-glacial events in the basin (Hansel and Mickelson, 1988).

Factors that affected glacial and postglacial lake levels in the Lake Michigan Basin include: 1) the advance and retreat of ice margins that blocked or uncovered outlets, 2) downcutting of outlets, 3) major increases and decreases in the volume of water entering the lake, and 4) differential *isostatic* changes in the altitudes of parts of the basin or outlets (Hansel and others, 1985). Generally, these mechanisms work in combination to control the major lake events (lake phases) in the basin.

Reliable information on lake levels in the Lake Michigan Basin indicates that high semi-stable levels first occurred during the Glenwood II lake phase. Initially, the lake level in the basin rose during the early part of the phase when the northern outlets at the Straits of Mackinac and the Indian River lowland became closed off during readvance of the ice margin. The rising lake level activated the Chicago Outlet, an overflow channel through the Valparaiso Morainic System and the Tinley Moraine southwest of present-day Chicago. Conditions at the Outlet were probably partly or entirely responsible for controlling the high semi-stable lake levels in the Lake Michigan Basin (Wright, 1918; Bretz, 1951, 1955; Hansel and others, 1985).

The high semi-stable lake level of the Glenwood II phase, which occurred about 12,900 to 12,700 years before present (BP) (Hansel and others, 1985), resulted in considerable development of the Glenwood Beach in northwestern Indiana and northeastern Illinois. Based on the internal architecture of the beach deposits, Thompson (1987) concluded that the elevation of the semi-stable Glenwood level ranged from about 620 to 630 feet (189 to 192 meters) above m.s.l.

The end of the Glenwood II lake phase and the beginning of the Two Creeks lake phase corresponds in time with the deglaciation of the northern outlets about 12,400 years BP. Drainage through the northern outlets lowered the level in the Lake Michigan Basin below the present level from about 12,000 to 11,800 years BP (Hansel and others, 1985).

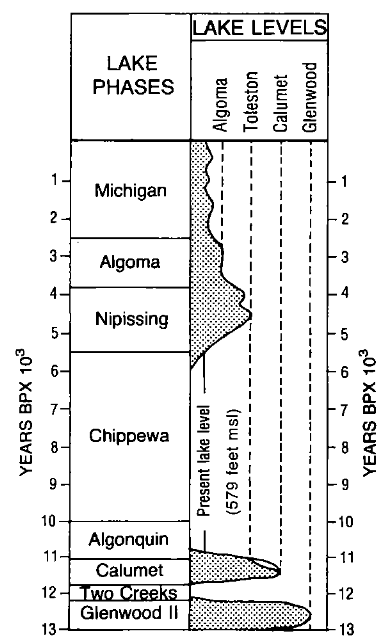
Readvance of the ice margin soon after 11,800 years BP marked the beginning of the Calumet lake phase. After the northern outlets became blocked, the Chicago Outlet was reactivated as the lake level rose and then stabilized about 11,500 years BP. The Calumet Beach in northwestern Indiana developed during the Calumet lake phase when the lake level stabilized at elevations ranging from 603 to 610 feet (184 to 186 meters) above m.s.l. (Thompson, 1987).

Retreat of the ice margin from the Straits of Mackinac about 11,000 years BP caused water in the Lake Michigan and Lake Superior Basins to be confluent with Lake Algonquin in the Lake Huron Basin (Hansel and others, 1985). As a result, the lake level in the Lake Michigan Basin was lowered below the present-day altitude of Lake Michigan during most of the Algonquin lake phase. Low lake levels also continued into most of the Chippewa lake phase which ended about 5,500 years BP.

The transition from the Chippewa lake phase (low lake level) to the Nipissing lake phase (high lake level) after 6,000 years BP corresponds approximately in time with the end of the *Hypsithermal* episode of Holocene climatic history, when warmer drier conditions of early Holocene were replaced by cooler and wetter conditions in the northern Midwest (Bartlein and Webb, 1982). Initially, water in the basins of Lakes Michigan, Superior and Huron were confluent during the early part of the Nipissing lake phase. As differential uplift elevated the northern outlet at North Bay, lake levels rose and the Chicago Outlet was reactivated. Lake levels in the Lake Michigan Basin rose above the present-day level between 6,000 and 5,000 years BP and attained a maximum level between 4,700 and 4,000 years BP (Hansel and others, 1985). The high semi-stable lake levels during the Nipissing phase of ancestral Lake Michigan resulted in the formation of the Toleston Beach. Thompson (1987) indicated that the elevation of the Toleston level of ancestral Lake Michigan ranged from about 597 to 603 feet (182 to 184 meters) above m.s.l.

A lowering of the lake level about 3,800 years BP marked the end of the Nipissing lake phase and the beginning of the Algoma lake phase in the Lake Michigan Basin (see figure). Incision of the St. Clair River channel at Port Huron was considered to be responsible for the end of the Nipissing *transgression*, but a more gradual process in which the rate of erosion of the outlet channel partly kept pace with ongoing differential uplift probably occurred (Hansel and others, 1985). Lake level fluctuations occurring on a scale of 200 to 300 years characterize the Algoma and Michigan lake phases. The fluctuations can be thought of as climate-related changes in lake levels that were adjusted to channel depths of the St. Clair River at Port Huron (Hansel and others, 1985).

Lake levels during the Algoma phase fluctuated as high as 587 feet (179 meters) above m.s.l. about 3,200 years BP. In addition, fluctuations as high as seven feet (two meters) above the present lake level occurred about 1,500, 1,000, and 450 years BP (Hansel and others, 1985).



of alleviating problems caused by high lake levels. The Board found that only small improvements are practicable without costly regulatory works and remedial measures. The Board also concluded that the most promising measures for minimizing future damages to shore property are strict land-use zoning and structural setback requirements.

In 1981, the International Great Lakes Diversion and Consumptive Use Study Board, established by the IJC, examined effects of **consumptive use** and **diversions** on water levels and flows of the Great Lakes Basin. The Board found that consumptive uses of water reduce the net water supply to the lakes, thereby lowering lake levels, resulting in economic benefits to coastal zone interests and losses to navigation and power interests. The Board concluded that the diversion rates into, within and out of the basin cannot be altered to reduce threat of extreme high levels on the Great Lakes without causing an overall long-term net economic loss and that diversion rates cannot feasibly be altered to reduce threat of extreme low levels on the Great Lakes during periods of low supplies. The IJC did, however, recommend to the governments surrounding the lakes that a mechanism be established for institutional consultation, so that monitoring could be undertaken and appropriate public policies formulated, to address potential impacts of new or increased diversions and consumptive uses.

Record high lake levels, occurring again in 1985 and 1986, resulted in a series of studies and publications concerning Great Lakes water levels. Bixby (1985) prepared, for the Center for the Great Lakes, an overview of Great Lakes Water levels. The U.S. Army Corps of Engineers (1984a) prepared a publication on Great Lakes water level facts. Briefings were held by the Corps (1985) and the International Joint Commission (1985) with Senators and representatives of the Great Lakes basin states concerning water levels of the lakes. The Great Lakes Commission (1986) published a report concerning water level changes and factors influencing the Great Lakes.

A recent investigation has been undertaken by the IJC at the request of the United States and Canadian governments to re-examine and report on methods of alleviating the adverse consequences of fluctuating water levels in the Great Lakes-St. Lawrence River Basin using the most up-to-date techniques and information. Phase I of the International Great Lakes Level Board (IJC) investigation was completed (1989). Phase II was completed in March, 1993.

Phase I (1989) is a progress report which consists of an Executive Summary, Main Report and seven subject-specific Annexes. The major conclusions reached in the Phase I report are that: 1) the Great Lakes water level fluctuation situation must be approached on a system-wide basis; 2) that specific measures aimed at affecting system-wide water level fluctuations are probably futile; 3) and that there must be a recognition of need for a fundamental change in the conventional approach to alleviating adverse consequences. Phase I identified the priority goals of developing a set of principles to guide decision-making, a strategy that could promote effective government action, and a methodology for evaluating measures for specific, local situations in a broad and systemic context. Secondly, Phase I also concludes that measures, particularly combinations of measures, may have high potential for alleviating adverse consequences at specific locales.

Phase II aimed at four collective objectives: 1) a set of binational principles as guides for decision-making; 2) an overall strategy and general plan of action; 3) improvements in governance; 4) refinements in understanding of critical aspects of the system.

As part of Phase II, an options document was completed and circulated for public comment in November 1992 and a series of public meetings were held in February, 1993 for public comment on a Draft Final Report which contained recommendations. The final report was released in March, 1993. The documents include information on the following topics: 1) key results of technical studies; 2) guiding principles for governments; 3) measures to reduce impacts of fluctuating water levels; 4) emergency actions in response to crises conditions; 5) institutional arrangements; and 6) communications practices.

Coastal processes and erosion

The intensity of storms on Lake Michigan plays a primary role in determining the amount of erosion that occurs in any given year. Without storms, there would be no waves or currents to move large quantities of sand along the beach and lake bottom. Lake level affects whether waves attack low on the beach face when lake levels are low, or waves attack high on the back beach at the base of the erodible dune-bluff (figures 23 and 24), when lake levels are high.

In general, times with high lake levels and severe storms usually result in the highest erosion rates along the unprotected portions of Indiana's shoreline. Times of low lake levels and mild storms usually result in low erosion rates.

Long term records covering both types of erosion conditions are needed to get a reasonable estimate of the 'background' erosion rates that can be expected for a particular portion of the shoreline, for use in coastal zone management planning.

Storm winds generate waves by transferring some of the wind energy to the surface of Lake Michigan. The wind energy is stored in the form of waves moving across the lake surface. Waves grow bigger as more wind energy is added. Out in deep water, very little wave energy is lost from waves as they move from one side of the lake to the other. But, when the waves reach shallow water at the coast, the stored wave energy is converted into 'breaking waves' and 'water currents' capable of eroding and moving sand (figure 23).

The strongest and fastest currents found in Lake Michigan are concentrated around the edge of the lake in a narrow 'breaking wave zone', starting in water depths between 18 to 20 feet deep and extending to the beach. This zone is also the location of the greatest volume of sand transport (littoral drift).

If wave crests approach the coast parallel to the beach, sand movement is primarily onshore and offshore. But, when waves approach the coast at an angle, water currents move 'alongshore' and can carry sand in the direction the storm waves are moving. The amount of sand that moves depends on sand availability, the size of the waves and the length of time the waves are present to drive the water currents in one direction.

The 'net' direction of sediment movement is the direction that the largest volume of sand moves over a given period of time. If a small amount of sand moves east during the first part of a storm, but more sand moves west during the latter part of the same storm, the net direction of sand movement would be toward the west. If this pattern persists storm after storm, a net direction of sediment movement is established for that part of the coastline.

From the Michigan state line to Gary, Indiana, the net direction of sand movement (littoral drift) along Indiana's coast is from the east toward the west (figure 25). But, from the Illinois state line to Gary, Indiana, the net

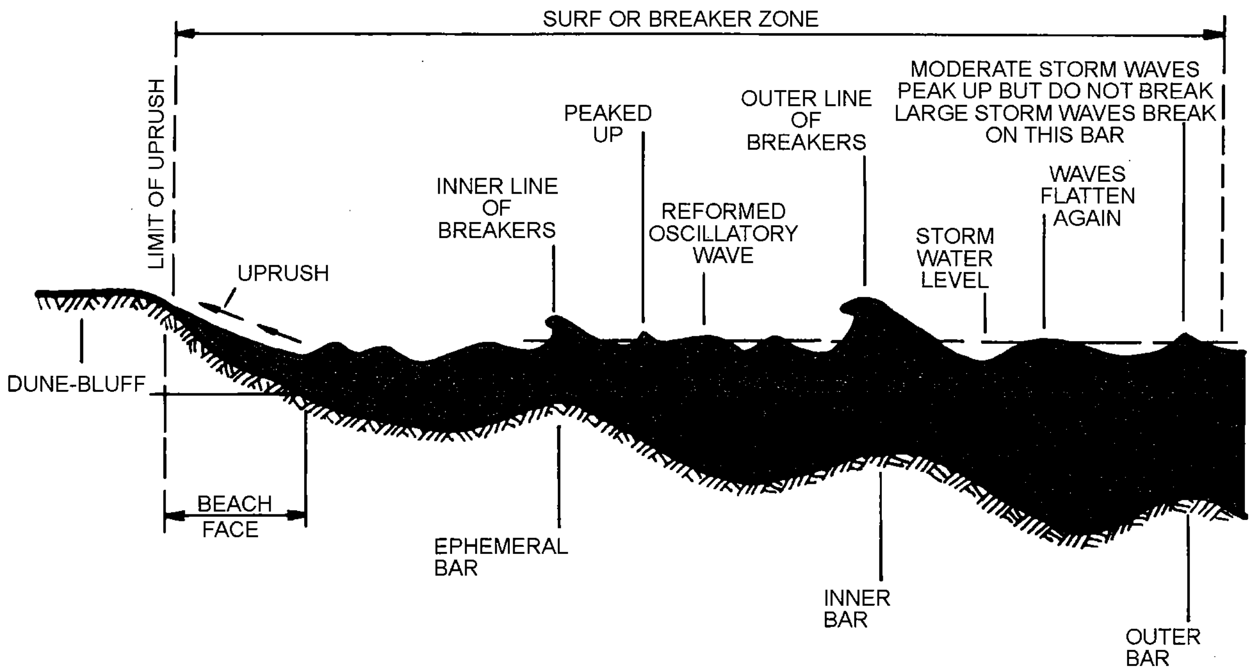


Figure 23. Representative profile across Lake Michigan coastal area

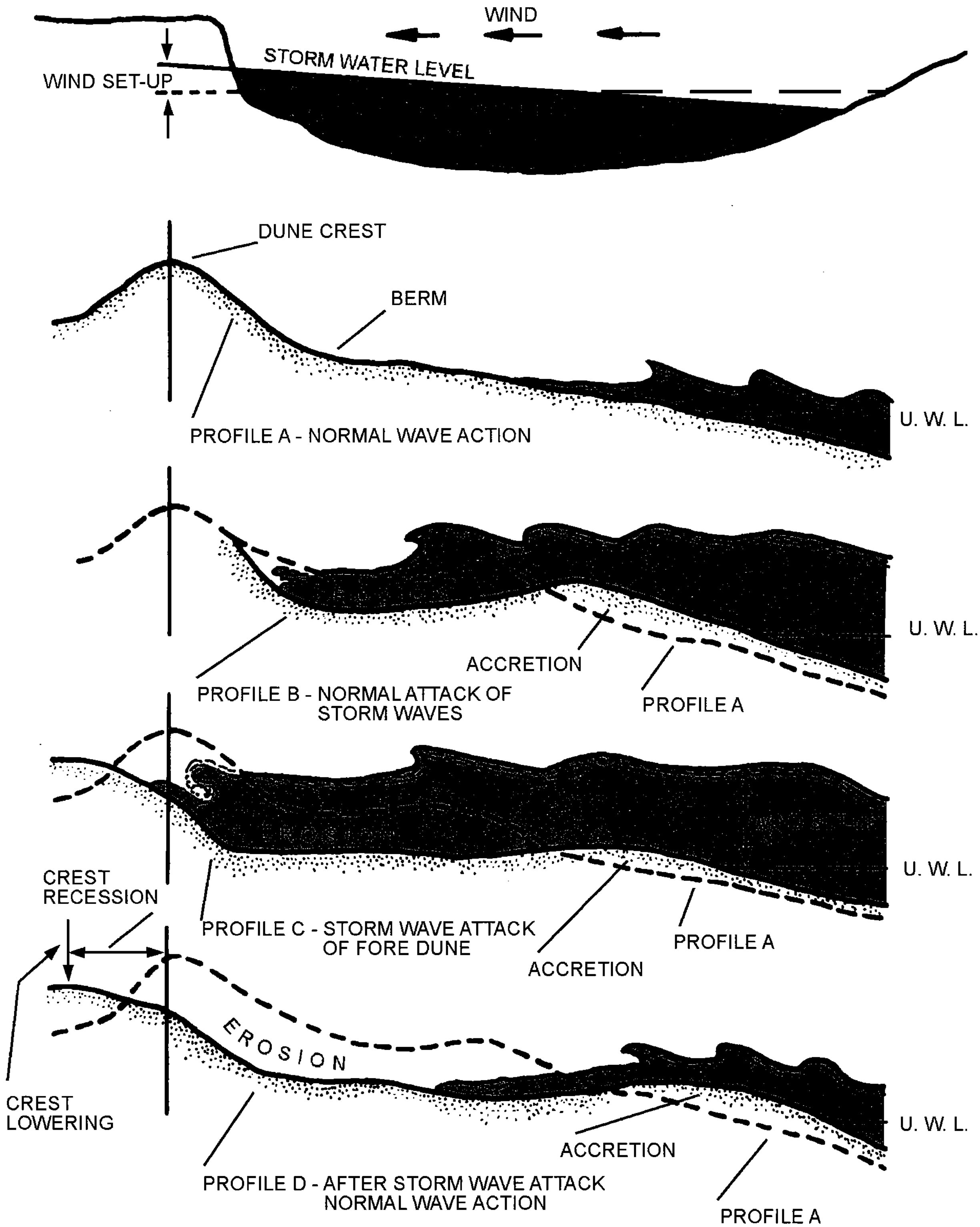


Figure 24. Schematic of wind set-up and resulting erosion

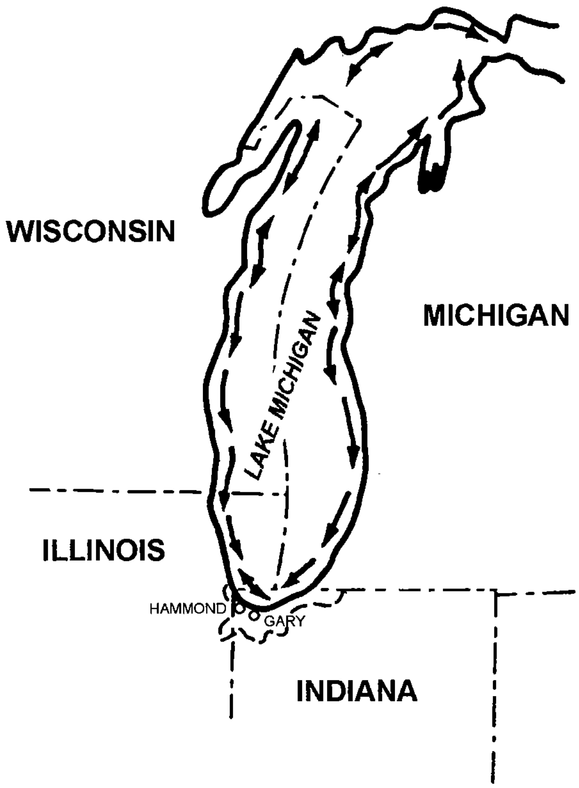


Figure 25. Net direction of littoral transport, Lake Michigan shoreline

direction of sand movement is from the west toward the east. These opposite directions of net sediment movement is expected, due to two determining factors (figure 25).

The first factor is that the most powerful storm waves approach both portions of Indiana's coast from the north, since the strongest storm winds blow out of the northwest, north and northeast directions. These winds are able to transfer considerable energy into waves coming from the north because there is approximately 300 miles of open water between the north end of Lake Michigan and the Indiana coast.

The second factor actually responsible for the opposite net directions of sand movement, east and west of Gary, is the different orientation of the shorelines. Since Gary is located at the southern-most tip of Lake Michigan, the shoreline east of Gary is oriented in a northeast by southwest direction. The shoreline west of Gary is oriented in a northwest by southeast direction. As storm waves approach from the north, the different orientation of the shorelines results in both currents flowing toward Gary, Indiana.

Seasonal climate and erosion

Winter storms are generally high-intensity and destructive in nature, resulting in 'narrow winter beaches' along the Indiana coast. During the summer, some storms may be intense, but these are also accompanied by gentler, constructive wave events resulting in 'wide summer beach' widths.

This seasonal difference in storm intensity results in beaches coming and going in a yearly cycle of narrow winter beaches and wide summer beaches. Once cold winter weather has lowered the surface water temperature of Lake Michigan to near 0 degrees Celsius (32 degrees Fahrenheit), periods of air temperature at or below 0 degrees Celsius can initiate the formation of lake ice. When this coincides with winds blowing onshore, ice can begin to form along the lake's frozen beach. The first winter lake ice has been recorded as early as late December. By January, constant low temperatures combined with strong winter winds and waves can push enough ice toward the coast to form an 'ice complex' as wide as the breaking wave zone, composed of alternating high 'ice ridges' and low lagoons. The general location of the ice ridges coincides with the location of the lake bottom sand bars.

Coastal ice provides a buffer between winter storm waves and the erodible beaches and dune-bluffs, reducing the amount of damage that would occur if the ice had not formed. Usually by March, warm air temperatures have caused the ice ridge complex to break up. Occasionally, a winter season is too warm to allow the normal formation of the protective shore ice, allowing winter storm waves to reach the erodible coast that year.

Human influence

Man-made lands

The Surveyor General of the United States conducted a survey of Indiana's Lake Michigan shoreline between 1824 and 1849. Between the time of the survey and 1900, the shoreline was altered significantly by "reclamation" of approximately 700 acres of "submerged land". These "submerged lands" were filled either as a result of human activity to create valuable lake frontage or by natural *accretion.*

When industry began to expand around the southern end of Lake Michigan at the beginning of the twentieth century, land having the potential for industrial development was in great demand. Hence, several companies planned substantial encroachments into the lake to expand their facilities. In anticipation of industrial expansion into Lake Michigan, Congress passed a joint resolution in 1906 which required permits from the federal government prior to filling of the lake bottom. The resolution required approval by the Secretary and Chief of Engineers of the Department of War for the planned man-made lands in Lake Michigan.

In 1907, the littoral (riparian) owners along Lake Michigan were given the right by the state of Indiana to fill in submerged land adjacent to their shoreline property (I.C. 4-18-13). The legislation stipulated that man-made fills could not extend beyond lines established by the U.S. Army Corps of Engineers; and it required that accurate surveys of the proposed fills be made. The legislation further stipulated that after the survey had been filed with the secretary of state, the governor **shall** issue authority to fill in and improve such land. After the in-fill had been completed, accurately surveyed, and fees paid, the governor was required to issue a patent for the man-made land.

Over the years, the filling of the lake bottom along the Indiana shoreline proceeded at a rapid and steady pace creating peninsulas of land extending into the lake. In 1973, the legislation was amended to provide a discretionary **may** instead of the mandatory shall in the issuance of state permits to fill in submerged lands.

The Indiana Department of Natural Resources in 1979 attempted to inventory man-made lands and compile a complete record of authority-to-fill permits and patents (IDNR, 1979a). Since the 1907 legislation, approximately 6515 acres of man-made lands have been authorized by the state. At the time of the IDNR inventory in 1979, patents for 3604.436 acres were located. As of November, 1994, patents for an additional 448.45 acres have been located and three patents are pending for an additional 57.593 acres (Personal communication, James Lewis, Indiana Land Office). Table 8 provides additional details.

The enabling state legislation for permitting filling-in submerged lands was further amended in 1990. The recent amendments provide that old lake-fill permits were to expire December 31, 1991, unless extensions were requested. Initially, after the change in legislation, three permit holders requested extension; however, as of November 1994, only one permit holder was requesting a right-to-fill. The permit for extension is currently under administrative appeal.

The 1990 amendment also stipulated that any permit for filling or reclaiming land issued after June 30, 1990 now expires five years after the date the permit was issued.

Structures perpendicular to the shoreline

Man-made lakefill structures and breakwaters, oriented perpendicular to the shoreline, divide the Indiana coastline into five segments called 'littoral cells' (figure 26). This report is adopting the same littoral cells defined by the U.S. Army Corps of Engineers for Indiana's Lake Michigan coast. Large structures can restrict or even block the movement of sand into and out of these cells. Reaches 1 and 2, between Michigan City and the Port of Indiana comprise a single littoral cell.

If a structure extends far enough out into Lake Michigan that it reaches beyond the lakeward boundary of the breaking wave zone, the structure may block virtually all (100 percent) of the sand from passing that point. This structure is called a 'primary sand trapping

Table 8. Man-made land along the shoreline of Lake Michigan

Man-made lands	acres
Authorized by the state of Indiana in 1907	6515.783
Filled and patented (1979 IDNR study)	3604.436
Filled, but no patent located (1979 IDNR study)	84.469
Filled, but exempted from state permit	87.000
Additional filled and patented (to Jan. 1993)	448.450
Filled, patent pending	57.593

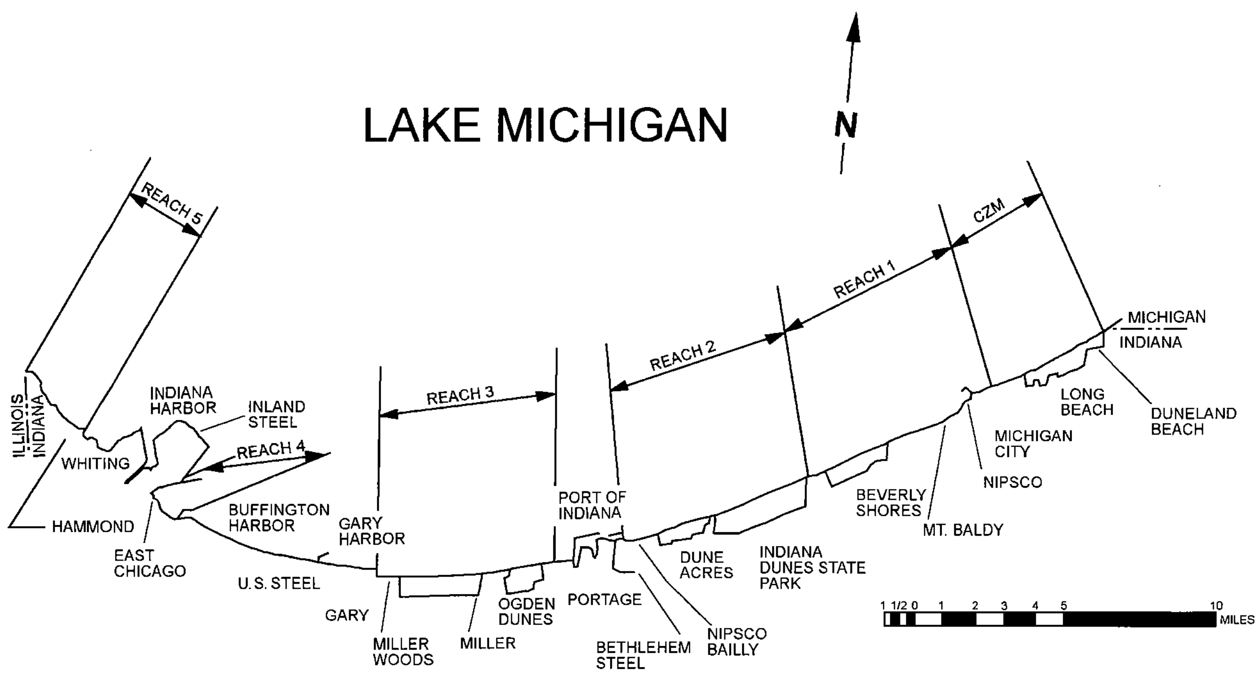


Figure 26. Location of five littoral cells along the Lake Michigan shoreline in Indiana
(adapted from Wood and others, 1988)

structure' and is classified as a 'total littoral barrier'. If little or no sand can enter or leave either end of a cell, a 'closed littoral cell' is created. The sand in a closed cell can move back and forth within that cell, but that sand is not available to contribute sand to an adjacent cell. Erosion of beaches and dune-bluffs continues to add sand to the littoral drift, replacing sand that is lost to deeper water offshore during intense storm events.

Smaller structures which do not extend out beyond the lakeward boundary of the breaking wave zone may form a 'partial littoral barrier'. These are called 'secondary structures' if they block and retain only 25 to 75 percent of the sand moving along the coast. In this case sand leaks around the lakeward end of the structure, from one littoral cell to another. 'Tertiary structures' are smaller still, and usually affect less than 25 percent of the breaking wave zone width. On the updrift side of a littoral barrier, erosion may decline or stop as an accretional 'fillet' (figure 27) forms a widening beach in response to sand being trapped. The volume of sand retained determines the size of the fillet. If sand accumulation continues over a long period of time, wind transport of dry sand to the back beach area can begin to create new sand dunes. This blowing sand is usually trapped and stabilized by native dune grasses which contribute to dune height growth. This process occurs at three locations along Indiana's shoreline; east of Michigan City, east of the Port of Indiana in Portage, and east of the U.S. Steel lakefill breakwater in Gary.

In response to sand accumulating against the east side of the U.S. Steel breakwall due to net westward sand transport, new vegetated dunes have grown 117 feet lakeward and beach widths have grown 170 feet lakeward between 1967 and 1979 in this accretional area.

When sand (littoral drift) is abundant enough to maintain wide beaches and broad offshore sand bars, the erodible portions of the Indiana coast are provided considerable protection from storm waves. However, erosion may still occur even under ideal conditions if severe storms and high lake levels occur together.

Effects of shore-parallel man-made structures

Shore protection structures, oriented parallel to the shore, tend to increase erosion rates on adjacent property by creating a non-eroding coast of sheet steel,

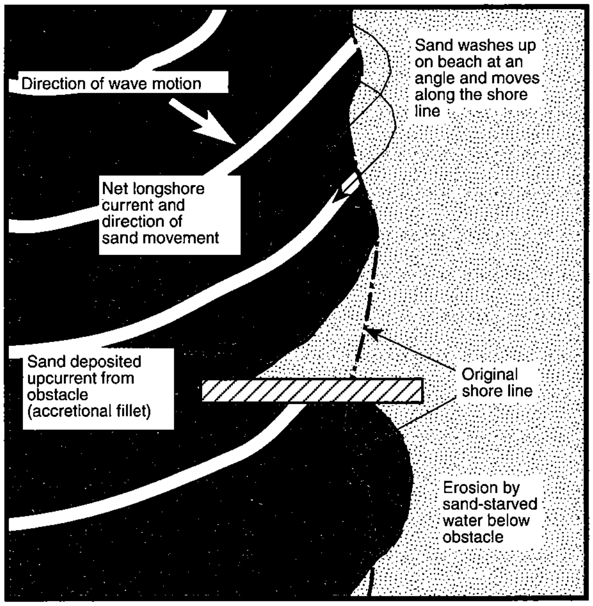


Figure 27. Diagram of shore-perpendicular structure impact on shoreline

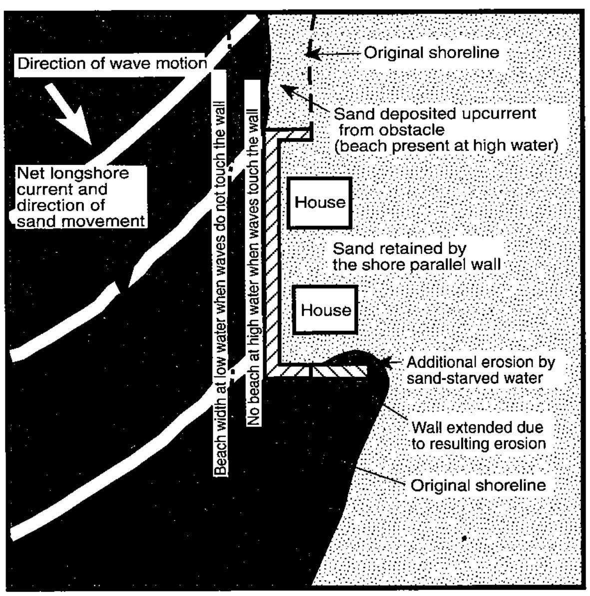


Figure 28. Diagram of shore-parallel bulkhead/ seawalls impact on shoreline

concrete, and wooden walls or rock revetments. While these structures do not stop sand from moving along the beach and lake bottom, they prevent erosion which normally would have contributed sand to the littoral drift necessary to maintain protective beaches and offshore sand bars. This lack of sand contribution creates a 'sand-starved' condition in front of the erosion protection structure. Reduction of this 'sand deficit' is usually accomplished at the expense of the adjacent erodible coast (figure 28).

In general, areas of Indiana's coast that are continually 'sand starved' usually have 'long-term erosion rates' consistently higher than other parts of the coast.

Erosion on the downdrift side of man-made structures

If sand (littoral drift) is not abundant enough to maintain wide beaches and broad sand bars at a particular location, erosion rates may be higher there compared to other parts of the coast, even though the same wave energy and lake levels are present at both sites. The deficit of sand may be due either to natural or man-made conditions.

Erosion rates usually increase dramatically on the downdrift side of a new structure as a result of severe sand-starved conditions created by sand being retained on the opposite (updrift) side of the littoral barrier. When no input of sand is available to replace sand that continues to be moved away from the structure in the downdrift (net) direction, beach widths become narrow and the offshore sand bars lose height and width. This allows more wave energy to reach the shoreline, increasing erosion of the erodible beach and dune-bluffs.

In July 1986, The Great Lakes Coastal Research Laboratory, Purdue University initiated a study to assess shoreline conditions and lake dynamics along Indiana's 45 miles of coast (Wood and others, 1988). The study was designed to incorporate existing beach and nearshore survey data bases, recent aerial photography, wave climatology, and coastal dynamics models to produce an evaluation of present coastal conditions and potential coastal hazards. The following general discussion about erosion rates was taken from the completed study. Appendix 4 contains additional details of structural impact to sand movement at specific sites along the shoreline of Lake Michigan in Indiana.

BEACH NOURISHMENT

Protecting the natural shoreline from erosion using breakwalls, bulkheads and rock revetments creates detrimental "sand-starved" conditions by retaining sand that would normally have eroded and provided the sand necessary to maintain beaches and offshore sand bars. While these "hard" structures control erosion in one location, the resulting sand-starved conditions cause increased erosion on unprotected adjacent properties.

An alternative method of reducing or temporarily stopping excessive erosion of the natural coast is to provide a "man-made" beach and dune-bluff. Feeding sand to a coast is referred to as "beach nourishment". Beach nourishment works by reducing sand-starved conditions by supplying sand needed for waves and currents to rebuild and maintain the natural protective beach and sand bar system.

"Hard" structural methods of erosion prevention directly oppose powerful erosive wave forces right at the shoreline. In contrast, beaches and sand bars are nature's way of gradually dissipating storm wave energy across the width of the breaker zone before the waves reach erodible dune-bluffs.

The supply of beach-nourishment sand can come from many sources. When a coastal structure traps sand on one side, creating erosion problems on the downdrift side, the trapped sand can be dredged and moved (by-passed) around the structure. This mechanical by-passing of sand places the same sand on the downdrift shoreline that would have arrived there naturally if the structure was not present. Sand trapped by a structure can also be moved back updrift (back-passed) to the portion of the coast where it eroded.

In some areas, sand deposited by glacial ice or by coastal processes during ancient lower lake level stages, may exist offshore and could be used as nourishment material. However, it is essential to insure that removal of offshore material does not adversely affect the way waves approach the shoreline. If deepening offshore water depths results in more wave energy reaching the shore, the benefits of placing that sand on the beach may be offset by increased erosion rates.

When potential sources of natural sand serve a more useful purpose where they are, or there is no other readily available source of beach-nourishment sand along the coast, sand can be obtained from inland sources, like quarries, and trucked to the beach.

Quarry sand can be "sized" to either match the natural beach material, or be slightly or significantly larger than the native beach sand. Properly sized sand is able to remain on the shoreline and move between the beach and offshore sand bars just like the native sand would. If the nourishment sand is too small, it may be carried so far offshore during a storm, that it is lost from the littoral transport system.

Beach nourishment sand must be free of contaminants that might be suspended or dissolved in the water as the sand is reworked by storm waves.

The most significant advantage of beach nourishment over "hard" coastal structures is that beach nourishment does not cause sand-starved conditions; it actually reduces the deficit of sand.

Erosion and reworking of nourishment sand provides three important beneficial effects. First, beach-nourishment sand directly protects the natural dune-bluffs from wave attack by serving as a sacrificial dune and beach buffer zone between the waves and the previously eroding natural coast. Second, beach nourishment reduces erosion on adjacent properties by supplying sand to the regional beach and sand bar system. Both the beach nourishment project site, and the adjacent shoreline benefit from the placement of nourishment sand. This contrasts with the construction of "hard" structures which protect one area from erosion while increasing erosion in another. Third, beach nourishment creates beaches that can be used for recreation. The gentle slope of the beach face helps dissipate wave energy as waves rush up the surface. These lower energy conditions allow sand to settle out and remain close to and rebuild storm damaged beaches.

In contrast, "hard" structures tend to reflect some wave energy back offshore. This reflected wave energy interacts with incoming waves, increasing the amount of wave energy immediately offshore of the structure. Higher energy conditions tend to push sand away from the wall, creating deeper water instead of a beach. Consequently, beaches tend to disappear from in front of "hard" walls that come in direct contact with waves.

The decision of which method of erosion protection to use depends on whether the presence of a beach is important to the use of the shoreline, and whether erosion on the shoreline adjacent to the project is of concern.

With time, beach-nourishment sand is completely mobilized as it moves down the shoreline providing protection to downdrift property owners as new beaches and sand bars. When all the

The Mt. Baldy shoreline, located immediately downdrift of the Michigan City breakwater complex has been observed to erode more than 20 feet in one storm season. This Mt. Baldy area has a 'long-term' background erosion rate of approximately 10 feet per year, compared to the average background erosion rate of 3 feet per year or less along most of Lake Michigan's coastline.

In the central portion of Mt. Baldy, a total of -65 feet of dune-bluff recession occurred from July 1983 to July 1985. This excessively high loss rate occurred during the time Lake Michigan was approaching its recent October 1986 high lake level. This short-term average erosion rate of over 30 feet per year far exceeds the long-term average of 10 feet per year mentioned above.

The dune-bluff recession rate on a survey station west of Mt. Baldy (SR-12, Wood and others, 1988) was only 21.5 feet per year from 1983 to 1985. The recession rates farther to the west (survey stations SR-10 and SR-8) are approximately -5 feet per year for the same period. This decrease in short-term erosion rates from the east toward the west is expected because erosion rates are generally highest immediately downdrift of a sand-trapping structure where sand-starved conditions are most severe (Mt. Baldy). With increasing distance from the breakwater structure (survey lines SR-12, SR-10 and SR-8, respectively) the contribution of sand from erosion of the beach, dune-bluff beach-nourishment sand is carried downdrift, the project site must be "renourished". The life of a nourishment project may vary depending on many factors, including: the volume of sand placed, lake level, intensity of storms, protection from severe winter storm waves by shore ice, proximity to "hard" shore protection structures, the sand sizes used, and the extent of sand depletion of the natural beach and offshore sand bar system before the nourishment was placed.

In a similar fashion, every "hard" structure must be maintained and repaired after being exposed to the forces of Lake Michigan over a given time period. Small scale beach nourishment projects, as part of routine and emergency dredging projects, occur on a nearly yearly basis along the Indiana shoreline. Maintaining open boat channels, keeping water intake crib facilities clear of clogging sand and new construction are the primary reasons for dredging.

The State of Indiana has taken the position that beach nourishment is beneficial, and should be encouraged along the Lake Michigan shoreline whenever possible.

State law IC 14-3-15-2, called the "Sand Nourishment Fund" provides a mechanism to protect and increase sand in Indiana along Lake Michigan. Coastal communities can obtain funds through their local state representatives which can then be used for 1) the deposit of sand along the coast of Lake Michigan in Indiana, 2) the design and establishment of systems that cause sand to be deposited along the coast of Lake Michigan in Indiana, and 3) the prevention or reduction of the degradation of sand along the coast of Lake Michigan in Indiana.

Under another State law, IC14-3-1-14.4, the IDNR imposes a royalty fee for Lake Michigan dredge permits for removal of minerals from its bed. However, as an incentive, this royalty fee can be waived if dredging projects agree to place suitable dredge materials along the Lake Michigan shoreline as beach nourishment for the beneficial use of the general public. Unfortunately, in the past, clean lake sand used to be barged to deep water and dumped because it was a cheap method of disposal. Downdrift shorelines in Indiana suffered severe erosion as a result of this past practice.

While beach nourishment is encouraged, "hard" coastal erosion prevention structures may serve as a backup line of defense in case funding or sand to renourish a beach is not readily available. Therefore, a combination of beach nourishment and a "hard" structure might be used in residential coastal communities where a rapid loss of beach nourishment and dune-bluff might threaten a home in a single storm event.

Industrial property and many houses located on Indiana's coast already use "hard" walls and rock revetment to protect their property from destruction by erosion. But only the communities of Ogden Dunes and Beverly Shores have been actively using the combined protection of "hard" protective measures and beach nourishment. The nourishment sand is regularly provided by the dredging efforts of the Northern Indiana Public Service Company (NIPSCO). NIPSCO (Bailly Plant) must dredge to keep its water intake from being clogged by Lake Michigan sand trapped updrift of the Port of Indiana. Seventy-five percent of the dredged sand is "by-passed" to Ogden Dunes and deposited on the outer sand bar in approximately 12 feet of water. The other twenty-five percent is "back-passed" to Beverly Shores.

Two designed beach nourishment projects have been conducted by the Federal government in Indiana. The first was in 1974 when 227,000 cubic yards of sand was placed along 3000 feet of the shoreline in front of the Mt. Baldy sand dune downdrift of Michigan City. One mile downdrift of this site, 13,000 linear feet of rock revetment was placed along the shoreline of Beverly Shores. The second beach nourishment in 1981 was at the same Mt. Baldy location but on a smaller scale of only 80,000 cubic yards. Both were extremely successful at stopping the devastating erosion while the nourishment sand lasted. There is a third beach nourishment project under study by the Chicago District of the U.S. Army Corps of Engineers which proposes to nourish the entire two miles of shoreline between Michigan City and Beverly Shores. The time of implementation is uncertain at this time.

Another alternative gaining support on Federal and State levels is the establishment of "set-back" criteria creating zones where construction in "high erosion hazard" areas is regulated. Indiana does not yet have set-back legislation as of this writing. However, if Indiana becomes part of the federal Coastal Zone Management program, passage of this type of law would be recommended.

A set-back line is determined by taking the "long term average erosion rate" (such as 10 ft/yr) and multiplying it by 30 years. This "30 Year Set-Back" line would then be 300 feet back from the top of the dune-bluff. Theoretically, this would give a structure built behind that line a life expectancy of 30 years, before it would have to be torn down or moved before it fell into the lake due to erosion. The use of beach nourishment could possibly extend the life expectancy of a house built in a set-back restricted zone.

and offshore sand bars gradually reduces the severity of the sand-starved conditions, resulting in lower erosion rates.

In Portage, sand accumulation updrift (east) of the Port of Indiana caused beach widths to expand lakeward more than 500 feet between the time construction began in 1967 to 1984 (Wood and others, 1988). Immediately downdrift of the Port of Indiana, the Ogden Dunes shoreline began to erode at a rate higher than historical background rates shortly after the Port of Indiana breakwater and bulkhead complex was begun. As sand was trapped and retained on the updrift (east) side, sand-starved conditions were created toward the west at Ogden Dunes.

The U.S. Steel lakefill breakwater, located at the southern-most tip of Lake Michigan in Gary does not have a high erosion condition associated with either end of its structure, even though it extends approximately 2000 feet out into Lake Michigan. On the east side, sand accumulates due to the net westerly movement of sand. Toward the west there is approximately 6.8 miles of armored harbors and industrial bulkheads protecting the coast, extending well into the part of Indiana's coast where net littoral drift is in an easterly direction. Therefore, both ends of the structure, stretching from the Gary Harbor complex (in the east) to Buffington Harbor (in the west), could be considered 'updrift' ends.

Shoreline management in Indiana

Management of Indiana's shoreline is subject to a diverse array of federal, state and local jurisdictions. Both the State and Federal governments have co-jurisdiction over the waters and bed of Lake Michigan in Indiana, and the navigable streams, rivers and other tributaries that drain water from Indiana's portion of the Lake Michigan watershed. The Indiana Dunes National Lakeshore federal park also has concurrent jurisdiction over a portion of Lake Michigan's waters within 300 feet of the shoreline within park boundaries.

The boundary between State and local jurisdiction is defined by a fixed elevation, the *Ordinary High Water Mark* (OHWM) of 581.5 feet IGLD 1985. This boundary lies along the line where the OHWM elevation meets either the sand of the shoreline or the face of a coastal structure.

Since coastal processes are dynamic, the location of the boundary between State and local jurisdiction changes with accretion or erosion of a particular portion of the shoreline. When sand accumulates and the shoreline expands lakeward into Lake Michigan, the boundary line also moves lakeward, increasing the area under local jurisdiction. In contrast, when erosion occurs, the boundary line moves landward, decreasing the area of local jurisdiction. Therefore, when the area of local jurisdiction increases, the area of State jurisdiction decreases. When the area of local jurisdiction decreases, State jurisdiction increases. The fourty-five mile strip of Indiana's Lake Michigan shoreline is a truly unique resource of the state. It provides vast opportunities, even though it is a relatively short, narrow corridor of land. An otherwise landlocked state, Indiana is provided opportunities by its lakeshore that might not ordinarily be realized by a mid-continent state: a vast fresh-water supply for the coastal population and industry, food supply, international commerce and economic potential, energy, recreation, and places of great natural beauty and unique ecological relationships.

Although a very limited resource, Indiana's shoreline has much to offer to many diverse users; hence, competition and conflicts are inevitable. Historically, significant changes have occurred along the shoreline as a result of the competition for use; and the shoreline now accommodates a diversity of uses, ranging from heavy industry to environmental preservation.

During the past two decades, numerous situations have focused public attention on the lakeshore. High lake levels in the mid-1970s and mid-1980s, severe erosion of the lakeshore, and destruction of homes and beach property have caused citizens to have a more than casual interest in coastal processes and dynamics. Changes in the steel industry have affected the economy, the population, and the land use adjacent to the lakeshore. Conflicts among users of the lake, for example, swimmers vs. watercraft have resulted in questions of lake access. Water quality concerns for the lake and its shore have caused changes in business practices and waste treatment and discharge.

Significant economic, social and physical changes are once again occurring along the coast. A six-city Lake Michigan Marina Development Commission is developing marinas, and local governments are anxious to use their shorelines to stimulate economic diversity. Steel mills are downsizing and citizens are urging preservation and restoration of the shoreline environment. It is predictable that conflicts and problems associated with changing use of Indiana's Lake Michigan lakeshore will persist.

If Indiana's Lake Michigan shoreline is to fulfill its potential for recreational and economic growth, a balance must be found among diverse land and water uses. For nearly two decades, there has been a growing recognition of the need for a sound coastal management strategy, policy and plan to protect and, where possible, to reclaim Indiana's coastal zone by managing and using this environmentally sensitive area wisely.

Coastal Zone Management Program

In the late 1970s, Indiana received program planning funds from the federal Coastal Zone Management program. A number of important technical studies resulted, but the state did not meet all requirements for ongoing participation in the federal program.

A new initiative is currently underway to build a coastal zone management program for Indiana. Much of the discussion in this report related to Coastal Zone Management is taken from a document entitled "Toward a Management Plan for Indiana's Shoreline on Lake Michigan" prepared for the Indiana Department of Natural Resources by the Northwestern Indiana Regional Planning Commission, January 1993. The initiative was undertaken to compile a body of knowledge about the coastal zone and to determine whether an Indiana coastal zone management plan would con-form to requirements of an existing federal program or be independently developed by a state-local consortium or other mechanism.

The completed report is in two volumes. Volume I consists of four chapters. The first chapter discusses statements and written submissions, which were solicited as part of a series of public meetings held in Whiting, Gary, Portage, and Michigan City, to discuss the future of Indiana's shoreline. The second chapter is a survey of federal, state and local statutes which govern Indiana's coastal zone. The third chapter assesses the federal Coastal Zone Management program and the opportunities and constraints it offers the state of Indiana. The fourth chapter recommends steps toward the development of an Indiana shoreline management program. Volume II presents a bibliography of existing plans, studies and reports about Indiana's coastal zone.

Major conclusions reached by the preparers of the coastal zone management report are: 1) Existing and emerging Indiana shoreline problems and opportunities require regional comprehensive planning and policymaking. Such issues as demand for public access, conflicts among shoreline users, development pressures on remaining natural areas, development of marinas and related facilities, residential versus recreational development, changing land and water uses due to surplus industrial lands, the need for environmental remediation and restoration, shoreline erosion, tourism and economic development, can best be addressed through the planning and policymaking framework of a shoreline management program; 2) The land and water uses of Indiana Lake Michigan shoreline are regulated and controlled by a piecemeal scheme of federal, state and local statutes, rules and regulations. A comprehensive, shoreline-wide plan is needed. 3) Indiana's participation in the federal Coastal Zone Management program would be of assistance in the above regards.

During the course of researching the Coastal Zone Management (CZM) program, staff of the Northwestern Indiana Regional Planning Commission (NIRPC) concluded that the federal program offered Indiana the necessary regulatory framework and incentives to properly manage its shoreline. Thus, NIRPC staff felt that preliminary findings regarding the CZM program warranted the early attention of the Indiana Department of Natural Resources (IDNR).

Thus, in January, 1992, NIRPC staff met with representatives of the IDNR to apprise them of the opportunities and requirements of the federal CZM program and the potential for obtaining a grant in fiscal year 1993 to begin development of an Indiana Coastal Zone Management program. Steps were consequently taken to acquire a program development grant under Section 305 of the Coastal Zone Management Act. Indiana has received a federal grant for $166,000 for October 1993 through September 1994 to begin development of an Indiana CZM program. An additional grant has been pursued for 1994-1995 and it is anticipated that an approvable Indiana CZM program will be submitted for inclusion in the federal CZM program in the fall of 1995.

SURFACE-WATER HYDROLOGY

The surface water resources of the Lake Michigan Region include Lake Michigan; the Little Calumet, Grand Calumet, and Galena Rivers; Trail Creek; an extensive network of smaller tributary streams and ditches; several natural and man-made lakes; ponds and man-made excavations; and scattered remnants of marshes, swamps, and other wetlands.

These surface-water features comprise a considerable part of the hydrologic cycle (figure 2). The hydrology of lakes, streams, and wetlands is not only closely related to precipitation, but also to topographic, geomorphic, and hydrogeologic conditions.

HISTORICAL PERSPECTIVE

The present surface-water hydrology of the Lake Michigan Region is markedly different from the natural drainage conditions that existed prior to permanent settlement of the area. Extensive industrialization and urbanization of the region during the 1800's and 1900's led to considerable alteration of the original landscape and the natural surface-water hydrology.

The most extensive changes include modification of the Lake Michigan *nearshore* and *lakeshore* areas and channelization of the Grand Calumet and Little Calumet Rivers. After the construction of harbors and canals in the region, industries expanded lakeward as submerged areas in the northwestern part of the Region were filled in with slag. In addition, lakeshore lowlands containing swamps and marshes were filled with sand from nearby dune and beach complexes.

Significant changes in the surface-water hydrology of the interior parts of the Lake Michigan Region also occurred. Most of the changes were confined to central Lake County, where large ditches were constructed to improve drainage. Several residential communities are built on areas that were poorly-drained.

Early and recent history

Until the latter part of the 19th century, the natural character of the Lake Michigan Region hydrology was little altered from what existed when the present shoreline of Lake Michigan was formed 2,500 years ago. Headwater streams flowed from the crest of the Valparaiso Moraine to join sluggish rivers which traversed areas of gentle relief in the Calumet Lacustrine Plain, then emptied into Lake Michigan. The courses of the lowland streams were influenced by a series of dune-capped beach ridges which provided the only major topographic expression on the otherwise featureless lake plain. Water tended to collect in the long strips of narrow land lying in the shallow valleys between the ridges to form ponds, marshes, swamps, and languid rivers.

A history of fluctuating lake levels and *paleoshorelines* of ancestral Lake Michigan are recorded in the dune-beach complexes which occupy the Calumet lake plain. Three relict beaches capped by sand dunes (figure 16), and the modern dunes of present day Lake Michigan extend across the Calumet Lacustrine Plain approximately parallel to the Lake Michigan shoreline. From south to north and oldest to youngest, the dune-beach complexes are the Glenwood, Calumet, Toleston and the Lake Michigan sand hills. Additional details about ancestral Lake Michigan and its shorelines may be found in the chapters on **Physical Environment** and **Coastal Environment**.

Between the Calumet Beach Ridge (figure 16) and the Lake Michigan sand hills lay a broad level wetland. While patches of marsh and swamp dotted the Calumet region both further inland and among the sand hills, the wetland north of the Calumet Beach Ridge was distinctive in its shape as a single continuous strip. From Michigan City west through the Indiana Dunes National Lakeshore lay the Great Marsh, which averaged half a mile in width and included a northern rim of timbered swamp and a broad, grassy wetland. The Great Marsh was centered on Dunes Creek, which flowed into Lake Michigan through a channel between the dunes (Cook and Jackson, 1978). To the west of the Great Marsh, the wetland was reduced to a narrow strip approximately one-quarter mile wide which included wet grassland and a white pine swamp. Still further west, the wetland broadened again to encompass the lower meanders of the Little Calumet River where the river breached the Calumet Beach Ridge and skirted its northern slope. The vast wetland evolved primarily as shallow backwaters of Dunes Creek and the Calumet rivers and as long shallow lagoons left between high beach ridges when lake levels of ancestral Lake Michigan dropped. The Great Marsh still exists, but most of the wetland further west is only a memory.

The sand hills or dunes near Lake Michigan lay to the north of the Great Marsh and the marshes of the Little Calumet River. Between the sand hills, depressions scoured out by the wind held pockets of wetlands. A remaining example of such intradunal ponds may be found behind the foredunes on present-day West Beach near Ogden Dunes. There were also parallel beach ridges with intervening swales which contained classic interdunal wetlands such as the ones found in Miller Woods at Gary. Geographically part of the sand hill area, the inter- and intradunal wetlands were separated by higher topographic contours from the broad marshes of the Little Calumet and the Great Marsh to the south. Through most of the nineteenth century, the sand hills or dunes near Lake Michigan were isolated from the rest of the region by the intervening marshlands of the Great Marsh and the marshes of the Little Calumet River.

Wetlands were generally considered wastelands, unsuitable for development or farming, except for pasture and water-tolerant crops. The earliest extensive use people made of the vast Calumet wetland areas was for the plant and small animal life to be found there. Hunting, trapping, and gathering of native plant life thrived. Small mammals of the marsh and swamp were important to the fur trade in the early years of the nineteenth century. The first and only permanent white settlement in the early history of the area was a trading post established by Joseph Bailly in 1822. The common muskrat was the staple, but otter and mink, and other small wetland mammals lived on into the twentieth century to provide food and sport for area residents (Cook and Jackson 1978).

In addition to mammals, an abundance of wild fowl attracted hunters to the many wetlands of the Calumet region. Wild rice attracted birds to the marshes. The Lake County marshes of the Little Calumet became especially famous for water birds. The lagoons around the old Indiana mouth of the Grand Calumet also became famous for birds, providing a resting place for migratory swans as late as the 1960's. Although the Great Marsh did not achieve equal fame for wild fowl, it too attracted nesting and migratory birds. In spite of hunting and reduced habitat, most bird species have survived in the area including the sandhill crane and great blue heron (Cook and Jackson, 1978).

Useful plants were also available in the wetland areas including a wide variety of herbs and spices such as wild peppers, mints, and ginger. The shrub layer contained a wide variety of berry-bearing species including wintergreen, blackberries, huckleberries, blueberries and cranberries. A large cranberry marsh, measuring about one-sixth of a mile from north to south, once existed in the southeast part of the town of Dune Acres until it was drained to make way for a golf course.

In 1850, Congress gave the "swamp lands" of the country to individual states in which they were located. The swamp lands were to be sold and the money used to drain and "reclaim" the lands. Swamp land in the Calumet region sold for an average of $1.25 per acre and has since been drained extensively for various types of development.

Because the beach ridges of the Calumet Lacustrine Plain were high and dry in an otherwise relatively impenetrable wetland area, they became major transportation routes, first as Native American trails and later as railroads. The first substantial modification of the Calumet region began in 1851 as railroad tracks were constructed through the Calumet lake plain to link the rapidly-growing city of Chicago with older cities such as Fort Wayne, Indianapolis and eastern seaboard cities.

Growth of the Chicago and Gary areas, advances in transportation, and development of technologies intensified the pressure on the once isolated wetland areas. Improved transportation systems made the areas easily accessible for recreational, residential and industrial development. Sand mining and dredging became a major activity in the Calumet lake plain.

During the twentieth century, however, conflicts arose over land use of the lakeshore region and the accompanying dune complexes. Industry was interested in port development on Lake Michigan, and many residents were interested in preserving the natural beauty of the area.

The first official act to preserve part of the dunes and wetlands along the south shore of Lake Michigan was the creation of Indiana Dunes State Park in 1925 between Dune Acres and Beverly Shores. In 1966, Congress devised a compromise between the two conflicting uses by creating both the Port of Indiana and Indiana Dunes National Lakeshore.

The Calumet River System

The Little Calumet and Grand Calumet Rivers have a long history of channel modifications, flow reversal and diversions. Both rivers were parts of a single river called the "Calumet River", which flowed sluggishly westward through the Calumet Lacustrine Plain from its headwaters in LaPorte County, Indiana (Cook and Jackson, 1978). The Calumet River made a hairpin turn near present-day Blue Island in Illinois and flowed eastward, back into Indiana, before discharging into Lake Michigan at present-day Marquette Park Lagoon in Gary. Another, much smaller "Calumet River" in Illinois drained Lake Calumet into Lake Michigan.

The two "Calumet" rivers were thought to have become connected more than a hundred and fifty years ago (Moore, 1959) by a channel created by Indians pushing and pulling canoes through the marshes between Wolf Lake and Lake Calumet. During the early 1800's the larger and smaller Calumet Rivers were permanently connected by a canal which was built at the site of an Indian portage in Illinois (Cook and Jackson, 1978).

Segments of the modified drainage network were given the present-day names "Grand Calumet River" and "Little Calumet River" as early as 1821 by surveyor John Tipton (Indiana Historical Bureau, 1942). The segment of the larger Calumet River upstream from the canal is the present-day mainstem of the "Little Calumet River", and the segment between the canal and its mouth in Gary is the present-day "Grand Calumet River". The river that drains Lake Calumet into Lake Michigan is presently called the "Calumet River", although Tipton considered it part of the Grand Calumet River (Cook and Jackson, 1978).

Following construction of the canal, the mouths of the Calumet and Grand Calumet Rivers frequently became clogged with sand, refuse, and weeds. The mouth of the Calumet River in Illinois was cleared during development of the Calumet Harbor at Chicago in the 1870's, promoting greater flow toward Illinois. Eventually, the mouth of the Grand Calumet River near the present-day Marquette Park Lagoon became permanently closed (Cook and Jackson, 1978). The present outlet for the Grand Calumet River was created in the early 1900's when the Indiana Harbor Ship Canal in northwestern Lake County was completed.

Large-scale modification of the watershed of the Little Calumet River began in 1850 when Hart Ditch was excavated from the town of Dyer to a site near Munster to improve local drainage. The Upper Plum Creek Basin in Illinois, formerly drained by Thorn Creek, became part of the Hart Ditch watershed. In the early 1900's, the watershed of Hart Ditch was increased when the Cady Marsh and Spring Street Ditches were constructed to drain marshlands. The drained areas are now occupied by parts of Highland, Griffith and Schererville.

A drastic change in the hydrologic regime of northwestern Indiana occurred after 1922 following construction of the Calumet Sag Channel in Illinois. This new channel connected the Little Calumet River at its hairpin turn in Illinois to the Chicago Sanitary and Ship Canal. Runoff from part of the Little Calumet River watershed was diverted out of the Lake Michigan drainage basin via the Calumet Sag Channel and into the Mississippi River Basin.

Further changes to the watershed of the Little Calumet River occurred in 1926 when Burns Ditch was constructed between Deep River in Lake County and Salt Creek in Porter County to improve local drainage. This area was traditionally known as "the marshes of the Little Calumet" because the river had no definable banks in the midst of swampy or marshy wetlands, and in some places the river widened into lake-like sheets of water that exceeded one mile in width (Cook and Jackson, 1978).

Excavation of Burns Waterway from Burns Ditch to Lake Michigan in 1926 caused flow from the eastern part of the Little Calumet River to be diverted directly into Lake Michigan.

Periodic dredging is required in the Calumet River System to maintain navigational channels at authorized depths to accommodate large, deep-draft commercial ships. The dredged sediments, however, are polluted and pose a disposal problem. Discussion on dredging activities in the Region may be found in the **Surface-Water Quality** section of this report.

The Little Calumet River watershed still contains many poorly-drained areas. The floodplain of the main river and its tributaries is one of the most flood-prone areas in the state.

Levees and flood control

The Little Calumet River Basin

The Calumet Lacustrine Plain in northwestern Indiana and the adjoining region in northeastern Illinois contain areas that are highly susceptible to flooding. Areas lying close to the mainstem of the Little Calumet River and its tributaries in northern Lake County have one of the most critical flooding problems in Indiana.

In general, floods in northern Lake County occur almost every year and may last up to a few weeks.

Limited flood protection along the Little Calumet River historically has been provided to some extent by banks of dredge spoil from early channelization and ditching. Additional low-stage flood protection has been provided by small levees along the residential and industrial communities located along the western part of the river in Lake County.

The U.S. Army Corps of Engineers (1984b) reported that levees along the Little Calumet River at Hammond, Highland and Munster can provide protection from only the 2-year to 8-year floods. Not surprisingly, the levees have performed unsatisfactorily during past flood events. In general, flood peaks can be intensified in residential and urban areas because buildings, roads and parking lots promote runoff which rapidly over fill the surface drainage networks.

In tributary basins of the Little Calumet River, areas of farmland are partially protected against flooding by agricultural dikes and spoil-bank levees formed by dredge material (spoil) from ditching and channel maintenance projects. Ridges of spoil banks can act as levees, but the degree of flood protection can be quite variable, particularly in areas bordered by agricultural dikes. Spoil-bank dikes and levees vary greatly in dimensions, materials, stability and effectiveness of flood protection because of a lack of engineering design, poor construction and unacceptable maintenance.

In many places, spoil bank levees are interrupted by drainage ditches, abandoned stream channels, roads and railroads. Moreover, the sandy debris-laden dredge spoil is highly susceptible to seepage and erosion. These factors, combined with limited local maintenance and clogged drainage ditches can result in the failure of spoil bank levees during floods.

Major developments

Environmental aspects of the problems in the Little Calumet River Basin were first addressed by the Lake Michigan Region Planning Council during its study of the Little Calumet River in 1968. The council sought to: 1) demonstrate potential benefits of planning beyond the immediate problems; 2) help local governments realize the necessity for comprehensive and well-coordinated efforts; and 3) stimulate the public demand for and responsibilities associated with developing a quality environment.

In 1969, the Little Calumet River Advisory Committee was created under executive order to study the needs of communities with respect to flood control, drainage, stream pollution, recreation and recreational navigation in the Little Calumet River. The Committee presented recommendations that emphasized the development of goals, objectives and policies.

Recommendations by the Committee were later adopted by the Little Calumet River Basin Commission to coordinate the development of over 320 square miles or almost 83 percent of the Little Calumet River Basin. The Commission sought to: 1) eliminate flooding; 2) establish effective recreational activities; 3) control water pollution; and 4) establish land conservation practices. The Commission's essential objectives, though slightly modified through time, include: 1) to participate and coordinate with the U.S. Army Corps of Engineers to bring about a realistic flood control program; 2) to seek favorable federal and state approval and funding; 3) to prepare a plan for securing non-federal share of funds from state, county and local sources; 4) to prepare land and water conservation programs in coordination and cooperation with other agencies; and 5) to prepare appropriate new legislation as required. In fulfilling its responsibility, the Little Calumet River Basin Commission must work in cooperation with the Northwestern Indiana Regional Planning Commission, and the Indiana Department of Natural Resources.

The Little Calumet River Basin Commission initiated and completed minor flood-control measures which included localized dredging of the river channel, clearing culverts and installation of riprap. Costly flood-control projects requiring high expenditures could not be undertaken because funds came only from the individual communities that paid into the Commission.

In 1980, the Little Calumet River Basin Development Commission was created by state statute to provide non-federal sponsorship and funding for flood control, recreation and recreational navigation improvements along the Little Calumet River in Lake and Porter Counties. To fulfill its duties, the Development Commission works with the Federal Government, the U.S. Army Corps of Engineers, and state agencies for project development, approval and implementation.

The state statute pertaining to the Little Calumet River Basin Development Commission was amended in 1984 to include changes on the Development Commission's membership requirements and its geographic area of jurisdiction and contained a new section on regulations concerning drains. However, the main responsibilities of the development commission were not changed.

The first major role of the Little Calumet River Basin Development Commission is active participation in the Little Calumet River Project, which was authorized for construction by section 401 of the 1986 Water Resources Development Act (P.L. 99-662).

The flood control and recreation project, as authorized, consists of replacing existing spoil bank levees with new levees, floodwalls, closure structures and appurtenant drainage structures; the construction of new set-back levees with closure structures and appurtenant drainage structures; modification of portions of the existing channel with accompanying bridge relocations; and a water control diversion structure. The project is designed for a 200-year level of flood protection. A recreation trail with five support areas consisting of parking, sanitation, picnicking and play facilities; nature observation overlooks; and canoe launches will also provide recreation opportunities. In addition, upon project completion and certification, numerous structures will be removed from the floodplain hazard area, resulting in increased property values and elimination of expensive flood insurance premiums.

Work on the 6-year Little Calumet River Project began in September of 1990. At the present, a few features of the project are completed.

Trail Creek

Trail Creek, a small stream that drains the northwestern part of LaPorte County directly into Lake Michigan, became important during the 1830's when its mouth was selected as the site for a commercial harbor. Although natural harbor conditions at the mouth of Trail Creek were far from ideal, there was no better or comparable harbor site on the Indiana portion of the Lake Michigan shoreline.

Early reports on Trail Creek described it as a sluggish stream that was obstructed by a bar at its mouth. Based on an 1835 survey report, Trail Creek was 30 feet wide and one foot deep at its mouth, but was as much as 120 feet wide and six feet deep further upstream (Munger, 1979).

Work on the harbor at the mouth of Trail Creek began as a federal navigation project in 1836 with construction of east and west piers which were extended periodically through 1869 (U.S. Army Corps of Engineers, 1990). A detached breakwater was constructed in 1889, but was replaced during the period 1903-1904.

The federal project was essentially completed by 1910; however, frequent dredging of the mouth and lower reaches of Trail Creek continues because of recurring sedimentation. Both the channel and mouth of the river have been dredged within the past five years.

The U.S. Geological Survey, under contract with the U.S. Army Corp of Engineers, began a study in 1990 to characterize suspended-sediment in Trail Creek at Michigan City, Indiana. The information will be used to assess whether the upland areas of the basin are contributing enough sediment to cause the sediment deposition problem in the harbor (Crawford and Jacques, 1992).

Because some sediments in Trail Creek channel are polluted with nutrients and arsenic and unsuitable for open lake disposal, disposal of dredged sediments is cause for concern. Additional discussion on disposal of contaminated sediments may be found in the **Surface-Water Quality** section of this report.

One of the few tributaries to Lake Michigan in Indiana, Trail Creek is very important to recreational boaters and commercial fishing operations. Most of the activity centers on salmon and trout fishing in Lake Michigan. Because of a salmonid stocking program managed by the Indiana Department of Natural Resources, Trail Creek is Indiana's most noted salmonid stream.

Local concern for maintenance of the harbor and channel and improvement of water quality in Trail Creek has resulted in formation of a coalition to address and rectify continuing sedimentation and water quality problems. The coalition, comprised of individuals, interested private groups, and various city, county, state, and federal representatives, is called Trail Creek Improvement Program (TIP).

The stated goal of TIP is to develop and implement a multi-faceted restoration project for the Trail Creek waterway. TIP plans to improve water quality and reduce sedimentation and nonpoint source pollution within the Trail Creek watershed. To achieve these goals, Michigan City and TIP have acquired U.S. Environmental Protection Agency (EPA) federal grant funds through Section 319 of the Federal Water Pollution Control Act by a Memorandum of Understanding with the Indiana Department of Environmental Management. Among the planned projects of TIP are development of a Watershed Management Plan and installation of a demonstration silt trap to decrease sedimentation within the channel of Trail Creek. Additional discussion about TIP may be found in the **Surface-Water Quality** section of this report.

Galena River

A small area at the headwaters of the Galena River is one of nineteen wetland conservation areas in the state (Indiana Department of Natural Resources, [1989]). The Galena River has not been significantly impacted by human influence.

SURFACE-WATER RESOURCES

Lake Michigan provides abundant quantities of water for withdrawal uses such as industrial, energy production and public supply in northwestern Indiana. Water for non-withdrawal uses such as instream recreation is provided by Lake Michigan, in addition to the other lakes and many streams in the Region. Wetlands and the smaller lakes in the Region are not considered potential water supply sources, but their occurrence and regulation directly affect land use and its associated water resources development.

Wetlands

Wetlands are a major hydrologic feature of the Lake Michigan Region. In general terms, wetlands occur where the ground-water table is usually at or near the ground surface, or where the land is at least periodically covered by shallow water. Because the presence of water creates a unique environment, wetlands support plants and animals specifically adapted for life in water or saturated soil.

Wetland types in Indiana can be grouped according to the classification scheme used by the U.S. Fish and Wildlife Service (Cowardin and others, 1979; Cowardin, 1982: U.S. Fish and Wildlife Service, 1986). The structure of this classification is hierarchical, progressing from the most general levels of systems and subsystems to the more specific levels of classes and subclasses. The latter two levels in the hierarchy can be further subdivided according to water regime (duration and frequency of flooding), water chemistry, soil type, and dominant plants or animals.

Wetlands in Indiana belong to three of the five major wetland systems identified by Cowardin and others (1979). **Lacustrine** wetlands include permanently flooded lakes or reservoirs of at least 20 acres, and smaller impoundments whose maximum depths exceed 6.6 feet at low water. **Riverine** wetlands are contained within a natural or artificial channel that at least periodically carries flowing water. **Palustrine** wetlands are associated with areas and/or shallow bodies of water which usually are dominated by wetland plants. Palustrine wetlands include not only vegetated wetlands commonly called *marshes, swamps, bogs, sloughs,* or *fens*, but also isolated catchments, small ponds, islands in lakes or rivers, and parts of river floodplains. Palustrine wetlands also may include farmland that would support *hydrophytes* if the land were not tilled, planted to crops, or partially drained.

A comprehensive inventory of Indiana's wetlands was initiated in 1981 by the U.S. Fish and Wildlife Service as part of its National Wetlands Inventory. The inventory process involves identifying and classifying wetlands from high-altitude aerial photographs, then transforming the photographs into detailed maps (1:24,000 scale). The location and classification of each wetland is then digitized and stored in a computer. The computerized data for Indiana is now accessible for analysis through the use of a geographic information system (GIS).

Inventory of basin wetlands

According to an analysis of the computerized data, the Lake Michigan Region contains about 7,242 wetlands covering a total of approximately 65 to 68 square miles (table 9), or roughly 11 percent of the Region's total land area (figure 29). Although Lake Michigan and its harbors also are classified as wetlands, these water bodies were excluded from the analysis.

Palustrine wetlands constitute about 98 percent of the Region's wetlands, and about 92 percent of the total wetland area. Riverine and lacustrine wetlands account for about 2 and 6 percent, respectively, of the Region's total wetland area.

Palustrine forested and palustrine emergent wetlands together constitute about 59 percent of the Region's wetlands and about 76 percent of the wetland area (table 9). Staff of the IDNR have preliminarily

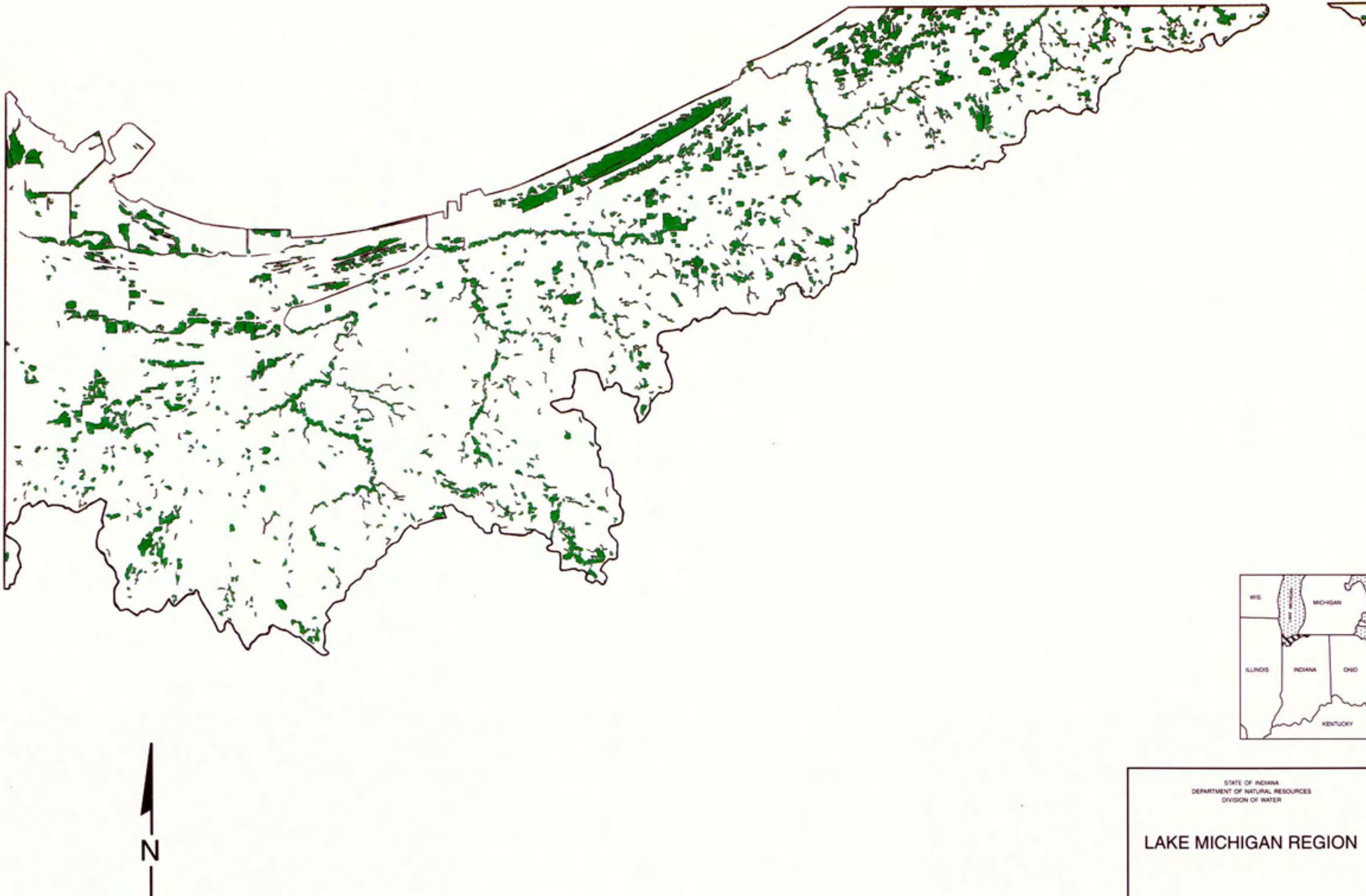


Figure 29. Wetlands of 5 or more acres
(adapted from U.S. Fish and Wildlife Service national wetlands inventory)

Table 9. Estimated number and area of Region wetlands

{Values were determined from a computerized data base of the U.S. Fish and Wildlife Service National Wetlands Inventory.}

Wetland classification: Classification follows the system described by Cowardin and others(1979).

Wetland Classification	Estimated number	Percent of total	Estimated area (sq mi)	Percent of total
Palustrine, aquatic bed	303	4.2	1.0	1.4
Palustrine, emergent	2758	38.1	20.5	30.1
Palustrine, forested	1543	21.3	31.1	45.8
Palustrine, scrub shrub	430	5.9	4.9	7.2
Palustrine, unconsolidated bottom/shore	2058	28.4	5.2	7.7
Riverine, unconsolidated bottom/shore	35	0.5	1.2	1.7
Lacustrine, aquatic bed	1	>.1	0.1	0.1
Lacustrine, emergent	1	>.1	>.1	0.1
Lacustrine, unconsolidated bottom/shore	113	1.6	4.0	5.9
Total	7242	100	68	100

identified these wetland classes as state priority wetland types (Indiana Department of Natural Resources, 1988c).

Palustrine forested wetlands are characterized by large, woody vegetation that is at least 20 feet tall. Palustrine emergent wetlands, commonly called marshes, meadows, fens, or sloughs, are characterized by erect, rooted, *herbaceous* hydrophytes, excluding mosses and lichens. In emergent wetlands, hydrophytic vegetation is present for most of the growing season in most years.

The largest contiguous tracts of palustrine forested and palustrine emergent wetlands in the Lake Michigan Region occur in a 1- to 3-mile-wide band located just south of Lake Michigan and extending from Michigan City westward to Gary. This area once was occupied by a vast marsh including the Great Marsh along Dunes Creek and the marshlands of the Little Calumet and Grand Calumet Rivers. Many of the wetlands in this band are part of the Indiana Dunes National Lakeshore and the Indiana Dunes State Park.

Scattered palustrine wetlands also are common along the Region's major streams, particularly the Little Calumet and Grand Calumet Rivers and Deep River. Notable areas include Clark and Pine Nature Preserve.

Wetlands in the Lake Michigan Region can be further characterized by the duration and timing of surface inundation, using the classification scheme described by Cowardin and others (1979). About one-half of the Region's wetlands are either seasonally flooded (37 percent) or temporarily flooded (16 percent). About 21 percent of the Region's wetlands are semi-permanently flooded, and about 12 percent are either saturated or permanently flooded. The box on this page describes these five wetland categories.

Wetlands in the Lake Michigan Region also can be described by size category. About 40 percent of the Region's individual wetlands are one acre or smaller; 48 percent are between one acre and 10 acres; 10 percent are between 10 and 40 acres; and 2 percent are greater than 40 acres.

Lacustrine wetlands include Wolf Lake, George Lake and several other lakes, ponds, and gravel pits. As noted previously, Lake Michigan and its harbor areas also are categorized as lacustrine wetlands.

Wetland protection programs

Once perceived as "wastelands", Indiana's wetlands historically have been ditched, dredged, tiled or filled to allow for agricultural production and other economic development. Many of the wetlands in the Lake Michigan Region have given way to industrial and urban development.

Although the perception of wetlands as barren or useless land still persists, there is a growing awareness of the valuable functions of wetlands. Wetlands not only play a role in the hydrologic cycle (figure 2), but also provide a wide range of benefits, including floodwater retention, water-quality protection, erosion control, fish and wildlife habitat, and recreational and aesthetic opportunities (see box on following page).

In general, wetland values have largely been overlooked until recent years, when state and federal agencies developed or expanded programs that at least indirectly afford some protection for wetlands. These state and federal programs generally are designed to balance the need for wetland protection with developmental and drainage needs. Appendix 5 summarizes selected programs having a good potential for protecting the wetlands of northern Indiana, including the Lake Michigan Region.

A number of local entities in the Lake Michigan Region are considering or have already adopted wetland protection ordinances. The town of Beverly Shores has adopted an ordinance, and Porter County has an ordinance for its unincorporated areas. The city of LaPorte, which lies just outside the boundary of the Region, also has a wetland protection ordinance.

Because the number and extent of wetlands protected through regulatory programs are limited, non-regulatory programs involving land acquisition and voluntary measures often are the major factors in wetland protection.

Changes in land use are limited on lands acquired for specific purposes, such as parks or nature preserves. Moreover, many public-private partnership programs discourage certain developments or land-use changes that would harm wetland habitats.

In the Lake Michigan Region, significant wetland tracts totaling about 12,258 acres (Dolak, 1985) are being protected on state- and federal-owned properties, the Indiana Dunes National Lakeshore and Indiana Dunes State Park (IDNL/IDSP). These tracts include fragile fens, intradunal ponds, and bogs.

Water regime of wetlands in the Lake Michigan Region

Seasonally flooded wetlands contain surface water for extended periods, especially early in the frost-free crop growing season, but usually become dry by season's end. When surface water is absent, the ground-water table often is near the land surface.

In **temporarily flooded** wetlands, surface water is present for brief periods during the growing season, but the ground-water table usually lies well below the land surface for most of the season. Plants that grow both in uplands and wetland are characteristic of the temporarily flooded regime.

Semi-permanently flooded wetlands contain surface water throughout the growing season in most years. When surface water is absent, the ground-water table is usually at or near the land surface. The region's semi-permanently flooded wetlands typically are found along river corridors or adjacent to the larger lakes.

In **saturated** wetlands, such as fens, ground water is at the land surface for extended periods during the growing season, but surface water is seldom present.

In **permanently flooded** wetlands, water covers the land surface throughout the year in all years. Riverine and lacustrine systems constitute the majority of permanently flooded wetlands.

Lakes

Lake Michigan and the Great Lakes Systems

The Great Lakes, which include Lake Michigan, are the dominant hydrologic feature in midcontinental North America. The Great Lakes System, extending over 2,000 miles and having a surface area of 95,000 square miles, is the largest fresh water lake system in the world (see figure 30). Four of the five Great Lakes are boundary waters dividing the United States and Canada. Of the 298,000 square miles in the entire Great Lakes Basin, approximately 115,000 square miles constitute the tributary area within the United States and 88,000 square miles lie within the borders of

WETLANDS VALUES AND BENEFITS[1]

Wetlands as a landform provide a unique **water storage** function in river basins by temporarily retaining water in upstream reaches and slowing its release to downstream reaches. During flood periods, the storage capacity of the low-lying areas characteristic of wetlands can help to decrease floodwater velocity and increase the duration of flow, consequently reducing flood peaks. During dry periods, some of the stored water may discharge into the main river channel, thereby helping to maintain streamflow.

In the present day Lake Michigan Region, the floodwater storage provided by wetlands and other depressional areas helps reduce the velocity of overland runoff and attenuate flood peaks. Because some depressional areas have no defined drainage outlet they do not contribute directly to surface runoff during flood events. Many of these noncontributing areas may contain lakes, ponds or other wetlands.

Under certain conditions, water from wetlands may supplement **ground-water recharge** at certain times of the year. Local ground-water recharge may occur at times in the vicinities of the interdunal wetlands and potentially in the upland morainal wetlands such as Pinhook Bog.

In most of the Lake Michigan Region, however, lakes and other wetlands primarily act as areas of **ground-water discharge**. These wetlands typically have formed where the ground surface intersects the water table. Wetlands are most likely to serve as ground-water discharge points at depressional lakes and along major river systems where regional ground-water flow patterns are toward the main channels. Ground-water discharge into floodplain wetlands is especially significant during dry periods because the ground-water seepage helps to maintain streamflow. Similarly, ground-water discharge into lacustrine and palustrine wetlands can help to maintain water levels in these systems.

Wetlands can play an important role in **water-quality maintenance** and improvement by functioning as natural filters to trap sediment, recycle nutrients, and remove or immobilize pollutants, including toxic substances, that would otherwise enter adjoining lakes and streams. Although natural wetlands in Indiana cannot be used for wastewater treatment, a few artificial wetlands have been created to filter wastewater effluent.

Wetlands play a role in **erosion control** along lakeshores and streambanks by stabilizing substrates, dissipating wave and current energy, and trapping sediments. Lakeshores frequently subjected to wave action generated by heavy boat traffic can especially benefit from the stabilizing effect of adjoining wetlands.

The value of wetlands as **fish and wildlife habitat** has long been recognized. Most freshwater fish species can be considered wetland-dependent because 1) almost all important game fish spawn in the aquatic portions of wetlands, 2) many fish use wetlands as nursery grounds, and 3) many species feed in wetlands or upon wetland-based food.

Hundreds of species of vertebrate animals found in Indiana require wetlands at some time in their lives. Muskrats and beavers are examples of common Indiana furbearers that are totally dependent on wetland environments.

The popularity of waterfowl hunting relates directly to the importance of wetlands as feeding, nesting, resting, and wintering grounds for waterfowl.

Wetlands provide the natural habitat necessary for the survival of some endangered species. In Indiana, more than 120 plant species and 60 animal species that depend on wetlands at some time in their lives are considered as either endangered, threatened, rare or of special concern.

Many **recreational activities** take place in and around wetlands, including hunting, fishing, nature study and birdwatching. Because of the aesthetic quality of wetlands, these lands often are key features of public parks and outdoor recreation areas. In the Lake Michigan Region, wetlands are an important visitor attraction at most state-owned properties and at many public and private parks, recreation areas, and natural areas.

[1] Portions of this discussion were adapted from a report by the Division of Outdoor Recreation (Indiana Department of Natural Resources, 1988c).

Canada (Great Lakes Basin Commission, 1975c).

The Great Lakes consist of Lakes Superior, Michigan, Huron, Erie, and Ontario. The lakes form a chain of reservoirs with each draining to the next. Lake Superior, the largest, is the uppermost and westernmost. It drains to Lake Huron by way of St. Mary's River. Lake Michigan also drains to Lake Huron.

From Lake Huron, water flows to Lake Erie by way of the St. Clair River, Lake St. Clair and the Detroit River. The outflow of Lake Erie, the second smallest and the shallowest of the Great Lakes, is mainly through the Niagara River to Lake Ontario. Lake Ontario water then flows into the St. Lawrence River which carries the total outflow of the Great Lakes some 541 miles to the Gulf of St. Lawrence thence, to the Atlantic Ocean.

Lake Michigan, the Great Lake within the boundary of this report, is the only Great Lake which lies entirely within the United States. Having a length of 307 miles, a breadth of 118 miles, and average natural depth of 279 feet, Lake Michigan is connected to Lake Huron by the Straits of Mackinac. Because the Straits are wide and deep, Lake Michigan and Lake Huron respond to precipitation and changes in levels and flows as if they were one lake. Direction of currents in the Straits alternates from east to west depending upon barometric pressure and wind conditions; however, the net flow is eastward.

Additional information about the origin, early history, and water level fluctuations of Lake Michigan and other Great Lakes may be found in the chapter entitled **Coastal Environment**.

Sources of hydrologic data for Lake Michigan and other Great Lakes

The U.S. Geological Survey is the prime agency

Bogs- relics of the Ice Age

Bogs are Ice Age relics which are often found adjacent to swamp forests. Fairly common in the more recently glaciated landscape of northern Wisconsin, Michigan's Upper Peninsula, and Maine, they are rare this far south. Indiana Dunes National Lakeshore is fortunate to have two within its management boundaries, Cowles Bog west of Mineral Springs Road in Dune Acres and Pinhook Bog south of Michigan City. The two bogs, famous in biological literature, have been dedicated by the National Park Service as National Scientific Landmarks.

Bogs, marshes, and swamps differ basically in substrate and physiography and in plant communities which they support. Bog and marsh communities are dominated largely by herbaceous plants or shrubs that fill depressions with their organic remains. Swamps, on the other hand, are depressions usually occupied by tall woody vegetation.

Bogs are like marshes in that they develop when vegetation fills in space which was once occupied by clear water. Bogs are different in that they have virtually no drainage, a condition that creates highly acid conditions and a low oxygen content that hinders decay. The water of bogs is usually brown; that of marshes tends to have a greenish tinge.

Cowles Bog, once called the "Tamarack Swamp" for its clump of 25-foot tall tamaracks, contains a raised peat mound that supports a unique assemblage of wetland vegetation compressed into a relatively small geographic area. Lying back of the lake front dune belt between the Calumet and Toleston Beach Complexes, the bog is a 56-acre tract located within the west end of the Great Marsh. The main body of the bog is formed from fibrous marsh plants, but there are woody plants encroaching from the dune side.

The complex environments, both natural and man-made in and around Cowles Bog, provide a variety of unusual botanical and geologic features. The diverse ecosystem assemblage of beaches, dunes, ponds, wetlands, and forests and the developed successional patterns of the bog and its surrounding area have attracted scientific interest for nearly a century. Pioneer studies on plant succession were conducted in the bog by Henry C. Cowles in the early 1800's. More recently, the National Park Service and the U.S. Geological Survey have been cooperating in scientific studies of the Lakeshore since 1973, most of which have centered in the Cowles Bog area.

The geology of the bog affects the hydrology, which in turn affects the distribution of plant communities and the development and evolution of the peatland. The geology of the unconsolidated materials in the Cowles Bog area consists of, from bottom to top, a basal clay-rich till which is a part of the Lake Border Moraine, a layer of sand which is overlain by marl containing sand seams and shells, and a top layer of peat. A 1200- by 450-foot mound exists near the center of the bog where the clay-rich basal till layer is breached and sand is present.

Ground water is the primary source of water supplied to Cowles Bog. The hydrology of the bog is complex , but can be simplified into two aquifers; a near-surface aquifer in the sands, marl and peats above the till and a confined aquifer which occurs beneath the till of the Lake Border Moraine.

Ground-water flow in the near-surface aquifer is from the dune-beach complexes toward the Great Marsh, except for short periods of time after large rainfalls when flow direction reversal may occur locally. In the confined aquifer, ground-water flow is generally toward the north. However, in the area of the peat mound where the confining till is breached and the two aquifers are connected, ground-water flow from the confined aquifer is upward (Cohen and Shedlock, 1986 and Wilcox and others, 1986). Despite the upward flow of water, there are no visible springs on the peat mound.

Wilcox and others (1986) indicate that water in and around the mound is from the sub-till aquifer because the low tritium concentrations and relatively high mineral contents of the water indicate that the waters near the mound were recharged prior to the open air hydrogen bomb testing in the 1950's. Water from wells located away from the mound have higher tritium and lower mineral content than the water near the mound, which indicates a shorter residence time. The pH for Cowles Bog is near-neutral; and although officially named a bog, the soil, vegetation, and water-quality characteristics of Cowles Bog indicate that the area is probably better termed a fen (Boelter and Verry, 1977).

Pinhook Bog, located in LaPorte County near the crest of the Valparaiso Moraine, is regarded as the finest bog in Indiana. Pinhook bog represents a landscape feature rare in Indiana, the well-developed sphagnum bog typical of the northern lake states and Canada. At normal water levels there is very little open water in the bog, but the surface mat of peat moss is well saturated. There are several tiny ponds, but no unfilled central pond or lake as found in many bogs (Lindsey and others, 1970).

The bog occupies a deep ice-block depression surrounded by low morainal ridges. It was initially a *kettle lake* with a clay-lined bed. Sphagnum moss and other organic matter from floating plants gradually accumulated and altered the original clear-water kettle lake into a peaty bog. The sphagnum grew rapidly and, with its ability to hold 10 to 20 times its weight in water, it eventually became thick enough to support trees. Although live sphagnum is common, most of the surface soil material in the bog is of fibrous or woody composition.

The source of water in Pinhook Bog, in contrast to Cowles Bog, is solely from surface water runoff or precipitation; hence, there is a difference in plant communities. Poor circulation and the slow decay of the sphagnum moss mats creates an acidic and oxygen-poor environment, which further slows decay of organic matter by inhibiting bacterial growth.

Botanically the bog provides a harsh environment that is low in nutrients. One special adaption to the bog environment is the development of carnivorous plants such as the sundew and pitcher plant. The sundew plant actively traps insects with leaves that are covered with flexible hairs which fold together to encompass the prey. The pitcher plant captures small insects in its pitcher-shaped leaves by attracting them with nectar, trapping them with downward pointing hairs, and digesting them with enzymes and bacteria.

Among the rare floral types found in the bog are orchids such as the yellow fringed orchid and the pink lady slipper.

Peat layers in bogs provide information to scientists concerning past environments. A botanist, G.K. Guennel identified pollen at various depths in Pinhook bog and made interpretations about climatic changes in the past. Based on the pollen study, the climate in the early history of the bog was interpreted to be moist and cold, after which, it became cold and dry; more recently, the climate has become more warm and dry than in previous times.

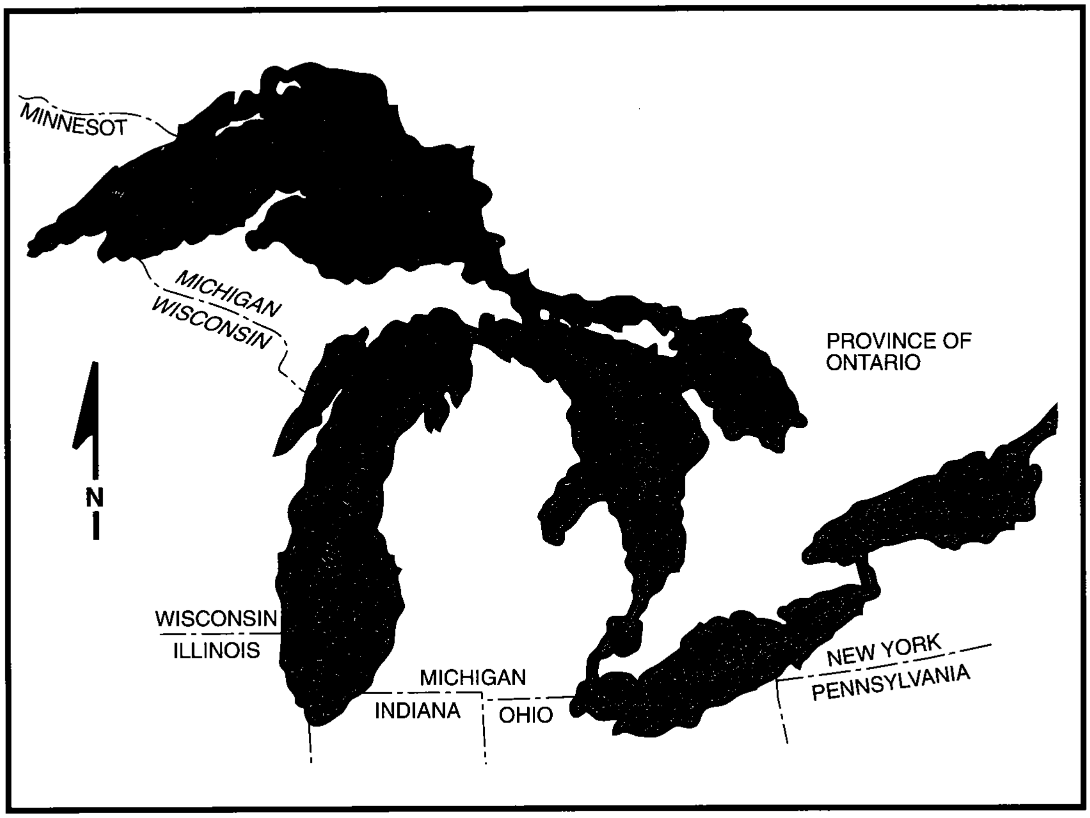


Figure 30. General map of the Great Lakes

responsible for gathering, recording, and publishing data on surface water hydrology within the United States portions of the Great Lakes Basin. The data are collected and prepared for publication in cooperation with other Federal, State, local, and private agencies. To a more limited extent and for specific purposes, many other Federal, State, county and municipal agencies, plus other public and private entities, gather and record surface-water data for the Great Lakes System. Data concerning surface water hydrology generated in the Canadian portion of the Great Lakes Basin are available through Environment Canada, Water Survey of Canada.

Stream-gaging stations, which usually measure water-surface elevation, are used to collect basic data. Much of what is known about the hydrology of the Great Lakes System is learned from stream-gaging stations located on tributary streams. Rating curves are developed for each station to relate measured water-surface elevation to the generally more useful stream discharge data. Rating curves are developed by measuring average stream velocities and cross-sectional areas and relating these data to concurring water-surface elevation. Because the cross-sectional regimen of many stations undergoes constant change, the rating curves are periodically readjusted to reflect the change. The section within this chapter entitled **Streams** contains information regarding the stream-gaging stations within the Lake Michigan Region.

Factors affecting water supply of the Great Lakes and Lake Michigan

Natural cycles of precipitation, runoff, evaporation, and ground-water inflow and outflow affect the amount of water supplied to the Great Lakes System. Inflow and outflow affect water supply of individual lakes. Storage capacity defined by individual lake water levels and geometry determines water availability for differing uses on a sustained basis.

The large surface area and storage volume of the Great Lakes System act as a natural regulator of lake water levels. Therefore, the range from highest quantity stored to lowest quantity stored is only about 1.3 percent of the average volume of water contained in the lakes. This modulating effect means that any change in water supplies to the upper part of the system remains within the system for some time, as much as 15 years, before its full effect is felt on the downstream lakes (Great Lakes Basin Commission, 1976a).

Other lakes

Many fresh-water lakes lie within the Lake Michigan Region. The lakes are located primarily in the urban and industrial areas of northern Lake County and within the Valparaiso Moraine area along the Region's southern boundary.

A number of the lakes in the Region are natural in origin, some of which were formed in depressions left by irregular deposition of glacial drift, while other lakes known as kettle-hole lakes, were probably formed by the melting of isolated masses of buried glacial ice. Still other lakes were formed south of the lakeshore in the long strips of land which lay in the narrow valleys between beach ridges.

Some small shallow lakes remain scattered along the floodplain of the Little Calumet and Grand Calumet Rivers and in the interridge lowlands of LaPorte and Porter counties. The lakes close to the main river channels are remnant *oxbows* of the old river channels, or depressions where the old rivers had no definable banks. The U.S. Fish and Wildlife Service and the IDNR, Division of Fish and Wildlife classify these surface-water bodies as palustrine wetlands because of their shallow depth and because they are not considered part of the main channel. Most oxbow lakes are only temporarily or seasonally flooded, but some may be permanently flooded.

In one sense, the remnant lakes (wetlands) of the Calumet River corridors are man-made because they were formed when the river was dredged and straightened, leaving the original river channel isolated to form oxbows. In another sense, they are considered as natural lakes because oxbow lakes commonly are formed along meandering rivers by natural cut-off processes.

Most of the artificial lakes in the Region consist of old gravel pits, borrow pits, and impoundments of surface drainage networks. The two largest artificial impoundments in the Lake Michigan Region, Lake George at Hobart and Lake Louise in west central Porter County, are the largest lakes that lie entirely within the Lake Michigan Region.

Selected information on both natural and artificial lakes having a known surface area of at least 25 acres is presented in table 10. The list of lakes in the table is not inclusive, but represents lakes for which there is available information from the updated DNR lakes guide (1993b). The locations of most lakes in the Region are apparent from fold-out maps or plates presented elsewhere in this report.

An unknown number of lakes in the Region have been totally destroyed or greatly diminished in size by drainage or infilling. Lakes occupying low-lying areas between beach ridges were once filled with sand from the dune/beach complex to create additional land. Lakes have also been used as disposal places for industrial by-products. In addition, other lakes have been filled-in gradually by natural or man-induced sedimentation and *eutrophication*.

The following paragraphs provide descriptive information gathered from numerous sources on selected lakes in the Lake Michigan Region. Additional information is provided in the **Surface-Water Quality** section of this report.

At the western edge of the Calumet lacustrine plain, three lakes existed prior to land modification. Wolf, George, and Berry Lakes were remains of a former large bay of Lake Michigan. Only Wolf Lake remains intact today, while Berry Lake was drained to allow for development of Whiting and East Chicago, and George Lake has been filled extensively with slag and sand by adjacent industries (Holowaty and others, 1991).

Wolf Lake consists of seven interconnected, artificially-divided basins roughly centered on the Indiana/Illinois border near the southwest shore of Lake Michigan. The Indiana portion of Wolf Lake is separated from the Illinois portion by a levee just west of the state line. Several culverts connect the two halves. The lake has a surface area of approximately 385 acres in the Indiana portion and a maximum depth of approximately eight feet (table 10, columns 3 and 5, respectively).

Although Wolf Lake once flowed north into Lake Michigan, the old channel now ends approximately one quarter mile south of the Lake Michigan shoreline. Prior to industrialization and urbanization in the area, Wolf Lake has been described as one of outstanding natural beauty and a haven of wildlife. It is said to have abounded in fish and small fur-bearing animals, and was a great feeding and resting area for water fowl. When high winds prevailed on Lake Michigan, Wolf

Table 10. Selected data for major lakes

{Data compiled from Glatfelter and others, 1986; Hoggatt, 1975; Indiana Department of Environmental Management, 1986a and 305b 1988-1989 [1990]; and Indiana Department of Natural Resources, Division of Water, revised Guide to Indiana Lakes (1993b) and miscellaneous unpublished files.}

Surface area: Acreage at established level: only lakes having a surface area of at least 25 acres and/or U.S. Geological Survey gage records are tabulated.

Capacity: At average or established level; expressed in million gallons (mg).

Established level: Average normal water level, as determined by local courts; expressed in feet above mean sea level (fmsl).

Period of record: Refers to lake-level data collected by the U.S. Geological Survey under cooperative agreement with the Indiana Department of Natural Resources, Division of Water.

Trophic class and lake management group: Data from Indiana Department of Environmental Management, 1986a and 305b report [1994?].

Lake	Drainage Area (mi^2)	Surface area (acres)	Capacity (mg)	Maximum depth (ft)	Established level (fmsl)	Period of record	Trophic class[1]	Lake management group[2]
LAKE COUNTY								
George (at Hammond)	—	78	—	12	—	—	4	V & VIIA[3]
George (at Hobart)	124	270	879	14	602.23	1946-	3	IV A
Golf	—	30	—	12	—	—	—	—
Wolf (in-basin)	5.7	385	—	8	—	1946-49	3	IV A
LAPORTE COUNTY								
Clare	—	30	—	—	—	—	—	—
Hog	—	59	224	52	—	—	1	VII A
Ron DeNardo	—	40	—	—	—	—	—	—
Swede	—	33	—	15	—	—	2	VII A
PORTER COUNTY								
Louise	2.6	228	645	34	717.0	—	—	—
Mud	—	26	—	—	—	—	—	—
Rice	—	38	58	—	—	—	—	—
Schneider	—	38	—	—	—	—	—	—

[1] Class 1- high-quality lakes assigned a total of 0-25 eutrophy points; class 2— intermediate-quality lakes assigned a total of 26-50 eutrophy points; class 3— poor-quality lakes assigned a total of 51-75 eutrophy points; class 4— remnant natural lakes and oxbow lakes.

[2] Groups of similar lake types were derived from cluster analysis based on lake morphometry and trophic state. Groups applicable to in-basin lakes are summarized as follows:

Group	Surface area (acres)	Mean depth (feet)	Eutrophy points
IVA	26-385	2.0-7.3	50-65
V	30-414	5.5-15.7	2-18
VIIA	25-828	5.0-13.2	18-37

[3] Lake George at Hammond- North Basin is in Lake Management group V; South Basin is in group VIIA

Lake offered a comparatively protected area for huge flocks of ducks, coots and other water birds.

Water from Wolf Lake now flows west over a control structure, into a ditch which empties into the Calumet River. A portion of the old channel that led to Lake Michigan is now occupied by two large industrial plants. Much of the original water area of Wolf Lake is filled with wastes from steel mills and the city of Chicago. Within the state of Indiana, comparatively little of the original water area of the lake remains. Railroads run through and around the area, and a power line bisects the lake. Among the principal industries near the lake are oil refineries, steel mills, soap and soap products factories, and corn processing plants.

In spite of regional urbanization, Wolf Lake remains a somewhat unique ecological and recreational resource in northwest Indiana. Much of the Indiana portion of Wolf Lake's shoreline is owned by the city of Hammond. Development of the shoreline includes a city beach and city-owned boat launching ramp. The lake offers fishing and other recreational opportunities to a large number of people in this highly populated area. Wolf Lake is also still a valuable feeding and resting place for waterfowl.

George Lake (locally known as Lake George) at Hammond is a 78-acre shallow lake, having a maximum depth of approximately 12 feet (table 10, columns 3 and 5, respectively). The present lake, which is bisected by an east-west causeway, represents only a small portion of what was once George Lake prior to extensive filling. However, some significant wetlands remain within and along the shore of George Lake.

Within the narrow strips of land between the beach ridge complexes near the Porter and LaPorte county line, low-lying pockets once contained lakes and ponds. Through the normal progress of ecological succession, most of these open water bodies changed into marsh and swamp. Only four of the pockets seem to have held standing water consistently enough to earn individual recognition as lake or slough. From west to east, these were Long Lake, Mud Lake, Blag Slough, and Little Lake.

Long Lake, on the border between Lake and Porter Counties, was the largest of the interdunal lakes. It may have had a connection with the Grand Calumet River at one time. Surveyors in the 1830's depicted Long Lake as more than three miles long— almost five miles, if one includes the marshes extending from its eastern end. Long Lake was subject to visible shrinkage over the years, and the growth of nearby Gary further aggravated the reduction of the standing water area and the corresponding broadening of the shore marshes (Cook and Jackson, 1978).

Mud Lake lay a few miles east of Long Lake in Porter County. The second largest of the interdunal water bodies, Mud Lake may have had as much as 160 acres of standing water. Beginning in 1960, the lake was drained and filled to accommodate industrial construction.

Blag Slough and Little Lake, the smallest and easternmost of the four ponds, were drained for recreational development for the sand hill town of Dune Acres. They have since been returned to open water bodies as a result of ground-water level changes associated with development of a nearby dike and fly ash ponds.

The natural and man-made processes that have governed the development and demise of the interdunal lakes are complexly interrelated. It is hard to distinguish short-term fluctuations of water levels of the lakes from shrinkage caused by ecological succession, falling Lake Michigan water levels, or the influence of ditching activities drawing ground water away from the ponds and lakes.

Drainage modifications to improve waterway transportation and build railroads, roadways, and industries have also created a number of lakes including the Marquette Park Lagoon, an oxbow lake, and at least two borrow pit lakes which have recreational value.

Marquette Park Lagoon is a 25.6 acre lake located in the sand dune area of northern Lake County. A portion of the east end of the lake lies within the boundaries of a Gary City Park. A large portion of the western end of the lake is undeveloped and owned by IDNL. The lagoon narrows in the middle where Lake Street passes over it. The lagoon was once the mouth of the Grand Calumet River and is now the eastern part of what is referred to on some maps as the Grand Calumet Lagoon.

Another lagoon (also part of the Grand Calumet River) is located west of Marquette Park Lagoon. This lagoon is partially on U.S. Steel property. Although the west end of the lagoon has been filled, much of the area appears unaltered by man. The western lagoon is connected to Marquette Park Lagoon by a shallow channel.

One important oxbow lake is located in Kennedy Park at Hammond. Kennedy Park oxbow, adjacent to interstates 80 and 90, was formerly part of the Little Calumet River. The present lake was formed by levying off a loop of the river channel and digging out the land between the loop. The levee separating the lake from the river is under water during periods of high water. A small culvert also connects both bodies of water at normal water levels.

Two borrow-pit lakes, the Grand Boulevard Park Lake and Rosser Park Lake, were formed during construction of the interstate system. Both lakes have recreational value for the highly populated area of the Region. The Grand Boulevard Park Lake, located adjacent to Interstates 80 and 94 at Lake Station, is a 40-acre borrow pit having a maximum depth of eight feet. The Grand Boulevard city park includes a beach and picnic area as well as a boat ramp. Rosser Park Lake, located on the southeast quadrant of the junction of I-80/94 and I-65, is a 40-acre borrow pit having an average depth of 8 feet and a maximum of 26 feet.

Lake George at Hobart was created by placement of an earth dam across Deep River in 1846 to provide power for a grist mill. The largest lake entirely within the Region, this artificial impoundment has a surface area of approximately 270 acres and an estimated storage capacity of 879 million gallons (table 10, columns 2 and 3, respectively). It was acquired in the early 1920s by the city of Hobart to be used as a supplementary water supply and for recreation and boating. Water quality, however, has interfered with the achievement of fully realizing Lake George's intended use. Discussion on the water quality of Lake George may be found in the **Surface-Water Quality** section of this report.

Sedimentation and organic nutrient problems in the lake led the U.S. Army Corps of Engineers (1990) to recommend that dredging an estimated 90,000 cubic yards of sediment from Lake George would be required to restore storage capacity and water quality. Upland areas were recommended for disposal of the dredged sediments. As of this writing, no such dredging has occurred.

Lake Louise, a private impoundment near Valparaiso, is the second largest lake entirely within the Region. It has a surface area of 228 acres, a maximum depth of 34 feet, and a storage capacity of 645 million gallons (table 10, columns 3, 5, and 4, respectively).

Since 1942, records of the water-surface elevations of many Indiana lakes have been collected by the U.S. Geological Survey through a cooperative agreement with the Indiana Department of Natural Resources (formerly the Indiana Department of Conservation). Gage records of lake water levels are available for only two lakes in the Lake Michigan Region: Lake George at Hobart (1946-present) and Wolf Lake (1946-1949). Before 1976, lake stations generally were equipped with a staff gage which was read once daily by a local observer. Automatic digital water-stage recorders have since been installed at many lake stations, including the station currently gaged at Lake George at Hobart.

Lake-level data today are used primarily to monitor maximum and minimum levels, determine the location of shoreline contours for lakeshore construction projects, and investigate water quality and flooding problems. Gage records also are used in the occasional establishment of normal water-surface elevations, as described in Indiana law (I.C. 13-2-13). Levels have been established at two of the major lakes in the Region (table 10, column 6).

Between 1954 and 1968, the U.S. Geological Survey in cooperation with the Indiana Department of Natural Resources mapped more than 200 natural and man-made lakes in Indiana including Hog Lake in the Lake Michigan Region. Although originally intended for use in the establishment of normal water-surface elevations, these depth contour maps have since been used for many purposes, including fisheries studies and recreation.

Lake-level fluctuations

Within historic time, the water levels of Indiana's lakes have been altered decidedly by nature and by man. Changes in lake levels may occur overnight or over a long period of time. Lake levels also fluctuate with the seasons.

The historic draining and filling projects conducted in the Calumet region since the 1800s have greatly affected the region's natural lakes and their water levels. In general, ditching near a lake can intercept or divert surface drainage which normally would have entered the lake basin, thus reducing the drainage area contributing to the lake. If the ditch is constructed downgradient of a lake, ground-water leakage may be induced from the lake to the ditch. Moreover, lowering the local water table by surface or subsurface drainage or ground-water pumpage can reduce the amount of ground-water inflow to lakes.

State laws enacted since the 1940's have helped protect public freshwater lakes of natural origin from detrimental development and excessive water-level fluctuations (see box titled Lake regulations). Although many lake-level problems have been eased by provisions found in these statutes, undesirable fluctuations continue to occur on some lakes.

Streams

The Lake Michigan Region is drained by streams that once naturally emptied into the Great Lakes/St. Lawrence River basin. However, alteration of the landscape in parts of the Lake Michigan Region has led to considerable changes in the surface drainage patterns.

The principal drainage network in the Lake Michigan Region is presently formed by the Grand Calumet and Little Calumet Rivers. Both rivers, which drain the central and western parts of the Region, were once parts of the Calumet River system which emptied directly into Lake Michigan. However, large-scale changes to the Calumet River watershed, including channelization and construction of canals, have led to considerable alteration of the natural hydrology of the Lake Michigan Region. In addition, surface-water diversion by the state of Illinois transfers water out of the Calumet River system and into the Mississippi River basin.

Several smaller streams drain the eastern part of the Lake Michigan Region, which includes most of northwestern LaPorte County. These drainage networks, listed in order of decreasing drainage areas, include Trail Creek, Galena River, White Ditch, Spring Creek, Derby Ditch and Dunes Creek. The watersheds of Trail Creek, Derby Ditch and Dunes Creek all naturally drain directly into the Indiana portion of Lake Michigan.

Sources of stream-flow data

Stream gages in the Lake Michigan Region monitor the spatial and temporal variations in stream flow in the major watercourses of the Region. A few gages placed in strategic locations monitor the complex hydrologic relationships among the major surface-water systems of the Region. Hydrologic parameters derived from stream-flow records can be used to evaluate the water-supply potential of streams.

The U.S. Geological Survey, in cooperation with other government agencies and public entities, has maintained records of daily flow in several streams in the Lake Michigan Region since 1942. Groups that participate in the cooperative USGS program include the U.S. Army Corps of Engineers, Indiana Department of Environmental Management, Indiana Department of Natural Resources and the Little Calumet River Basin Commission.

Currently, records of daily *mean* discharge are collected at 11 *continuous-record stations* in the Region. Of the 11 stations, six are located on the Little Calumet River and its tributaries, two are on the Grand Calumet River, whereas the Indiana Harbor and Ship Canal, Trail Creek at Michigan City and Galena River near LaPorte each contain one station. Gage height records

Lake regulations

Because water-level fluctuation in lakes can restrict their usefulness for recreation, residential development, flood control and water supply purposes, state and local organizations have attempted to maintain average water levels on many lakes. In accordance with a 1947 state law (I.C. 13-2-13), the Indiana Department of Natural Resources (formerly the Indiana Department of Conservation) is authorized to have normal lake levels established by appropriate legal action. The Department also has the authority to initiate and supervise the installation of dams, spillways, or other control structures needed to maintain the established levels.

Established lake levels typically represent the average water-surface elevation that has prevailed for several years. Once an average normal water level is established by a local circuit court, the average lake level is to be maintained at that elevation. Temporary lowering of a lake level below its designated level requires prior approval from the local court and from the Natural Resources Commission, the administrator of the lake-level law. Such approval typically is granted only for shoreline improvements or lake restoration procedures.

A related lake law (I.C. 13-2-11.1) enacted in 1947 and amended in 1982 requires prior approval from the Natural Resources Commission for any alteration of the bed or shoreline of a public freshwater lake of natural origin. Permits are required not only for minor projects such as the construction of seawalls or sand beaches, but also for larger projects such as channel or lakebed dredging, boat-ramp construction and boat-well construction. In addition, a permit is required to pump water from a public freshwater lake.

Under a law passed in 1947 and amended in 1987 (I.C. 13-2-15), a permit is required for the construction, reconstruction, repair or recleaning of a ditch or drain that has a bottom elevation lower than the normal average water level of a freshwater lake of 10 acres or more, and that is located within one-half mile of the lake.

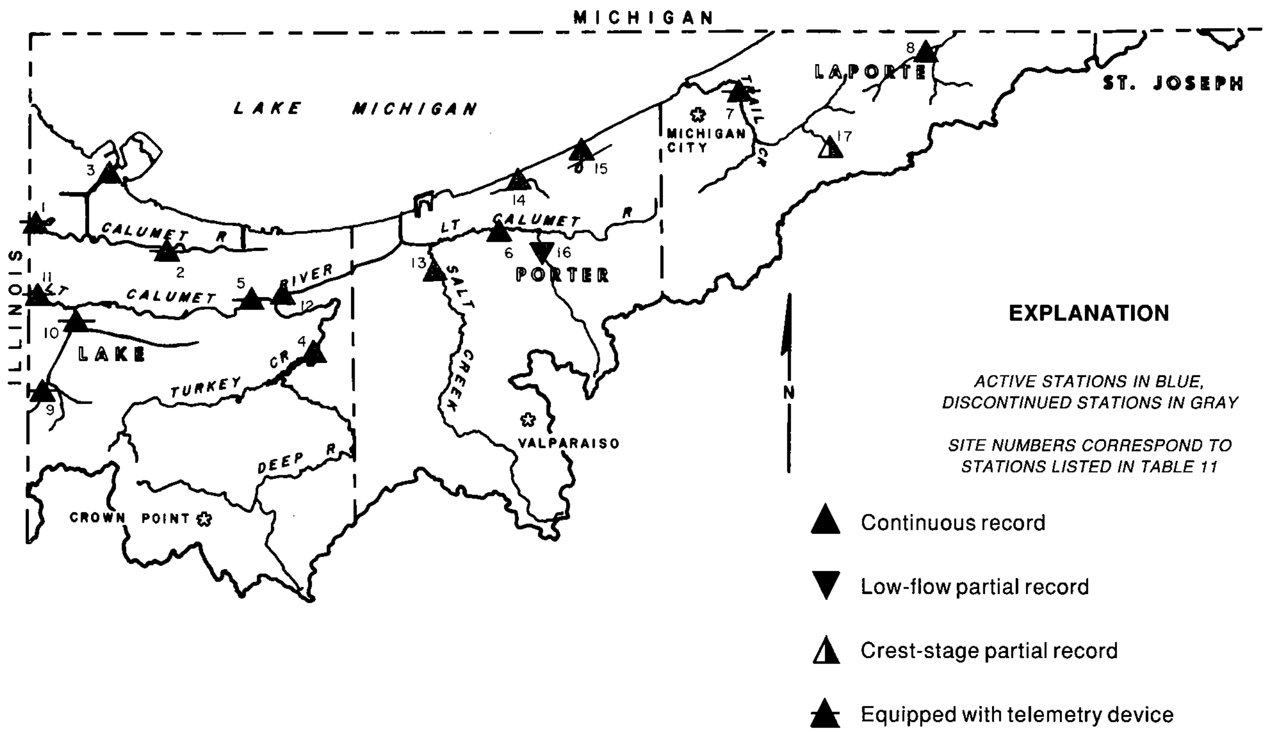


Figure 31. Location of stream gaging stations

are collected at the Little Calumet station at Gary and the Grand Calumet station at Gary (table 11, figure 31).

For automatic reporting of current river stages, seven gaging stations are equipped with telemetering devices (table 11). The instantaneous reporting of stream levels in this part of the state can be invaluable because of the frequent flooding of highly developed areas. River stages recorded at the various stations along the mainstem of the Grand Calumet and Little Calumet River can perhaps suggest flow reversals and diversions, although the complexity of the hydrologic environment preclude accurate determinations. Stream levels and discharges are used for the assessment of proposed flood-control structures and water-quality planning.

A sophisticated new apparatus, the ultrasonic velocity meter (UVM) was recently installed at a gaging station in the Indiana Harbor and Ship Canal to provide information on the hydrologic interaction between the Canal and Lake Michigan. The UVM provides nearly continuous discharge measurements in this complex hydrologic environment, and was the first of its kind to be installed in this country.

In contrast to the continuous-record stations, two gaging stations in the Lake Michigan Region have been operated as *partial-record stations* (table 11). At the low-flow partial-record station on Coffee Creek at Chesterton, flow measurements are recorded during dry periods. In general, a series of low-flow discharge measurements collected at a site can be later correlated with simultaneous daily mean discharges from a continuous-record gage on a stream draining a nearby basin of similar hydrologic characteristics. Using the correlation, the partial-record low-flow frequency characteristics can then be estimated using the frequency characteristics of the discharges collected at the continuous-record gage. Information on low-flow frequency at the partial-record station on Coffee Creek at Chesterton was reported by Stewart (1983).

The other partial-record site in the Lake Michigan Region, located on the East Branch of Trail Creek near Springville, has served as a *crest-stage station*. A crest-stage gage registers the peak stream stage occurring between inspections of the gage. Stage readings can later be converted to discharge values, and flood frequency characteristics can be determined. Table 11 lists the only partial-record station in the Region for

Table 11. Stream gaging stations

Map number: Station locations are shown in figure 31.

Station number: Numbers are U.S. Geological Survey downstream-order identification numbers. Letter abbreviations are as follows: T, telemetered station or data collection platform; UVM, ultrasonic velocity meter; L, low-flow partial-record station, frequency data published in Stewart (1983); C, crest-stage partial-record station, frequency data published in Glatfelter (1984).

Contributing darainage area: Portion of watershed that contributes directly to surface runoff. Total drainage area is shown in parentheses for watersheds with non-contributing portions. Area data are taken or derived from Glatfelter and others (1986), Glatfelter (1984), Stewart (1983) or Hoggatt (1975), depending on station type. Period of record: Refers to calendar year, whether or not data encompasses entire year.

Map no.	Station no.	Station name	Contributing drainage area (sq mi)	Period of record Dates
Active				
1	04092300T*	Grand Calumet River at Hohman Avenue at Hammond	Indeterminate	1991-
2	04092677T	Grand Calumet River at Gary[1]	Indeterminate	1991-
3	04092750UVM	Indiana Harbor Canal at East Chicago[2]	Indeterminate	1991-
4	04093000	Deep River at Lake George outlet at Hobart[3]	124	1947-
5	04093200T	Little Calumet River at Gary	5.8	1958-[4]
6	04094000	Little Calumet River at Porter	66.2	1945-
7	04095300T	Trail Creek at Michigan City	54.1	1969-
8	04096100	Galena River near LaPorte	14.9 (17.2)	1969-
9	05536179T	Hart Ditch at Dyer	37.6	1989-
10	05536190T	Hart Ditch at Munster	70.7	1942-
11	05536195T	Little Calumet River at Munster	90.0	1958-
Discontinued				
12	04093500	Burns Ditch at Gary (continuation of Deep River)	160	1943-92[5]
13	04094500	Salt Creek at McCool	74.6	1945-92[6]
14	04095050**	Dunes Creek at Porter	3.4	1979-82
15	04095100	Derby Ditch at Beverly Shores	4.64	1979-1980
Partial Record				
16	04093900L	Coffee Creek at Chesterton	15	
17	04095250C	East Branch Trail tributary near Springville	.17	

[1] Measures stage only
[2] Ultrasonic Velocity Meter: Measures total discharge to Lake Michigan
[3] Flow subject to regulation by operation of Lake George dam
[4] Period of record: June 1958 to September 1967, October 1968 to September 30, 1971 (discharge); December 13, 1984 to current year (gage heights only)
[5] Period of record: 1943-1991 (discharge); 1992 (gage height only)
[6] Period of record: 1945-1991 (discharge); 1992 (gage height only)
* Station number has been revised to 05536357.
** Records indicate a low-stage partial record station at Dunes Creek near Dune Acres with the same station number may have existed.

which flood frequency data have been reported by Glatfelter (1984).

The U.S. Geological Survey, under contract with the U.S. Army Corps of Engineers, has collected sediment data at the gaging station on Trail Creek at Michigan City for the years 1977-81 and 1990-91. Analyses of the data has been published by Crawford and Jacques (1992).

Factors affecting stream flow

The source of stream flow is precipitation. During a storm event, precipitation that falls on land infiltrates into the ground, or runs off the land surface to become overland flow or evaporates. Infiltration and overland flow rates vary considerably during a storm event, while evaporation rates do not change significantly.

Factors that control infiltration and overland flow rates include precipitation intensity and duration, topography, land use and land cover, antecedent soil moisture and soil permeability. Consequently, changes in land use and land cover, drainage patterns, ground-water levels, and stream geometry produce variations in stream flow.

Time variation in stream flow and its relation to temperature and precipitation can be illustrated by a graph of mean monthly values (figure 32). The difference between precipitation and runoff, which varies considerably during the year, can be attributed primarily to the seasonal differences in evapotranspiration rates, although soil and ground-water conditions also can play an important role.

Differences between precipitation and runoff are greatest during late summer and early fall when warm temperatures cause high evapotranspiration rates. Hence, much of the precipitation that would otherwise be available to streams is lost to the atmosphere. Moreover, ground-water levels are at or near their seasonal low, and base flow may be limited.

Small differences between precipitation and runoff indicate low evapotranspiration rates, which occur in late winter and early spring when temperatures are cool and plants are dormant or very young. In addition, the ground often is either frozen or saturated, and may be covered by melting snow. As a result of these factors,

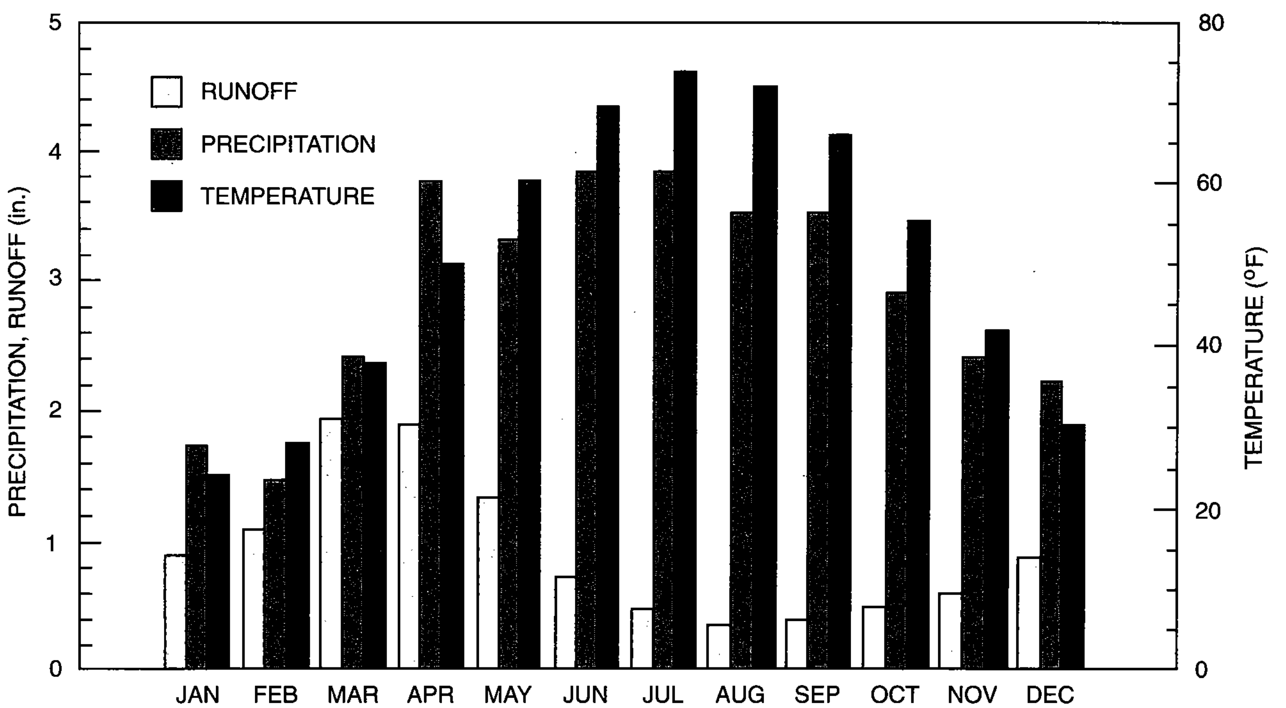


Figure 32. Variation of mean monthly runoff, precipitation, and temperature

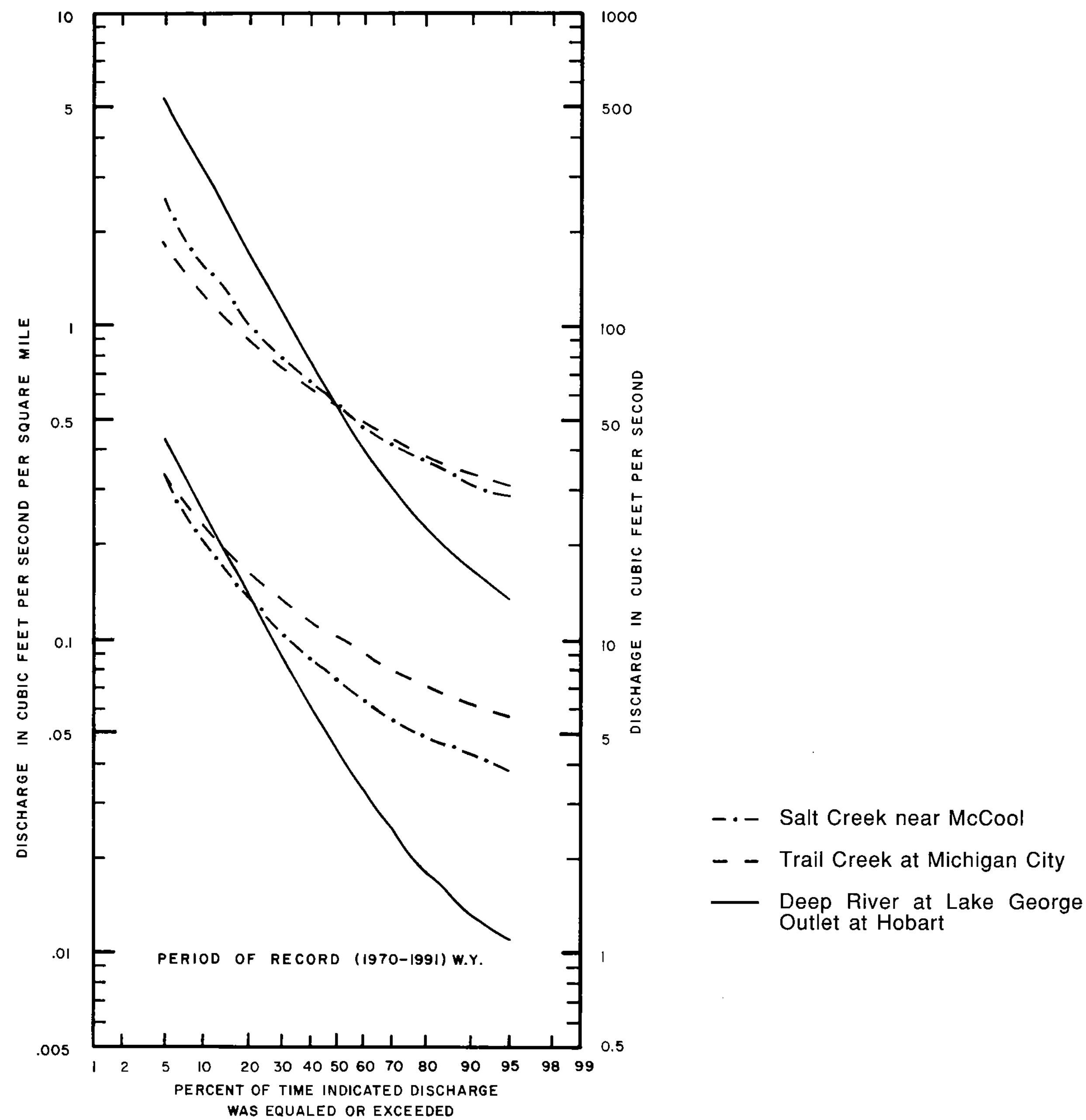


Figure 33. Duration curves of daily mean stream flow for Deep River at Lake George outlet, Salt Creek near McCool, and Trail Creek at Michigan City

more of the total precipitation is available to streams in the form of overland flow and base flow.

The spatial variation in stream flow can be illustrated by comparing runoff characteristics among different streams. Of the many stream-flow parameters that can be used to compare runoff characteristics, flow-duration analysis offers the advantage of not being influenced by the chronological sequence of daily flows.

Flow-duration curves of daily mean discharges, as presented in figure 33, show the percent of time that specified daily discharges are equaled or exceeded during a given period of record. The overall slope and shape of the duration curve is related to the storage characteristics of the drainage basin, which in turn are related to the topography and geohydrology of the basin.

A gently sloping duration curve of stream flow indicates a drainage basin with substantial surface and/or subsurface storage. Common surface storage features include lakes, ponds and depressions, while subsurface storage is promoted by permeable soils and sediments. Both surface and subsurface storage increase the time lag between the precipitation event and peak runoff, resulting in reduced overland flow rates and attentuated flood peaks. During dry periods, stream flow is sustained by the slow, steady release of water from the surface and/or underground sources.

A steeply sloping flow-duration curve indicates a stream draining a basin with little surface or subsurface storage. Flood peaks on this type of stream are high and rapid because most excess precipitation runs off the land surface and enters the stream. However, negligible overland flow and baseflow during dry periods may cause the stream to cease flowing.

Duration curves of stream flow in Deep River at Lake George Outlet, Salt Creek near McCool and Trail Creek at Michigan City, for the period of record 1970-1991 water year, are shown in figure 33. The flow-duration analysis was based on a common period of record to minimize flow differences which may be attributed to differences in local precipitation from short-term events. Two types of discharge, total discharge and *unit* discharge, were used to construct the duration curves. Although stream flow is commonly reported as total discharge, unit discharge measurements, i.e. flow rate per unit area of watershed, is preferred when making comparisons among different streams because the effect of unequal basin sizes on stream flow characteristics is minimized. Among the three flow-duration curves shown in figure 33, the curve for Deep River at Lake George Outlet at Hobart is the steepest by far. Data from Glatfelter (1984) suggest that surface storage may not be the primary factor influencing the overall shape of the duration curves because lakes, ponds and wetlands are four times more abundant in the Trail Creek (at Michigan City) watershed than in the Salt Creek (near McCool) watershed, yet the duration curves of both watersheds are relatively similar. Instead, geohydrology and perhaps land cover may be the predominant factors that influence the overall shape of the curves.

Surficial deposits in the watershed of Deep River upstream from the Lake George outlet consist of thick basal tills of the Valparaiso Morainal Complex and lacustrine clays and silts of the Calumet Lacustrine Plain (figure 17). The low permeability of these sediments promote surface runoff, while infiltration rates are kept low. In addition, the small amount of forest cover in the watershed (5.9 percent) (Glatfelter, 1984) do not intercept significant amounts of precipitation, thereby providing little delay and attenuation of flood peaks. The runoff coefficient or the fraction of total precipitation that runs off the land surface in this watershed is 0.45 (Glatfelter, 1984).

In contrast, the watersheds of Salt Creek near McCool and Trail Creek at Michigan City have runoff coefficients of 0.40 and 0.35 respectively (Glatfelter, 1984). Less surface runoff and greater subsurface storage in the watersheds are primarily due to surficial sediments of significantly greater permeability. Mixed drift, debris-flow tills, and lacustrine clays, silts and sand, form the surface of most of the Salt Creek (near McCool) watershed and the upper part of the Trail Creek (at Michigan City) watershed. Highly permeable deposits of beach and dune sands in the watershed of Trail Creek above Michigan City (figure 17) allow considerable infiltration of precipitation.

The abundance of springs along the eastern part of the northern flank of the Valparaiso Morainal Complex, which form the major source areas of Salt Creek and Trail Creek, indicates the existence of well-developed, shallow ground-water systems. Additional temporary storage due to interception of precipitation is probably significant in these watersheds since forest cover in the Salt Creek (near McCool) and Trail Creek (at Michigan City) watersheds are 12.6 and 20.1 percent of the respective drainage areas (Glatfelter, 1984).

SURFACE-WATER DEVELOPMENT POTENTIAL

The development potential of the surface-water systems for water supply purposes can have a great impact on several economic activities. The Lake Michigan Region will continue to utilize the abundant supply of fresh water in Lake Michigan for almost all of its water use. The development of streams as potential water supply sources may be possible in some cases, but other surface-water systems such as ponds, lakes, and wetlands are not considered as significant water supply sources because of their limited storage capacity, water-quality considerations, and in some cases regulatory and environmental constraints.

Lake Michigan and the other Great Lakes

Lake Michigan, the other Great Lakes, and the connecting channels form an invaluable surface-water system that provide the surrounding areas with enormous quantities of fresh-water for public supply, manufacturing, and both fossil fuel and hydroelectric power plants. In fact, industrial development of the region was based mainly on the availability of abundant freshwater supplies from the lake. In addition, the Great Lakes is used for commercial navigation, fishing, and various types of recreation.

The Great Lakes System, having a storage volume of approximately 5,440 cubic miles at low water datum, contains the single largest supply of fresh surface water on this planet. The volume of water within the Great Lakes is approximately six quadrillion gallons or 20 percent of the world supply of fresh surface water and approximately 95 percent of fresh surface water in the United States Great Lakes Basin Commission, appendix 11 (1975c).

The most immediate source of water supply to the Great Lakes System is an average annual direct precipitation of approximately 32 inches over a surface area of approximately 95,000 square miles. Another water supply source is runoff over the lands, which reaches the lakes over a period of time. The amounts of runoff to the lakes are relatively well-known, since records have been kept for a number of tributary streams. In general, runoff to the lakes is proportionate to amounts of precipitation. Average annual runoff to the Great Lakes System is approximately 32 inches.

Evaporation, a loss of water from the Great Lakes System, is approximately proportionate to depth of individual lakes. Lake Superior, the deepest has the lowest evaporative rate loss, losing an average of 21 inches per year. Lake Erie, the most shallow has an evaporative rate of 33 inches per year. Lowest evaporation for the Great Lakes System generally occurs in spring when the water temperature is close to or below the dew-point temperature of the air. The largest amount occurs in the fall when the water temperature is considerably higher than the dew-point temperature of the air.

Ground water inflow to the Great Lakes has been estimated by the U.S. Geological Survey to be nearly 2,000 cubic feet per second. Since the amount of ground water supplied to any of the lakes is small compared to runoff and precipitation, many investigators assume the difference between ground-water inflow and outflow to be negligible (Great Lakes Basin Commission, 1975b).

Lake Michigan contains approximately 22 percent, or 1180 cubic miles, of the total volume of Great Lakes water. Average annual direct precipitation for the Lake is approximately 30 inches over a surface area of 22,300 square miles. Average annual runoff from the land is approximately 23 inches, and evaporation is estimated to be 26 inches per year, on average. At the Lake Michigan outlet to the Strait of Mackinac average outflow is approximately 52,000 cfs. The volume or rate of flow of ground water entering or leaving Lake Michigan has not been quantified.

Analysis of the surface-water hydrology of the Great Lakes or Lake Michigan is beyond the scope of this report. Information of a more detailed nature, however, may be found by Sub-area in the Great Lakes Basin Commission Framework Study, Appendices 2 (1976a) and 11 (1975c).

Wetlands and lakes

As described previously in the Surface-Water Resources section of this chapter, there are numerous types of non-riverine wetlands in the Lake Michigan Region. Palustrine wetlands include marshes, swamps, bogs, and other areas covered at least periodically by shallow water. Lacustrine wetlands include the deep portion of lakes, gravel pits, and large ponds.

Although some palustrine wetlands in the Lake Michigan Region may store considerable amounts of water at certain times, the shallow water depth and the temporary nature of ponding does not make these wetlands suitable as water-supply sources. Moreover, regulatory and non-regulatory programs administered by state and federal agencies (appendix 5) discourage the detrimental exploitation of wetlands, including certain land uses which would adversely affect nearby wetlands. The values of wetlands and the need for their conservation was discussed earlier in this chapter.

Surface-water withdrawals in the Lake Michigan

Region occur on many privately-owned ponds and small lakes, primarily for irrigation purposes. Other withdrawals occur on ponds at sand and gravel production facilities.

Public freshwater lakes in the Region generally are not used for water supply. As discussed previously in this chapter, existing state laws discourage both direct and indirect significant pumpage from natural lakes. In accordance with Indiana law, lakes with a legally established average level are to be maintained at that level. Temporary lowering of the lake level requires approval by a local court and the Natural Resources Commission. Approval typically is granted only for shoreline improvements or lake restoration.

Even if state laws were amended to allow lowering of lake levels for supply purposes, treatment costs would probably limit uses to irrigation, livestock watering, or fire protection. Pumpage-induced lowering of water levels could detrimentally affect existing water quality, fisheries habitat, and adjacent wetlands. Moreover, significant lowering of lake levels would be objectionable to most lakeside property owners.

Adding lake storage for supply purposes also has considerable drawbacks. Amendments to current lake laws or approval for temporary lake-level increases would be required. Moreover, existing control structures at potential supply sites would have to be modified, because few lake-level control structures are designed to store water at elevations above the legal level. Furthermore, the inundation of lakefront property would be objectionable to lakeside property owners.

Because of these and other limitations, lakes other than Lake Michigan are not considered as potential water supply sources in the Lake Michigan Region.

Streams

The water-supply potential of streams can be evaluated on the basis of selected stream-flow characteristics, which are defined as statistical or mathematical parameters derived from stream-flow records. In this report, average and low-flow characteristics were defined at gaged sites using flow-duration curves, frequency analysis, and hydrograph separation techniques. These methods, which are described below, also can be used in other applications, including the design and operation of water-supply facilities, waste-treatment plants, reservoirs, and hydroelectric power plants; water-quality studies; waste-discharge regulation; and management of fish and wildlife habitat.

Methods of analysis

Average flow

Average flow is defined as the arithmetic mean of individual daily mean discharges for a selected time period, such as a week, month, season, year, or period of several years. However, average flow is commonly used to refer to the long-term mean annual discharge, which is the arithmetic mean of the annual mean discharges for the period of data record.

Recently, the U. S. Geological Survey replaced the term average flow with **annual mean**. However, in this report, the term average flow is used because its common meaning is widely known.

From statistical analysis of stream flow data, stream discharges do not follow a normal distribution, but rather a *skewed* distribution. The average discharge usually is greater than the median discharge, which is the flow rate equaled or exceeded 50 percent of the time.

Based on more than 40 years of record, the average flow in Deep River and Salt Creek is equaled or exceeded 25 to 30 percent of the time. Stream flow in Trail Creek shows a similar frequency characteristic based on 22 years of record.

The relation between average flow and drainage area is commonly used in hydrologic applications. In the Lake Michigan Region, a good correlation exists between long-term flows for selected continuous-record gages, which have been active for at least 20 years, and the respective drainage areas (figure 34). The mathematical relation shown in figure 34 may be used to estimate average flows at ungaged sites on streams in the Lake Michigan Region that drain areas of at least 17 square miles.

Flow duration

Flow-duration curves, as described in a previous section, show the percent of time that specified daily discharges are equaled or exceeded during a given period of record. By incorporating the entire range of stream flows, duration curves are useful for indicating overall flow characteristics and identifying differences in stream-flow variability. Duration curves also can be

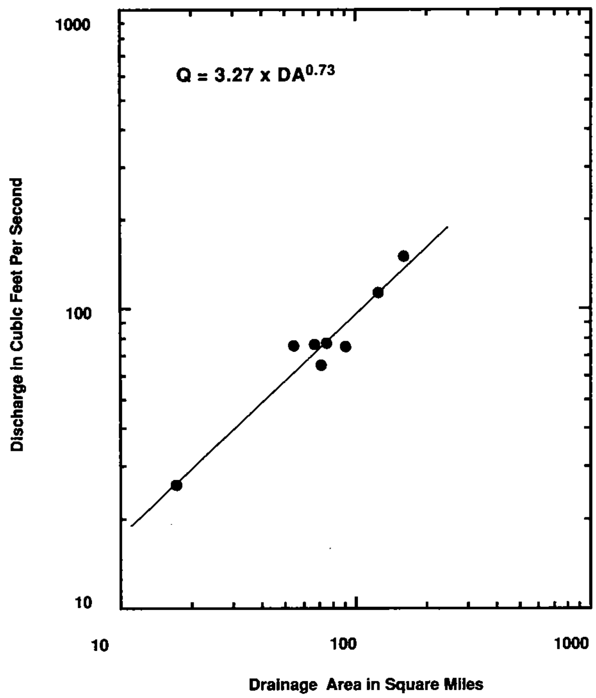


Figure 34. Relation of average discharge at continous-record gaging stations to total drainage area

used to estimate the percent of time that a given demand for stream flow can be satisfied, on average, over a long period of time. However, curves cannot be used to determine the sequence, statistical frequency, or duration of either adequate or deficient flows.

Flow ratio is a general term that can apply to many stream-flow parameters. In this report, the maximum-to-minimum ratio of annual mean flows and the ratio of 20-percent-duration to 90-percent-duration flows are used to indicate the variability of stream flow.

The 20-to-90-percent **flow-duration ratio** is a numerical index that represents the slope of the middle portion of the flow-duration curve (figure 33). As described previously, the flow-duration ratio (slope) reflects not only the presence of flood-attenuating factors in a watershed, but also the relative component of stream flow due to base flow.

The two major tributaries of the Little Calumet River, Deep River and Salt Creek, have flow duration curves of about 11 and 3, respectively. The lower ratio of Salt Creek indicates substantially higher amount of base flow, which leads to more sustained stream flows during dry weather.

Low flows

Low-flow frequency data can be used to estimate how often, on average, minimum mean flows are expected to be less than selected values. Low-flow characteristics commonly are described by points on low-flow frequency curves prepared from daily discharge records collected at continuous-record gaging stations. At stations where short-term records and/or base-flow measurements are available, correlation techniques can be used to estimate curves, or selected points on curves.

Low-flow frequency curves show the probability of minimum mean flows being equal or less than given values for a specified number of consecutive days. Figure 35 shows the relation of annual minimum mean discharges for 1-day and 7-day periods for Salt Creek at McCool and Trail Creek at Michigan City.

In this report, the following points on the 1-day and 7-day curves have been selected as indices of low flow: the minimum daily (1-day mean) flow having a 30-year recurrence interval, and the annual minimum 7-day mean flow having a 10-year recurrence interval (figure 35).

The 1-day, 30-year low flow is the annual lowest 1-day mean flow that can be expected to occur once every 30 years, on the average. In other words, it is the annual lowest daily mean flow having a 1-in-30 chance of occurrence in any given year. In this report the 1-day, 30-year low flow indicates the dependable supply of water without artificial storage in reservoirs or other impoundments. In many cases, the 1-day, 30-year low closely approximates the minimum daily discharge of record for streams in the Lake Michigan Region.

The 7-day, 10-year low flow is the annual lowest mean flow for 7 consecutive days that can be expected to occur, through a long period, on the average of once every 10 years. There is a 1-in-10 chance that the annual minimum 7-day mean flow in any given year will be less than this value.

In Indiana, the 7-day, 10-year low flow (7Q10) is the index for water-quality standards. The flow is used for siting, design, and operation of wastewater-treatment plants; for evaluating wastewater discharge applications and assigning wasteload limits to industrial and municipal dischargers; and as an aid in setting minimum water-release requirements below impoundments. In the future, the 7Q10 or other low-flow parameters may be used by the Indiana Department of Natural Resources to establish minimum flows of selected

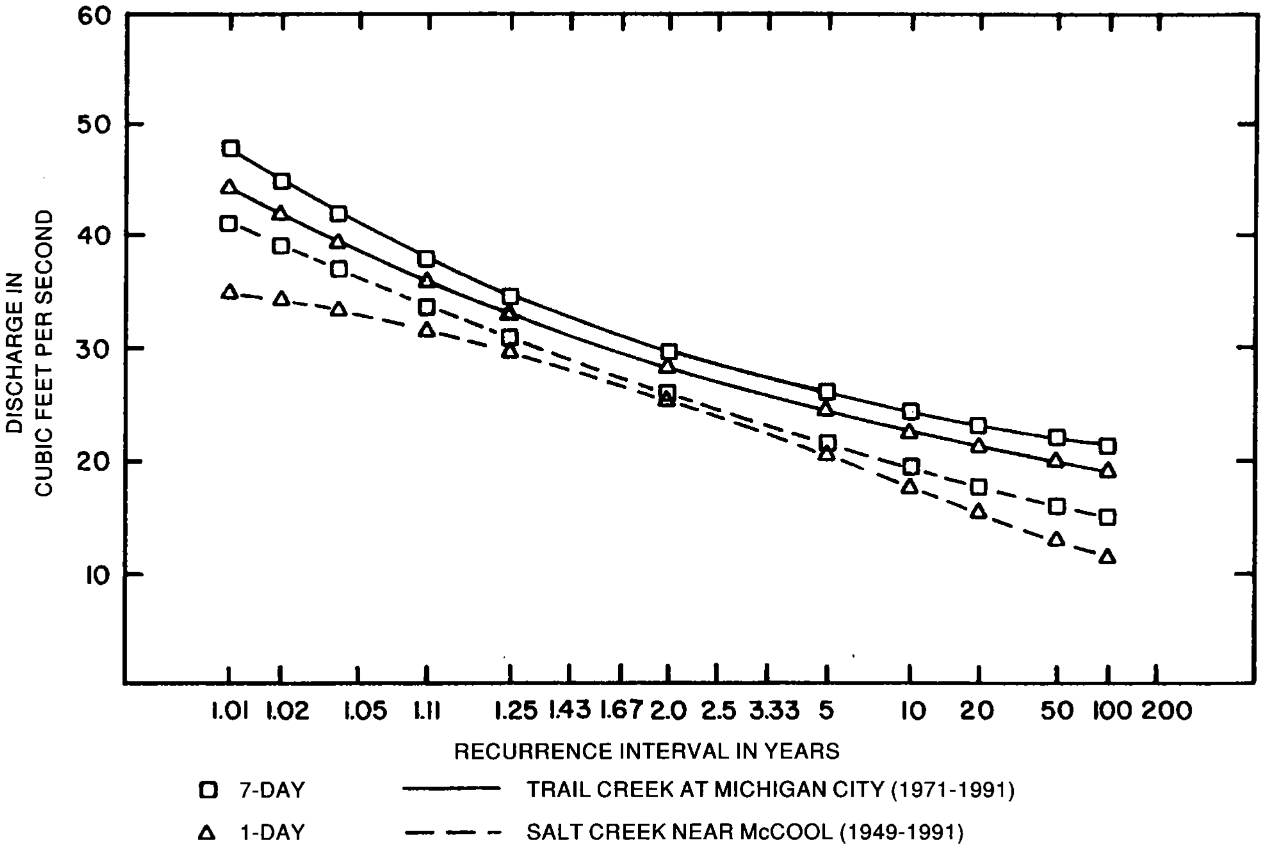


Figure 35. Frequency curves of annual lowest mean discharge for indicated number of consecutive days for Trail Creek at Michigan City and Salt Creek at McCool

streams.

The U.S. Geological Survey has developed a method for estimating the 7Q10 on ungaged streams in Indiana (Arihood and Glatfelter, 1986). Regression analysis was used to derive an equation which is most accurately applied to unregulated streams in northern and central Indiana which drain areas between 10 and 1000 square miles, and have 7Q10s greater than zero. The equation determined by Arihood and Glatfelter (1986) is as follows:

$$7Q10 = 1.66 \times DA^{1.03} \times RATIO^{-1.51}$$

where

DA = the contributing drainage area, in square miles;

and

RATIO = the 20-to-90 percent flow duration ratio.

In the Lake Michigan Region, regionalized flow-duration ratios mapped by Arihood and Glatfelter (1986) are summarized as follows:

* Little Calumet River Basin east of Burns Harbor – 3
* Little Calumet River Basin west of Burns Harbor – 10
* Grand Calumet River Basin – 10
* Galena River Basin – 3
* Trail Creek Basin – 3
* Selected tributaries to Lake Michigan – 3.

Although 7Q10s estimated from the equation and flow-duration ratios shown above may differ from values based on other regionalization techniques or partial-record data, the estimates are suitable for broad planning purposes. Site-specific design flows should be determined according to local watershed conditions

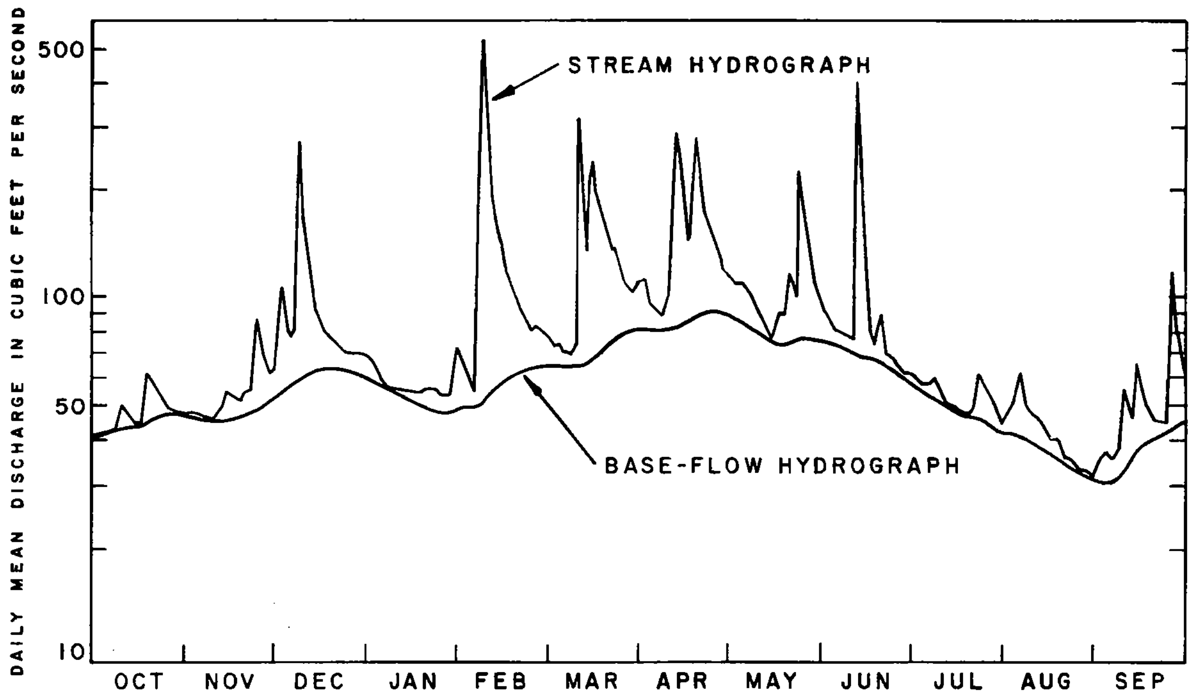


Figure 36. Example of stream-flow and base-flow hydrographs

and more detailed analyses.

Hydrograph separation

Hydrograph separation is a technique used to divide stream flow *(total runoff)* into its component parts of *surface runoff, interflow* and *base flow*. Surface runoff is the combination of precipitation falling directly upon the stream and water flowing over the land surface toward the stream *(overland flow)*. Interflow occurs when precipitation that has infiltrated the soil moves laterally through the soil toward the stream. For convenience, interflow and surface runoff can be combined into one category called *direct runoff*. Base flow is the portion of stream flow that is derived largely or entirely from ground-water discharge.

A graphical technique can be used to separate the base-flow hydrograph from a stream-flow hydrograph of daily discharges. As figure 36 shows, the hydrograph of daily stream flows is composed of peaks and valleys which often are quite sharp. Peaks represent the quick response of stream flow to storm runoff received as overland flow and interflow, and occasionally as ground-water flow from hillslopes adjacent to the stream. After peaking, stream flow recedes to a level which represents base flow contributions only because overland flow has ceased. The base-flow hydrograph therefore can be approximated by eliminating the sharp hydrograph peaks due to storm runoff, and drawing a smooth curve (figure 36).

The volume of total runoff for a given water year is computed by converting each daily discharge to a daily volume, then summing these values over the year in question. The total runoff volume can then be converted to inches by dividing it by drainage area. A similar technique can be used to compute the total annual base-flow volume.

The ratio of base flow to total runoff is one measure of the degree to which stream flow is sustained by ground-water discharge. This ratio therefore is an indicator of the dependability of a stream for water supply.

Average runoff of Lake Michigan Region

The total water-supply potential of a basin is the

Table 12. Average runoff of subareas within the Lake Michigan Region.

Watershed	Drainage Area (sq mi)	Unit flow (cfsm)	Discharge (cfs)	Runoff (in)	Volume (bg)
Little Calumet River into Lake Michigan	331	1.00	331.22	13.58	78.0
Little Calumet River into state of Illinois	56.6	0.83	46.98	11.27	11.1
Drainage into state of Michigan	56.6	1.50	84.90	20.36	20.0
Trail Creek and other streams directly into Lake Michigan	93.2	1.39	129.55	18.87	30.5
Grand Calumet River into Lake Michigan and adjoining Lake Michigan drainage	65	—	—	—	—

average precipitation that falls on the land surface and is not lost to evapotranspiration or used consumptively, such as being incorporated into a manufactured product. The theoretical maximum supply potential of a drainage basin as a whole can be defined as the long term average runoff, which includes both surface runoff and ground-water discharge to streams. However, the Lake Michigan Region is not a single drainage basin, but rather a mosaic of several watersheds of complex hydrology.

Accurate determination of average runoff of the Lake Michigan Region is an almost impossible task. Natural flow rates in the Grand Calumet River cannot be reliably estimated because most of the flow in the river is industrial cooling and processing water and waste treatment plant effluents. In addition, flow reversals between Lake Michigan and the contributing streams in the Region during periods of wind setup at the southern end of Lake Michigan can often lead to inaccurate determination of flow rates in the lowest reaches of the streams.

Table 12 shows the average runoff of various subareas in the Lake Michigan Region. The runoff of each subarea is determined using stream flow records at active and inactive gages, which have period of record data for at least 20 years as of water year 1991. This technique is based on the assumption that the average unit flow, as determined from gaging station records, is truly representative of the entire subarea. Surficial geology maps by Schneider and Keller (1970) and Gray (1989) were used to help delineate subareas of similar geohydrology within the Lake Michigan Region.

Supply potential of streams

The potential of individual streams in the Region for water-supply development is based on stream flows without regard to the potential construction of impounding reservoirs (either in-channel or off-channel), which would otherwise improve the water-supply of some streams. Variations in stream-flow are interpreted primarily on the basis of geologic, soil and land use differences among and within drainage basins.

Stream-flow characteristics for active and inactive continuous-record gaging stations having at least 20 years of data record as of water year 1991 are shown in table 13. Average and low-flow values for these stations are plotted in figure 37 to facilitate an assessment of the geographic variation in flows.

Streams that have relatively high sustained flows are more reliable than streams of low sustained flows, and thus are preferred for water-supply development. However, water quality determines the actual use of the water, and therefore plays an important role in water-supply development.

In the following discussion, only the Little Calumet River, its major tributaries and Trail Creek are considered in detail. Most of the other drainage networks in

Table 13. Stream-flow characteristics at selected continuous-record gaging stations.

{Stations had at least 20 years of data through water year 1991.}
Total drainage area, annual runoff, extremes: From Stewart & Deiwert (1992) except as noted. Contributing drainage area is shown in parenthesis for watersheds with non-contributing portions.

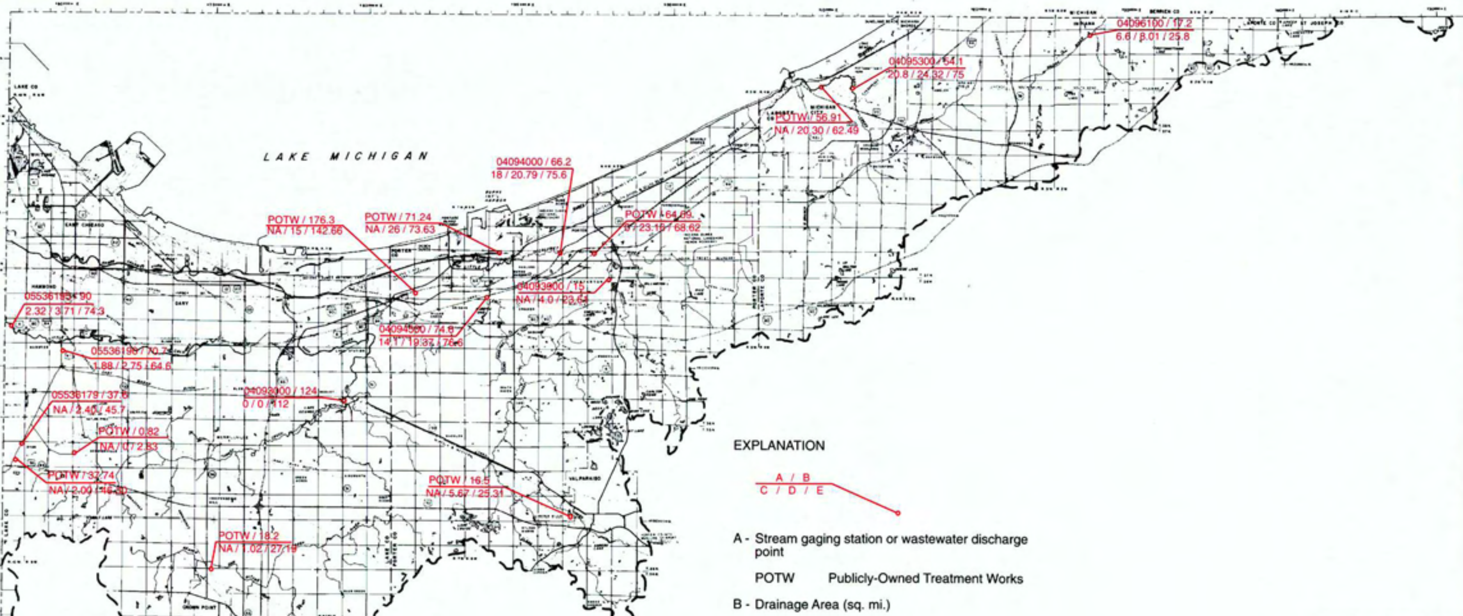
Extremes: Daily maximum represents maximum daily mean discharge; daily minimum represents minimum daily mean discharge

Low flows: Estimated by Division of Water using regression analysis

Ground-water contribution: Estimated by Division of Water using methodology of Pettyjohn and Henning, 1979, for hydrograph separation. Values are for water year 1988 except as noted.

Station name	Total drainage area (sq mi)	Annual runoff (in)	Extremes (cfs)				Low flows			Base flow (percent of total runoff)
			Annual mean		Daily		1-day,30-yr	7-day, 10-yr		
			max	min	max	min	(cfs)	(cfs)	(cfsm)	
LITTLE CALUMET RIVER										
at Porter	66.2	15.5	124	36.5	3040	17	18	20.79	0.31	68
at Munster	90	11.21	121	23.5	1160	1.9	2.32	3.71	0.04	—
TRAIL CREEK										
at Michigan City	54.1	18.85	109	50.5	2550	20	20.8	24.32	0.45	76
GALENA RIVER										
near LaPorte	17.2 (14.9)	20.35	32.6	21.0	650	6.7	6.6	8.01	0.47	83
TRIBUTARIES										
Deep River at Lake George outlet at Hobart	124	12.26	199	35.3	3900	0	—	—	—	—
Salt Creek at McCool[1]	74.6	13.95	121	36.2	2740	10	14.1	19.37	0.26	64
Hart Ditch at Munster	70.7	12.41	136	19.2	2600	1.6	1.88	2.75	0.04	43

[1] Gage discontinued



Industrial and non-municipal wastewater facilities are too numerous to analyze at this scale. The selected reference section includes titles of relevant wastewater studies.

EXPLANATION

A / B
C / D / E

A - Stream gaging station or wastewater discharge point

POTW Publicly-Owned Treatment Works

B - Drainage Area (sq. mi.)

C - 1-day, 30-year low flow (cfs)

D - 7-day, 10-year low flow (cfs)

E - Average flow (cfs)

NA - Data not available

Low flows are not calculated for the Grand Calumet River system because flows are complex and drainage areas indeterminate.

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

LAKE MICHIGAN REGION

Figure 37. Selected stream-flow characteristics

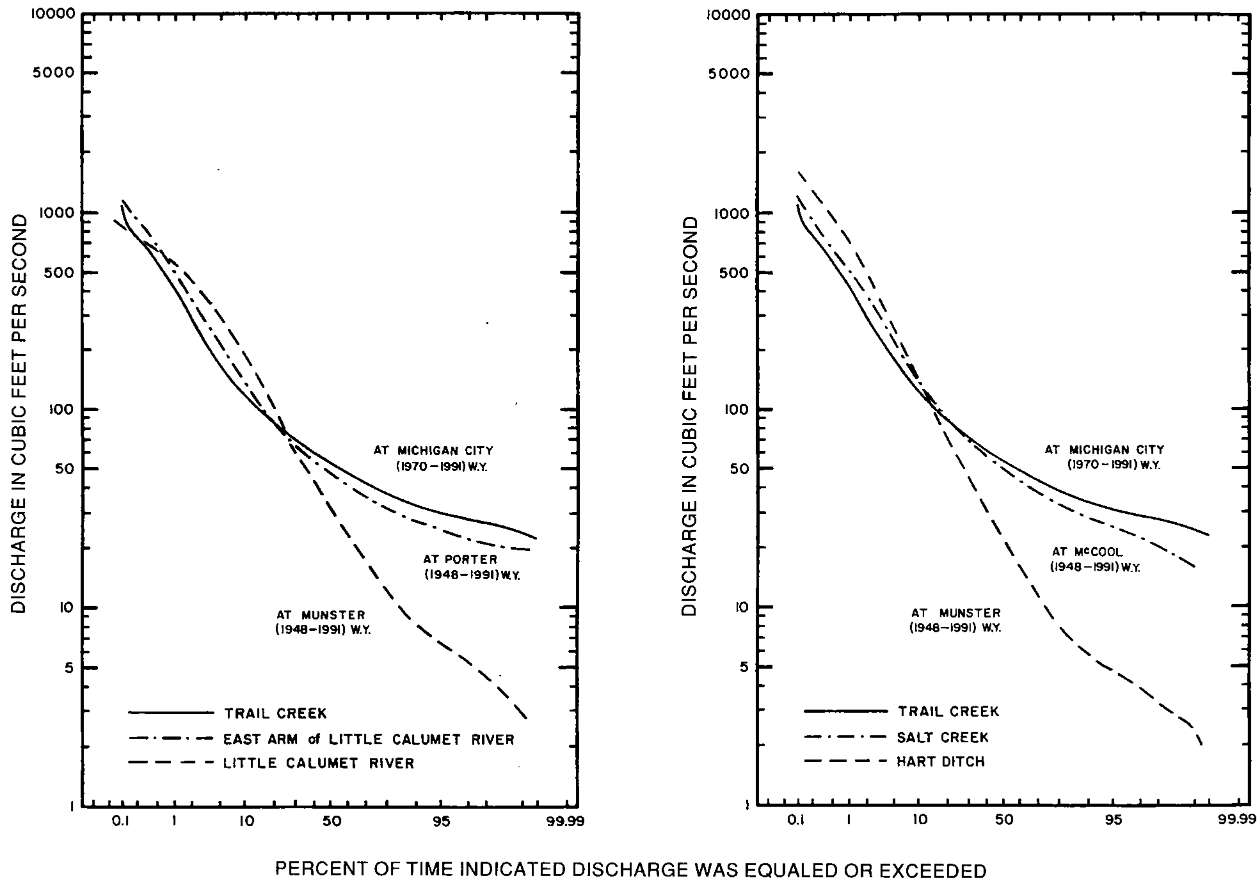


Figure 38. Duration curves of daily mean stream flow for gaging stations on Trail Creek, Salt Creek, Hart Ditch and Little Calumet River

the Region are too small for significant water-supply development. The Grand Calumet River has considerable flow, but natural-flow analysis is almost impossible because most of the flow in the river is industrial cooling and processing water and waste treatment plant effluents.

Little Calumet River System

The water-supply potential of the Little Calumet River and its tributaries varies considerably across the Lake Michigan Region because of the geographic variation in flows. Evidence for the spatial variation in development potential comes from low-flow and flow-duration curve comparisons, in addition to the relative extremes in mean annual stream flow.

The water-supply potential of the Little Calumet River and its major tributaries is greater along the reaches in Porter County than in Lake County. At the gaging station in the town of Porter, Porter County, the 1-day 30-year (1Q30) and the 7-day 10-year (7Q10) low flows in the East Arm of the Little Calumet River are 18.0 and 20.8 cfs, respectively (table 13). In contrast, the 1Q30 and 7Q10 low flows in the Little Calumet River at Munster, Lake County, are 2.32 and 3.71 cfs, respectively. When unit low flows are considered, the flow differences become even greater because the drainage area above the Porter gage is about 66 mi^2, whereas the drainage area above the Munster gage is about 90 mi^2. The ratio of maximum to minimum annual stream flow in the Little Calumet River is about 3 at Porter, and about 5 at Munster. Similar geographic trends in stream flow are seen among the major tributaries of the Little Calumet River. In Salt Creek near McCool, Porter County, the 1Q30 and 7Q10 low flows are 14.1 and 19.37 cfs, respectively, but in Hart Ditch at Munster, Lake County, the 1Q30 and the 7Q10 low flows are 1.88 and 2.75 cfs, respectively (table 13). The unit low-flow comparisons closely follow the actual low-flow comparisons because the drainage areas of both watersheds are similar in size, each just above 70 mi^2 (table 13). The ratio of maximum to minimum annual stream flow is about 3 in Salt Creek at McCool, and about 7 in Hart Ditch at Munster.

Low flows, i.e. 1Q30 and 7Q10, in Deep River at Lake George Outlet at Hobart (Lake County) could not be determined because of periods of no flow. However, the ratio of maximum to minimum annual stream flow is greater than 5, falling between the ratios of the Little Calumet River at Munster and Hart Ditch at Munster.

The high variability in flow at the gaging stations in Lake County is mainly due to the low permeability of the soils and the considerable degree of urbanization and development in the northern part of the county. The presence of impervious surfaces, such as roads, parking lots and buildings in a watershed amplifies flood peaks during storms by increasing runoff and decreasing the *time of concentration.*

Conversely, greater sustained (low) flows and lower ratios of maximum to minimum annual stream flow occur in the drainage networks of the Little Calumet River in Porter County because of higher ground water contributions. This geographic variation in stream flow is apparent in the flow duration curves shown in figure 38.

As explained earlier in the section entitled **Factors Affecting Stream Flow**, the surficial sediments in the tributary and mainstem areas of the Little Calumet River in Porter County are more permeable than in Lake County. Greater infiltration of precipitation leads to higher ground water contributions to streams in Porter County.

In both the Little Calumet River at Porter and Salt Creek at McCool, base flow comprises about 68 and 64 percent of the respective stream flow during a year of average precipitation (table 13). In Hart Ditch at Munster, base flow comprises, on average, about 43 percent of the total stream flow. Hydrograph separation techniques could not be used to determine base flow contributions to the Little Calumet River at Munster. A hydraulic divide across the streambed just east of the Hart Ditch confluence causes complex flow patterns during periods of varying water levels in Hart Ditch and the Little Calumet River.

Trail Creek

The water-supply potential of Trail Creek is the most favorable of all the streams in the Lake Michigan Region based on low-flow records at gaging stations which have been active for at least 20 years. Estimates of Trail Creek's 1Q30 and the 7Q10 low flows at the gage in Michigan City are 20.8 and 24.32 cfs, respectively (table 13). The ratio of maximum to minimum annual stream flow is slightly more than 2, by far the lowest of all major streams in the Region.

As discussed previously in the section entitled **Factors Affecting Stream Flow**, the surficial sediments in the watershed of Trail Creek are highly permeable compared to other watersheds in the Region. On average, base flow comprises about 76 percent of total stream flow in Trail Creek during a year of normal precipitation (table 13). In Galena River near LaPorte, base flow comprises an average of 83 percent of stream flow; however, total stream flow is small because the drainage area above the gage is only 17.2 mi^2.

At present, registered water withdrawals from Trail Creek are used for irrigation of two golf courses. A high-withdrawal facility used for energy production purposes is located in the mouth of Trail Creek. However, since the mouth of Trail Creek and Lake Michigan are parts of a contiguous surface-water body, withdrawals by the energy production facility do not come entirely from the Trail Creek watershed.

Water-quality problems in Trail Creek limit its water-supply development potential. Water quality of Trail Creek is discussed in the **Surface-Water Quality section** of this report.

FLOODING

Flooding in the Lake Michigan Region is primarily due to overbank flow and inadequate storm drainage. Overbank flow is commonly caused by a reduction in either channel slope or cross-sectional area, both of which reduce the transporting capacity of a river and lead to higher flood stages. For example, when structures are constructed in a floodway, the cross-sectional area available for flood flows is reduced, *backwater* levels are elevated, and flood peaks become amplified upstream of the structures.

In developed areas flooding can be caused by storm drainage systems which were built to handle excess runoff generated by the increase in impervious cover. When storm runoff exceeds the capacity of a designed drainage system, water backs up and causes flooding.

Most of the critical flooding in the Lake Michigan Region occurs along the mainstem and tributaries of the Little Calumet River in Lake County. Extensive development of the area, poor drainage characteristics of the soil, inadequate channel capacity to handle flood flows, and high water table all contribute to prolonged floods.

The largest and most damaging floods typically occur during early spring when saturated or frozen soil, prolonged or widespread rainfall, and snowmelt can combine to produce maximum runoff over large areas. Major floods also can occur in summer, fall and winter under certain combinations of precipitation events and hydrologic conditions. Floods are aggravated by the accumulation of debris, sediment, and ice at bridges and culverts because of backwater effects.

Flooding in the Little Calumet River watershed is most disastrous in northern Lake County because of the high concentration of development. During the major floods of October 1954 and July 1957, the communities of Gary, Griffith, Hammond, Highland and Munster incurred considerable property damage. Health hazards were created by the backup of sanitary sewers, while road damage in Griffith and Highland added to losses due to the floods.

In these flooded areas near the mainstem of the Little Calumet River, inadequate capacity of the channel had forced water into temporary storage across levees. Most of the levees were built during early urbanization and industrialization of the Region, with little, if any, attention given to design and floodway considerations.

Communities in the tributary areas, including Dyer, Hobart, Lake Station, and Schererville, also incurred property damage during the 1954 flood. Unfortunately, flooding in parts of Lake Station was aggravated by flow through gaps in the levees.

The widespread flooding in the Lake Michigan Region during October 1954 was due to an extensive storm which also affected the watersheds of the East Arm of the Little Calumet River in Porter County and Trail Creek in LaPorte County. In the town of Porter (Porter County), about 10 inches of rain fell during a 30-hour period. Considerable damage to roads and bridges occurred within the corporate limits of Portage and Porter. Daniels and Hale (1955) provide detailed discussions of the 1954 flood.

The most recent major flood in the Lake Michigan Region occurred in late November of 1990, when a high-intensity rain event dumped about 6 inches of rain over a 5-hour period in parts of Lake County (Federal Emergency Management Agency or FEMA, 1990). Slightly less rain occurred in Porter County, but the cumulative effects caused record flooding in many parts of the Region. Records for both highest daily mean and instantaneous peak flows were set at five of the Region's seven continuous-record gaging stations, which had "period of record" data for at least 20 years (table 11). Instantaneous peak stage records were established at four of the stations.

As a result of the destruction and damage caused by the late November 1990 flood, the President declared a major disaster for the state of Indiana, and Lake County was declared eligible for Individual Assistance. Losses due to flood waters from the Little Calumet River and its tributaries in Lake County totalled more than $7.2 million (Federal Emergency Management Agency, 1990).

Condition of damage due to the flood ranged from moderate to heavy in Dyer, the Black Oak section of Gary, and Schererville to severe in the Wicker Park section of Highland. Several possible health and environmental problems arose because of the flood. A significant threat was posed in Highland when leaks of petroleum products from a nearby gas station and above-ground home heating-oil tanks contaminated both water and homes (Federal Emergency Management Agency, 1990). Highly toxic polychlorinated biphenyls (PCBs), which are carcinogenic, were found in concentrations of 1,200 parts per million (ppm) in oil cleaned from the area. Generally, state and federal officials must be notified of cases when the concentration of PCBs exceeds 50 ppm. The source of the PCBs was initially believed to be contaminated heating oil, but the testing of oil from several tanks and homes proved negative. The original source of the PCB's was never determined, but the EPA has certified that the area is free of the contaminant (Federal Emergency Management Agency, 1990).

Flooding problems along the mainstem of the Little Calumet River in Lake County are expected to be alleviated to a considerable degree after completion of the Little Calumet River Flood Control and Recreation Project. Work on the project began in 1990 and is scheduled for completion by 1998. Details of the project are discussed previously in the subsection entitled **Levees and Flood Control.**

The other watersheds of the Lake Michigan Region have experienced flooding, but the damages incurred were minor. Past flooding problems in Michigan City, LaPorte County, are attributed to inadequate storm sewers and poor drainage characteristics of areas within the corporate limits. Although considerable extension and separation of the storm sewers have been performed, full benefits have not been realized or quantified.

The Grand Calumet River does not have a flooding problem. Most of the flow in the river is industrial cooling and processing water and waste treatment plant effluents.

Flood-flow characteristics of the Lake Michigan Region

The natural hydrology of the Lake Michigan Region has been considerably altered because of channelization projects, construction of canals and ditches, and modification of the shoreline and near-shore landscape in many parts of the Region. The influence of these man-made changes, in addition to differences in the surficial geology, topography, and degree of urbanization in the various watersheds combine to create complex flood-flow characteristics in the Lake Michigan Region. Further complexity in flow characteristics occur during periods of high lake levels and wind setup on the lake which can lead to actual flow reversals between the discharging streams and Lake Michigan. Figures 39 and 40 illustrate the spatial variation in the 10-year and 100-year flood flows in the Lake Michigan Region.

In the tributary areas of Deep River and Turkey Creek, which lie along the northern extent of the Valparaiso Morainal Complex, poorly-drained depressions and basins of internal drainage allow considerable storage of floodwaters. Consequently, the 10-year and 100-year flood flows in the tributaries of Deep River and Turkey Creek are among the lowest for a given drainage area in the Lake Michigan Region. The relatively low slope of these curves is also caused by the attenuating effects of depression storage.

Flood-flow characteristics in the Deep River and Salt Creek watersheds are not very different from each other (figures 39 and 40). The surficial geology and topography of both watersheds are similar. Depression storage in these watersheds may not be significant, but

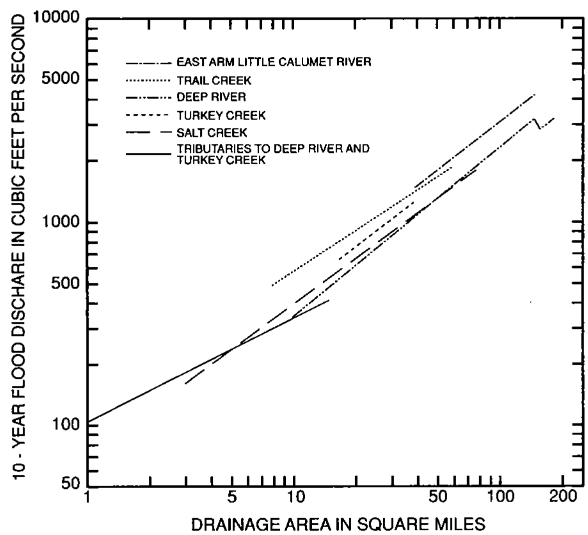


Figure 39. Relationship between drainage area and 10-year flood discharge for Salt Creek, Trail Creek and selected tributaries of the Little Calumet River

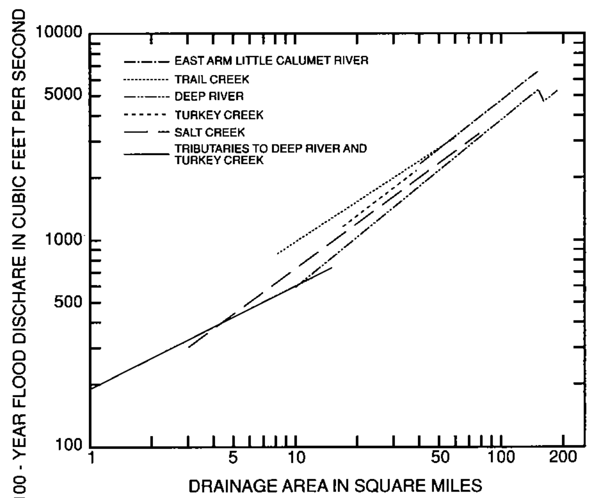


Figure 40. Relationship between drainage area and 100-year flood discharge for Salt Creek, Trail Creek and selected tributaries of the Little Calumet River

alluvial silt, sand and gravel along the mainstem valleys serve as temporary storage features, especially during periods of flooding.

Significantly higher 10-year and 100-year flood discharges occur in Turkey Creek for a given drainage area when compared to floods in Deep River and Salt Creek (figures 39 and 40). Alluvium in the Turkey Creek valley does not extend significantly beyond the channel, resulting in little bank storage during floods.

In the East Arm of the Little Calumet River and Trail Creek, the 10-year and 100-year flood discharge for a given drainage area are the highest among all major streams in the Lake Michigan Region (figures 39 and 40). This characteristic is probably attributed to greater precipitation in the eastern part of the Region, as well as high water-table and ground-water discharge zones in the downstream areas of the watersheds.

Leeward of Lake Michigan, lake-effect precipitation occurs when cold air passes over warmer lake water (Indiana Department of Natural Resources, 1990a). The frequency, intensity and duration of precipitation can be higher in these areas because of the orographic lifting of moist air over the topographic highs along the ridges of the Lake Border and Valparaiso Moraines.

Flood frequency

The initial indicator of a flood is the stage of a river, which is defined as the elevation of the river's water surface above a base elevation or datum. However, the relative size of a flood is based on the peak discharge rather than river stage because backwater effects due to ice, debris or vegetation can cause higher stages than would otherwise occur for a given flow. Peak-discharge data is collected from a network of continuous-record and crest-stage partial-record stream gaging stations operated jointly by the U.S. Geological Survey and IDNR Division of Water (see figure 31, table 11).

Stream gage records are used to determine peak-flow characteristics, which are helpful in both mitigating flood damages and planning for future floods. Discharge-frequency characteristics can be used for 1) the design and construction of roads, bridges, dams, levees and spillways; 2) the regulation of floodplains; 3) the management of water-control works such as dams and spillways; 4) the mapping of flood-prone lands; and 5) flood forecasting. Table 13 presents maximum peak flows recorded at continuous-record gaging stations having at least 20 years of data for the period of record ending in 1991.

The variability of flood or peak flows, like the variability of low flows, can be statistically described by frequency curves. Flood frequency is generally expressed as the probability, in percent, that a flood of a given magnitude (discharge) will be equaled or exceeded in any one year. The recurrence interval, the reciprocal of the exceedance probability, is the average number of years between exceedances of a given flood magnitude.

The 100-year flood, for example, is the peak discharge that is expected to be equaled or exceeded on the average of once in a 100-year period. In other words, there is a 1 percent chance that a peak discharge of at least this magnitude will occur in any given year. Similarly, the 50-year flood has a 2 percent chance of occurring any given year, the 25-year flood has a 4 percent chance, and the 10-year flood has a 10 percent chance.

It should be noted the recurrence interval, or frequency, represents the long-term average time period during which a flood exceeding a certain magnitude is expected to occur once. It does not imply a regular periodicity between floods. A peak discharge having a 100-year recurrence interval, for example, could possibly occur in two consecutive years, or even in two consecutive weeks. On the other hand, the 100-year flood may not occur for several hundred years. The discharge-frequency values only are accurate to the extent that the available discharges used in the statistical analysis are representative of the long-term discharge record.

Since 1976, the Division of Water has coordinated with the U.S. Geological Survey, U.S. Soil Conservation Service and U.S. Army corps of Engineers to determine peak discharge-frequency values for Indiana streams (Indiana Department of Natural Resources, 1990b).

For a given flood frequency, a relation between peak discharge and drainage area can be developed to allow the estimation of discharges at ungaged sites within a watershed, or within other watersheds having similar basin characteristics.

Floodplain management

Since the Lake Michigan Region was first settled in the 1800's, public and private agencies have expended

Table 14. Community participation in the National Flood Insurance Program for major region counties.*

(all communities in regular phase of NFIP as of July 15, 1994)

County	Community
Lake	Crown Point
	Dyer
	East Chicago
	Gary
	Griffith
	Hammond
	Highland
	Hobart
	Lake Station
	Merrillville
	Munster
	New Chicago
	Schererville
	Whiting
Porter	Beverly Shores
	Burns Harbor
	Chesterton
	Dune Acres
	Ogden Dunes
	Portage
	Porter
	Valparaiso
LaPorte	Long Beach
	Michiana Shores
	Michigan City

* The unincorporated areas of Lake, Porter, and LaPorte Counties participate in the National Flood Insurance Program under their respective counties.

billions of dollars to improve drainage and control flooding. Although most methods of floodplain management historically have involved channelization, ditching, dredging, levee construction, and land-treatment measures, increasing emphasis is being placed on floodplain regulation and non-structural alternatives, such as land-use regulations, flood insurance, floodproofing, flood warning, and flood damage relief.

A report by Grady and Rutledge (1982) describes floodplain management measures and various aspects of land-use planning for Indiana communities. Detailed floodplain management reports and flood insurance studies are available for most counties of the Lake Michigan Region. Most of these reports have been prepared by cooperative efforts of the U.S. Department of Agriculture (Soil Conservation Service), the Federal Emergency Management Agency, the State of Indiana (Department of Natural Resources), soil and water conservation districts, planning commissions, and other local agencies.

Existing floodplain management regulations in Indiana are governed by a combination of statutory laws at both the state and federal levels. In brief, the state establishes minimum standards governing the delineation and regulation of flood hazard areas. Moreover, the 1945 Indiana Flood Control Act (I.C. 13-2-22) prohibits construction, excavation or the placement of fill in a floodway without prior approval from the Natural Resources Commission.

The Indiana Department of Natural Resources, Division of Water administers the flood control law and also acts as the state coordinator of the National Flood Insurance Program, which further helps to regulate the development of flood-prone lands. According to requirements of the program, new construction in a flood hazard area must be located and built in such a way that the potential for damages and loss of life is minimized.

Under this program, which is administered by the Federal Insurance Administration of the Federal Emergency Management Agency, property owners are eligible to purchase federal flood insurance if their flood-prone community adopts and enforces adequate floodplain management regulations.

A community can initially enter the **emergency phase** of the flood insurance program by adopting preliminary floodplain management regulations to guide new construction in flood-prone areas, which are approximately delineated on a flood hazard boundary map based on a generalized study. During the initial emergency phase, limited amounts of flood insurance become available to local property owners.

The community can then enter the **regular phase** of the program after a detailed flood insurance rate map is issued following a flood insurance study, and after local officials enact comprehensive regulations that require all new or substantially improved structures to be built in accordance with federal floodplain management criteria. Under the regular program, the full limits of flood insurance coverage become available.

Table 14 shows participation in the National Flood Insurance Program by communities within the Lake Michigan Region. The term "community" refers to both unincorporated and incorporated areas which have a government authority capable of adopting and enforcing floodplain management regulations. By virtue of this definition, an incorporated town is considered independent of unincorporated areas, which are collectively defined as a separate community.

SURFACE-WATER QUALITY

Surface-water quality can be an important factor in developing sustainable and beneficial land- and water-use strategies. The presence of high-quality surface water can facilitate or enhance development by providing water suitable for public supply, industrial cooling, irrigation, livestock watering, recreation and aquatic life. In contrast, surface water containing certain toxic substances may pose a health threat to humans who consume tainted fish taken from contaminated waters. Moreover, the value of a surface-water source can be diminished by bacterial pollution, high levels of nutrients or unacceptable concentrations of inorganic and organic chemicals.

Degradation of water quality may result from urban, industrial, and agricultural land uses, because practices associated with these uses may introduce sources of pollution into the watershed. Such pollution sources include wastewater discharge, contaminated runoff, *combined sewer overflow* (CSO), atmospheric deposition, and accidental spills or discharges. There may also be a tendency for pollution sources to be grouped together along the banks of a river or shores of a lake, a result of numerous users needing water for cooling, manufacturing, transportation and other purposes. Water quality degradation can occur in urban and agricultural areas if sufficient pollution-control practices are not properly implemented.

Historical Overview

Water-quality planning in northwest Indiana

The northwestern part of the Lake Michigan Region, often referred to as the Calumet Area, is one of the major industrial centers of the United States. Steel, petrochemicals and other industries have been integral parts of the Calumet Area's economy for over a century. This extensive urban and industrial development has had detrimental effects on the environment and surface-water resources of the Calumet Area. Consequently, various agencies at the federal and state level have produced strategies for protection and restoration of Calumet Area surface-water resources.

Because much of the Region's drainage ultimately discharges into Lake Michigan, pollution in the Calumet Area has been a source of concern for Indiana and other states along the Great Lakes coast. One dispute concerning pollution in southern Lake Michigan resulted in some early environmental action in the Calumet Area. In 1944, the State of Illinois and the City of Chicago filed suit against the state of Indiana; the cities of Gary, Hammond, East Chicago and Whiting; and 16 Indiana-based industries regarding alleged water pollution in Lake Michigan. The plaintiffs in the suit claimed that pollution originating from northwest Indiana was impairing the use of Lake Michigan as a water supply. A consent decree specifying corrective measures was entered in 1945, and all involved parties were deemed in compliance by 1948 (U.S. Department of Health, Education and Welfare, 1965).

In the 1960s, evidence from various studies, reports, and surveys indicated that chronic water-quality problems were damaging the aquatic ecosystem of near-shore Lake Michigan. Bottom dredgings of the Lake between 1961 and 1963 indicated that much of the Lake floor off the Calumet Area was covered with dense, organic material. Subsequently, the *benthic* community was dominated by aquatic worms, fingernail clams and other pollution-tolerant organisms. Game fish species, such as trout and perch, were scarce in the Calumet Area shores of Lake Michigan because of poor water and bottom-sediment quality. Instead, pollution-tolerant species of fish such as carp, buffalofish, and sucker dominated the *nektonic* community (U.S. Department of Health, Education and Welfare, 1965).

Water-quality problems in Lake Michigan also decreased the utility of the Lake for people. For example, beaches along Lake Michigan in Hammond and Whiting were frequently closed because of high bacteria counts in the Lake waters. Water purification facilities in Hammond, Gary and East Chicago reported taste and odor problems attributed to phenols and other organic compounds. The Gary facility also reported some excessive ammonia concentrations at its intake crib during January of 1963; and January, February and March of 1964 (U.S. Department of Health, Education and Welfare, 1965).

It was also recognized in the early and mid-1960s that most streams in northwestern Lake County were affected by pollution (U.S. Department of Health, Education and Welfare, 1965). The Grand Calumet and Little Calumet Rivers were characterized by low dissolved oxygen, high *biochemical oxygen demand* (BOD), and aquatic communities dominated by pollution-tolerant organisms. Oil, grease, floating debris and offensive odors made these rivers unappealing to recreational boaters; and high coliform bacteria densities made them unfit for any body contact. Poor water quality was also inhibiting development of public recreation areas along the Little Calumet River in Cook County (Illinois) and was responsible for lowering property value assessments along the Grand Calumet River (U.S. Department of Health, Education and Welfare, 1965). Water-quality problems were causing negative impacts on the environment, public health, and the general quality of life in the Calumet Area.

One of the first government agencies to become involved with environmental issues in the Calumet Area was the U.S. Department of Health, Education and Welfare (DHEW). In December 1964, the secretary of DHEW organized a conference which focused on water pollution in northwest Lake County, Indiana and the Chicago area. Reports were presented on water quality and biotic conditions for Wolf Lake, Lake Michigan, the Grand Calumet River, Little Calumet River and other surface-water bodies in order to quantify the causes and extent of surface-water pollution in the area. Evidence from these reports indicated that the discharge of inadequately-treated industrial and municipal wastewater was the principal cause of surface-water quality degradation. Furthermore, factors such as CSOs, spills and dredging were having serious short-term or local effects on water quality (U.S. Department of Health, Education and Welfare, 1965).

The DHEW recommended numerous corrective actions to help alleviate the pollution load to Lake Michigan and Calumet Area streams. Most of the DHEW suggestions established pollution-control objectives and water-quality monitoring criteria for the Area. The recommendations included: 1) elimination, by treatment or exclusion of phenols, ammonia, phosphorous, acids, oil, tar and suspended matter from industrial discharges; 2) regular effluent sampling by industry to provide reliable estimates of waste outputs; 3) long-term monitoring of surface-water quality by state and local agencies; 4) secondary treatment for all municipal wastes; 5) disinfection of sanitary wastes prior to discharge.

In March 1965, a second conference was organized by the Secretary of the DHEW to address interstate water pollution in the Calumet Area. The meeting included representatives from the Indiana Stream Pollution Control Board, the Illinois Sanitary Water Board, the Metropolitan Sanitary District of Chicago, and the Federal Government. A technical committee was subsequently formed with representatives from each of these agencies. The committee would be responsible for monitoring water quality, determining reasons for the lack of improvement in water quality, and suggesting remedial actions (Technical Committee on Water Quality, 1970).

Progress evaluations were conducted by the Technical Committee in March and September of 1967 and December of 1968 to assess the implementation and effectiveness of the recommended pollution-control measures. These evaluations concluded that, although numerous pollution-control measures had been initiated, surface-water quality had not improved significantly (Technical Committee on Water Quality, 1970). In 1970, the fourth progress evaluation by the Technical Committee concluded that, although most recommended pollution-control measures had been emplaced by 1970, the surface waters in the Calumet Area were still seriously polluted. The failure of existing abatement measures was attributed to intermittent wastewater discharges and inadequate wastewater treatment, at some localities.

The Technical Committee also concluded that planned future pollution-control measures would not be sufficient to meet all future water-quality goals, and the committee suggested additional abatement measures. Some of these additional measures recommended by the Committee included: 1) recycling treated industrial and municipal wastewaters; 2) elimination or control of CSOs; 3) development by state or municipal agencies of contingency plans to deal with accidental discharges, such as spills or equipment failures; 4) daily sampling of wastes at each industrial outfall; 5) establishment of adequate and consistent effluent criteria for the area (Technical Committee on Water Quality, 1970).

New federal laws enacted in the 1970s provided a framework for a more systematic and comprehensive approach toward pollution control. Section 208 of the Federal Water Pollution Control Act of 1972 mandated that water pollution management be executed on an area-wide basis, and that involved agencies prepare comprehensive pollution-control plans for areas under their jurisdiction (Northwestern Indiana Regional Planning Commission, 1978). In 1975, the state of Indiana designated the Northwestern Indiana Regional Planning Commission (NIRPC) as the planning agency to develop the section 208 water-quality management plan for Lake and Porter Counties.

The section 208 water-quality plan was completed by the NIRPC in 1978. The plan described the surface-water conditions in Lake and Porter Counties, and presented strategies for controlling point and non-point sources of pollution in the two counties.

The primary goal of the NIRPC 208 plan was to protect high-quality surface waters and ground waters in the two counties (Northwestern Indiana Regional Planning Commission, 1978). The plan was not intended to serve as a strategy for remediation of water-quality problems in the area; therefore, it did not have any provisions for remediating areas of environmental degradation, nor did it address problems such as contaminated sediments, toxic pollutants in wastewater discharges, or cumulative pollutant loads on Lake Michigan (Holowaty and others, 1991).

Water-quality planning in the Lake Michigan Region has also been influenced by basin-wide environmental management strategies developed by the American - Canadian International Joint Commission (IJC - see insert on page 100). In 1972, IJC recommendations became the basis of the first Great Lakes Water-Quality Agreement between the United States and Canada. The primary goal of the agreement was to reduce pollutant loads to the Great Lakes and to control cultural eutrophication (Great Lakes Water-Quality Board, 1987). Emphasis was placed on municipal and industrial point-source discharge problems which had been documented by the IJC (Indiana Department of Environmental Management, [1988b]). The 1972 agreement was initially applied to the Lower Great Lakes Basin, but was extended to the entire basin in 1978 (Great Lakes Water-Quality Board, 1987).

In 1977-1978, the two countries conducted a formal review of the 1972 Water-Quality Agreement. It was concluded that, although discharge limits established in the 1972 agreement were generally being met, there were still major environmental problems in the Great Lakes Basin (Indiana Department of Environmental Management, [1988b]). Additional strategies were needed to correct long-term problems with sediment quality, indigenous fish populations, persistent toxic chemicals, and rehabilitation of ecologically degraded areas in the Great Lakes Basin (Great Lakes Water-Quality Board, 1987; Indiana Department of Environmental Management, [1988b]). The 1977-1978 review produced a second, more comprehensive water-quality agreement between the U.S. and Canada.

The second water-quality agreement requires restoration and maintenance of the physical, chemical and biological integrity of the Lakes. The IJC also requested that an "ecosystem-based" approach be used to restore and maintain water quality in the Lakes. An ecosystem-based strategy focuses on complex interactions among water, air, land and biota; it requires that the relationships among all components of the ecosystem be considered while in the process of addressing environmental problems. Such a strategy also requires that ecosystem improvement be used as the criteria for measuring the effectiveness of solutions (Indiana Department of Environmental Management, [1988b], 1993). The U.S. and Canadian governments endorsed the second water-quality agreement in 1978, and it remains the basic framework used by the IJC for developing Great Lakes water-quality policy.

A scientific subcommittee of the IJC called the Great Lakes Water-Quality Board (GLWQB) began to use the ecosystem-based approach in 1981 to identify sites within the Basin where environmental degradation was severe enough to necessitate special actions. Previously, the board had designated "problem areas" in the Great Lakes Basin where environmental guidelines and standards had been exceeded. However, there were no consistent criteria, either for identifying the problem areas, or for assessing the extent of environmental degradation within them. Furthermore, the problem areas were generally defined solely on the basis of water-quality data (Indiana Department of Environmental Management, [1988b]). After 1981, the Board began to designate Areas of Concern (AOC) which were assessed by using environmental quality data gathered from all media and evaluated with uniform standards (Indiana Department of Environmental Management, [1988b]).

The Great Lakes Water Quality Board identifies areas of concern (AOC) as locations where the objectives of the Great Lakes Water Quality Agreement have not been achieved or where jurisdictional standards and guidelines are violated. Each AOC requires remedial action to restore all beneficial, water-related uses. Designated areas of concern include municipal and industrial centers along rivers, harbors, and connecting channels in the Great Lakes Basin (Great Lakes Water-Quality Board, 1987).

The International Joint Commission

The American-Canadian Boundary Waters Treaty of 1909 outlines the basic principles for resolving disputes between the United States and Canada over the waters along common borders. One aspect of the agreement authorized the establishment of a binational organization to administer the terms of the treaty and to advise the two governments on boundary-water issues. The organization established under the agreement is known as the Great Lakes International Joint Commission (IJC). The IJC was first assembled in 1912, and remains involved in administration of the 1909 treaty and planning of Great Lakes policy (International Joint Commission, [nd]).

The IJC acts as an intermediary for boundary-water issues between the U.S. and Canada and it develops policies that are based on consensus between the two governments. Both nations appoint commissioners to the IJC; however, these commissioners do not work as representatives of their respective governments. Instead, the Commission attempts to act as a single body seeking common solutions to boundary-water issues. IJC recommendations are non-binding; therefore, implementation is at the discretion of both governments. The 1909 treaty however, does contain a provision allowing the two governments to refer issues to the IJC for a binding decision (International Joint Commission, [nd]).

In 1972, a scientific subcommittee of the IJC known as the Great Lakes Water Quality Board (GLWQB) was established to investigate a variety of water-quality problems occurring in the Great Lakes Basin. The GLWQB is composed of experts from both the U.S.A. and Canada who analyze Great Lakes water-quality issues and advise the IJC on options to resolve these issues. Water-quality issues studied by the Board include eutrophication in the Great Lakes, persistent toxic substances, remediation of ecologically degraded areas, and the overall ecological conditions in the Great Lakes Basin (Great Lakes Water Quality Board, 1987).

The Water-Quality Board is also involved with environmental remediation in the Great Lakes Basin. Using data from annual assessments of water quality, the Board designates Areas of Concern (AOC - see page 99) in the Basin. The Board also assists individual states and provinces in developing Remedial Action Plans (RAPs) for each AOC under their jurisdiction, and it evaluates the RAPs for adequacy and efficiency in resolving environmental problems. This review and assistance process assures that the RAPs utilize comprehensive, ecosystem-based strategies in restoration programs even though the RAPs are prepared by different jurisdictions with varying needs and resources.

Early in the 1980s, parts of northwest Lake County were placed on the list of Areas of Concern (AOC) by the Water-Quality Board. The northwest Lake County AOC consists of the west and east branches of the Grand Calumet River, the Indiana Harbor Canal, Indiana Harbor and nearshore Lake Michigan in the vicinity of Indiana Harbor (Indiana Department of Environmental Management, [1988b]).

At a 1983 public meeting sponsored by the IJC, local environmental groups met with USEPA representatives to press for remediation of the Grand Calumet River system. The USEPA Region V Administrator, subsequently committed to developing a Master Plan for Improving Water Quality in the Grand Calumet River/Indiana Harbor Canal (Holowaty and others, 1991).

The Master Plan was developed by the USEPA with the cooperation of the Army Corps of Engineers and the Indiana State Board of Health. A draft of the plan was submitted for public scrutiny and comment in 1984; the final form was issued in 1985. The Master Plan contains a summary of existing environmental problems, pollution sources, and water-quality control programs in the Grand Calumet River and Indiana Harbor Canal. The report concludes with recommendations for improving water quality and aquatic habitat in these streams (U.S. Environmental Protection Agency, 1985a). However, the Master Plan only addressed water-quality concerns and did not consider other issues relevant to the AOC such as air deposition, solid wastes and hazardous wastes disposal (Holowaty and others, 1991).

Shortly after the Master Plan was completed, pollution-control responsibilities were transferred from the Indiana State Board of Health to the Indiana Department of Environmental Management (IDEM). The IDEM was soon committed to developing a comprehensive plan to restore ecological integrity and beneficial uses to the AOC. The result of the efforts was the 1987 Northwest Indiana Environmental Action Plan (EAP). The EAP was developed in consultation with the USEPA, the USGS, the IDNR, the Army Corps of Engineers and the U.S. Fish and Wildlife Service. Public participation in the development process of the EAP was facilitated through a state established Citizen's Advisory Committee (CAC) composed of citizens-at-large, business and industry representatives, environmentalists, and educators (Holowaty and others, 1991).

The EAP did not represent a single document with a limited number of defined goals. Instead, it was a comprehensive plan which encompassed numerous programs, efforts and ongoing regulatory or investigative activities. The different programs encompassed by the EAP include the 1985 Master Plan and a comprehensive Remedial Action Plan (RAP) for coordinating environmental rehabilitation in the AOC (Indiana Department of Environmental Management, [1988b]). The EAP however, was never fully implemented and was not consistent with the IJC's goals of systematic and comprehensive remediation in the AOC (Holowaty and others, 1991)

Current water-quality management efforts

The Northwest Indiana Action Plan

Current strategies for environmental remediation in the Calumet Area are outlined in the Northwest Indiana Action Plan (NWIAP), which is currently being developed by the IDEM and USEPA. The plan requires that comprehensive and innovative approaches be used to solve environmental problems, and that success be measured from tangible environmental improvement. The NWIAP is being developed to outline common goals of the USEPA and state agencies in the Calumet Area.

The action plan identifies six restoration objectives for the Calumet Area (U.S. Environmental Protection Agency and Indiana Department of Environmental Management, 1992):

1. Ensure the remediation of sediments of the Indiana Harbor Canal and Grand Calumet River.
2. Achieve a high level of compliance with all federal and state environmental statutes.
3. Investigate and remediate petroleum distillate floating on ground water in the Area.
4. Initiate pollution-prevention activities with local industries and municipalities.
5. Develop the Remedial Action Plan (RAP) and Lakewide Management Plan (LaMP) to improve water quality in the Area of Concern and Lake Michigan, respectively.
6. Involve the public in the decision-making process by public participation and education efforts.

The enforcement activities outlined in objective number two of the Action Plan are facilitated through a Geographic Enforcement Initiative (GEI) Task Force maintained by the USEPA. Initiated in February of 1990, the GEI Task Force concentrates on developing and coordinating multimedia enforcement cases throughout northwest Indiana, and functions as a clearinghouse for enforcement activities. Some activities of the GEI Task Force have resulted in agreements and consent decrees with companies and agencies for environmental remediation (U. S. Environmental Protection Agency and Indiana Department of Environmental Management, 1992: U.S. Environmental Protection Agency, [1993?]).

The RAP and the Lake Michigan LaMP mentioned in the fifth objective are environmental management plans specified in the Great Lakes Water-Quality Agreement.

The Remedial Action Plan for the Grand Calumet River/Indiana Harbor Canal-Nearshore Lake Michigan Area of Concern

Before environmental remediation begins in an AOC, the IJC recommends that appropriate agencies and organizations identify and classify causes of environmental impairment in the AOC. The responsible agencies and organizations should then, develop and implement remedial actions based on the identified causes of impairment. The strategies are to be enunciated in a distinct Remedial Action Plan (RAP) developed for each AOC. The RAP identifies the specific actions needed to control existing pollution sources, abate contamination already present, and restore beneficial uses to an AOC. The RAP also provides a historical record of past remedial actions and changes in the environmental quality of the AOC, and a timetable for implementing remedial actions (Great Lakes Water-Quality Board, 1987; Indiana Department of Environmental Management, [1988b]). A RAP therefore, can be viewed as a technical management document to be used to coordinate and direct all concerned communities, agencies and programs toward common restoration goals, and to provide a framework for future analysis and decision making (Great Lakes Water-Quality Board, 1987; Indiana Department of Environmental Management, [1988b]).

Because the environmental problems in the AOC are complex, development and implementation of the RAP will be conducted in stages: 1) defining ecosystem problems, 2) reviewing and choosing solutions, and 3) implementing the solutions. By developing the RAP in stages, the remediation process will be organized in a way that should assure that problems will be defined and comprehensive solutions will be developed.

The stage 1 RAP defines the ecological problems in the AOC. This part of the RAP contains a description of current biological, hydrologic, and environmental conditions; in addition, it contains a description of human activities which have affected these parts of the ecosystem. It also identifies human conduct and institutional arrangements which obstruct environmental remediation in the AOC (Indiana Department of Environmental Management, 1993). The stage one RAP essentially describes environmental conditions and concerns in the AOC and sets priorities for the remediation process.

The first draft of the stage 1 RAP for the Grand Calumet River/Indiana Harbor Canal AOC was completed in 1988. The IDEM, USEPA and CAC met regularly, from March to November of 1988, to revise the RAP draft. Work resumed on revisions to the plan in 1990 with a special Citizen's Advisory for the Remediation of the Environment (CARE) Committee representing community interests in place of the defunct CAC (Holowaty and others, 1991). The stage 1 RAP was submitted to the IJC for review in early 1991.

When the stage 1 RAP was completed, some relevant studies on the extent of environmental degradation in the AOC had not been completed. Nevertheless, the stage 1 RAP was submitted for IJC review so that work could begin on stage 2 of the RAP (Indiana Department of Environmental Management, 1991). The IJC comments on the draft suggested that the stage 1 RAP would need considerable improvement, but the IJC recognized the need for additional studies to fully quantify ecological problems in the area. Therefore, as work progresses on the stage 2 RAP, periodic revisions will be made to stage 1 so that more efficient programs for implementing RAP goals can be developed (Indiana Department of Environmental Management, 1993).

The stage 2 RAP is currently being developed by the IDEM with the assistance of the USEPA. In May of 1993, the IDEM released a draft of the Water-Quality Component of the stage 2 RAP for public comment. The Water-Quality Component is only a part of the overall stage 2 process. Eventually, the stage 2 RAP will include components for habitat restoration, sediments, and land remediation (Indiana Department of Environmental Management, 1993).

The draft Water-Quality Component of the stage 2 RAP outlines strategies for restoration and protection of the water resources in the AOC. This component of the RAP defines the overall restoration goals for surface waters in the AOC, and describes general remedial activities which could assist in achieving these goals. The draft Water-Quality Component also summarizes alternate plans for remediation. The water resources considered in this component of the stage 2 RAP include nearshore Lake Michigan, the Grand Calumet River, the Indiana Harbor Canal, Wolf Lake, George Lake, interdunal wetlands and area ground waters (Indiana Department of Environmental Management, 1993).

The Water-Quality Component of the stage 2 RAP will be reviewed on a regular basis to evaluate the allocation of resources and progress being made toward restoring ecological integrity and beneficial uses in the AOC. During the review process, the stage 2 RAP will be modified if changes in environmental conditions or in regulatory practices necessitate such action. Progress reports generated from these reviews will be used to guide revisions to the programs and objectives outlined in the RAP.

The third and final stage of the RAP requires implementation of the remedial activities and programs needed for environmental restoration in the AOC. The programs outlined in the second stage will be implemented by different agencies, individuals, work groups and other RAP participants. Coordination of involved parties will be managed through the stage 3 RAP process (Indiana Department of Environmental Management, 1993). The stage 3 RAP, when developed, will seek to guarantee that the remedial measures are instituted by the appropriate authorities.

The Lakewide Management Plan

In 1987, amendments to the Great Lakes Water Quality Agreement (discussed on pages 99 and 100) required the governments of the U.S. and Canada to develop a Lakewide Management Plan (LaMP) for each of the Great Lakes. The purpose of a LaMP is to outline efforts and management practices required to reduce loadings and ambient levels of certain toxic and bioaccumulative pollutants in the Great Lakes. The LaMPs also provide a mechanism to coordinate federal, state, local and international programs relating to pollutant load reduction and water quality protection. Amendments to the Clean Water Act directing federal, state and local agencies to achieve the goals and objectives of the Great Lakes Water Quality Agreement establish legal mandate for LaMP development in the U.S. (U.S. Environmental Protection Agency, 1993b).

Because Lake Michigan is entirely within the U.S., development of the LaMP is ultimately the responsibility of the U.S. Environmental Protection Agency. Participation in the LaMP process by other federal government agencies, state governments, and private interests is facilitated through various groups and committees. The LaMP for Lake Michigan will outline technical efforts required for reducing the ambient concentrations and inputs of toxic pollutants in Lake Michigan. The ultimate goal of the LaMP is the virtual elimination of the input of persistent, bioaccumulative and toxic chemicals into the Lake environment. The LaMP also provides a summary of current knowledge regarding specific pollutants influencing the water quality of Lake Michigan (U.S. Environmental Protection Agency, 1993b; Illinois-Indiana Sea Grant, 1994).

The Indiana Department of Environmental Management participates in the LaMP development process for the state of Indiana. The IDEM plans to coordinate the Water-Quality component of the stage 2 RAP with development of the LaMP. Coordinating the development and implementation of the LaMP and RAP should facilitate meeting remediation goals and minimize any duplication of efforts (Indiana Department of Environmental Management, 1993).

In Indiana, some key activities in the development and implementation of the LaMP include: 1) identifying persistent toxic substances released from the Grand Calumet River Basin into Lake Michigan; 2) identifying specific sources of critical pollutants to the Grand Calumet and Lake Michigan ecosystems; 3) estimating the total pollutant load from the Grand Calumet River into Lake Michigan; 4) developing of pollutant load estimates and monitoring plans for individual sources; 5) identifying activities to reduce pollutant loads; 6) developing data management processes to routinely track and report pollutant load reductions (U.S. Environmental Protection Agency and Indiana Department of Environmental Management, 1992).

The Great Lakes Initiative

Federal and state agencies are presently developing a basin-wide strategy, called the Great Lakes Initiative (GLI), for protecting water quality in all of the Great Lakes. The GLI is a cooperative effort between the USEPA and the Great Lakes states to develop uniform environmental standards and practices for the entire Great Lakes Basin within the U.S. The initiative is intended to assure adequate protection of the Great Lakes ecosystem and to promote development of consistent water-quality standards for all the states in the Great Lakes Basin.

The GLI will set uniform discharge standards for the region. Prior to development of the Initiative, each Great Lakes state determined local discharge limits within its boundaries. Some states, therefore, were permitting higher discharges of certain constituents than other Great Lakes states. The Great Lakes Initiative however, will recommend revised surface-water quality standards and discharge practices for all Great Lake states (Indiana Environmental Institute, 1992; Rubin and others, 1993).

The ultimate goal of the GLI is to virtually eliminate the discharge of all toxics into the Great Lakes. The initiative proposes strict regulations on the levels of 28 toxic and *bioaccumulative* chemicals. Regulations are also proposed for "Tier II" criteria pollutants. Tier II substances are thought to be toxic, but hazards associated with them have not been fully determined or quantified (Rubin and others, 1993; Mehan and Grant, 1994).

The GLI will focus primarily on regulating and reducing point-source discharges in the Great Lakes Region. Non-point sources will partially be addressed by the 1990 Clean Air Act and new stormwater regulations. Furthermore, the USEPA is beginning work on another basin-scale strategy, the Great Lakes Toxics Reduction Initiative, which will address multi-media pollution issues in the region (Rubin and others, 1993).

The USEPA is also developing new criteria and guidelines for water quality and the discharge of pollutants into the Great Lakes. The new guidelines would require that significant increases in pollution discharges must be necessary and must support important social and economic benefits. These rules would also restrict, and possibly eliminate, the practice of establishing mixing or dilution zones in waters receiving state-permitted industrial or municipal discharges (Rubin and others, 1993).

The proposed criteria and guidelines have been published in the Federal Register (58 Federal Register 20802, 1993) under the title of Water Quality Guidance for the Great Lakes System. Committees involved with the Great Lakes Initiative developed the basis for procedures outlines in the Great Lakes Water Quality Guidance. Actual rules for the proposed Great Lakes Guidance were developed by the USEPA and the eight Great Lakes states with participation from municipalities on the Great Lakes, industry, academia, Native American tribes, and environmental groups. The proposed Guidance establishes minimum water-quality standards, antidegradation policies, and implementation procedures for waters within the Great Lakes Basin. The USEPA published the proposed Water Quality Guidance for the Great Lakes on April 16, 1993, and is currently under court order to finalize the Guidance by March 1995 (Mehan and Grant, 1994).

Trail Creek Watershed Management Plan

Trail Creek in northern LaPorte County is one of the more important *salmonid* streams in Indiana. An IDNR fish-stocking program has helped maintain this designated cold-water fishery since the early 1970's. Trail Creek is also classified by the IDEM as a recreational-use stream. Water-quality problems, however, have historically prevented Trail Creek from supporting these designated uses (Indiana Department of Environmental Management, [1988a] and [1994?]).

Efforts to improve water quality in Trail Creek began with upgrades at the Michigan City wastewater treatment plant. In 1984, the Michigan City Sanitary District received funding for design changes to reduce the amount of raw and undertreated sewage entering Trail Creek. The sanitary district plugged many CSO outlets, constructed a stormwater storage basin to eliminate combined sewer overflows, and increased the capacity of the treatment plant to reduce the frequency of bypassing (Indiana Department of Environmental Management, [1990]). However, this stream still does not support designated recreational and aquatic life uses.

In 1991, the municipality of Michigan City and the IDEM signed a Memorandum of Understanding (MOU) outlining the allocation of funds for water-pollution control in Trail Creek. Michigan City, in cooperation with the Trail Creek Improvement Program (TIP) committee, had developed a water-quality improvement plan for Trail Creek (see page 63 for a discussion of the TIP committee). This improvement plan consisted of various strategies to improve water quality, decrease sedimentation, and reduce non-point source pollution in the Trail Creek waterway. The IDEM agreed to reimburse Michigan City with funds from the USEPA for these water-quality activities.

The funds however, could not be accessed until a comprehensive watershed management plan was developed for Trail Creek. The IDEM subsequently contracted the Northwestern Indiana Regional Planning Commission to develop a watershed management plan for this stream. Community input to the plan was facilitated through the Trail Creek Watershed Management Resources Committee, a subcommittee of the TIP Committee composed of community, government, and private interests. The plan, completed in 1993, establishes four goals for the restoration of the Trail Creek watershed: 1) reduce potential health hazards due to poor water quality in the stream of Trail Creek; 2) improve conditions for aquatic life in Trail Creek; 3) increase the quantity and quality of recreational opportunities in the Trail Creek watershed in order to stimulate economic growth; 4) develop a public awareness of the unique and diverse opportunities that the stream of Trail Creek provides (Steve Davis, Indiana Department of Natural Resources, personal communication, 1993; Janellen McCoy, Northwestern Indiana Regional Planning Commission, personal communication, 1993).

One part of the Trail Creek Watershed Management Plan consists of a natural resource plan for controlling soil erosion in the Trail Creek drainage basin. The natural resource plan was developed by the Soil Conservation Service of the U.S. Department of Agriculture in cooperation with the LaPorte County Soil and Water Conservation District (SWCD). Development of this plan was sponsored by the IDEM, the NIRPC, the TIP committee, and the LaPorte County SWCD. The natural resource plan describes soil erosion on cropland, pastureland and woodland, and it develops alternative conservation plans for reducing erosion. The LaPorte County SWCD and local land owners will use the natural resource plan as a guide for future erosion-control activities (Bruce Milligan, U.S. Soil Conservation Service, personal communication, 1993).

Designated surface-water uses in Indiana

The Indiana Department of Environmental Management (IDEM) [1990] estimates that there are approximately 90,000 miles (144,000 km) of open-channel waterways in the state of Indiana. These waterways include navigable rivers, perennial streams, intermittent streams and drainage ditches. All of these waterways are considered "waters of the state" and are protected by Indiana stream pollution control laws.

The IDEM assigns one or more specific use classifi-

Table 15. Designated uses and use-support status of selected streams

{Adapted from Indiana Department of Environmental Management 1992-1993 305(b) [1994?]}

Designated surface-water uses in Indiana: Aquatic life; Recreation; Agriculture; Industrial; Public-water supply

Use support status: FS, stream is currently supporting designated use; PS, stream is partially supporting designated use; NS, stream is not supporting designated use at present.

Watercourse	Nearest town(s)	Designated use support status	Miles affected	Probable cause of impairment
Coffee Creek	Chesterton	NS (aquatic life)	2	Urban Runoff
Upper Salt Creek	Valparaiso	NS (aquatic life) NS (recreation)	4	Low D.O. Bacteria
Lower Salt Creek	Portage	NS (aquatic life) NS (recreation)	4	Low D.O. Bacteria
Upper Trail Creek and tributaries	Michigan City	NS (aquatic life) NS (recreational)	42	Bacteria, Pesticides Agricultural Runoff, PCBs
Lower Trail Creek	Michigan City	NS (aquatic life) NS (recreational)	3	Pesticides Bacteria, PCBs
Galena River and tibutaries	Heston, Lalimere	FS (aquatic life)	13	
Burns Ditch	Lake Station, Portage	NS (aquatic life) NS (recreational)	8	PCBs, Pesticides Bacteria
Little Calumet River	Porter, Chesterton	NS (aquatic life) NS (recreational)	6	Bacteria, PCBs Cyanide, Pesticides
Little Calumet River	Hammond	NS (aquatic life) NS (recreational)	10	Bacteria, PCBs Cyanide, Pesticides
Indiana Harbor Canal	Whiting, E. Chicago	NS (aquatic life) NS (recreational)	4	Bacteria PCBs, Pesticides Mercury Low D.O.
E. Branch, Grand Calumet River	Gary, E. Chicago	NS (aquatic life) NS (recreational)	10	Bacteria Oil and grease PCBs, Pesticides Cyanide Lead
W. Branch, Grand Calumet River	Hammond, E. Chicago	NS (aquatic life) NS (recreation)	3	Bacteria Low D.O. PCBs, Pesticides Lead Ammonia CSO, cyanide
Plum Creek	Dyer	FS (aquatic life)	4	
Hart Ditch	Munster, Highland	FS (aquatic life)	2	
Beaver Dam Ditch	Crown Point	NS (aquatic life)	7	Poor Habitat Low D.O.
Deep River	Hobart	NS (aquatic life)	4	Runoff, POTW Poor Habitat
Deep River	Lake Station	NS (aquatic life)	4	Sewage

cations to the streams of the state. The use classifications reflect the benefits that can be derived from the stream by people and wildlife. The types of designated stream uses in Indiana include: aquatic life, recreation, agriculture, industrial, and public-water supply. Of the total estimated 90,000 miles (144,000 km) of waterways in the state, the Indiana Department of Environmental Management [1994?] estimates that approximately 21,000 miles (33,800 km) can reasonably be expected to support designated uses. The watercourses that support designated uses consist of permanently flowing rivers and some intermittent streams that have adequate depth and duration of flow.

In a recent evaluation of the Lake Michigan Region, the IDEM assessed approximately 210 stream miles for aquatic life use and 102 stream miles for recreational use (Indiana Department of Environmental Management, [1994?]). Some of the streams in the Region are listed in table 15, along with designated uses, support status, probable causes of impairment, and miles affected. Many streams in the Region, particularly those in urban areas, cannot fulfill designated uses because of the adverse effects of pollution.

Water quality standards

Water-quality standards are legally established limits for various physical, chemical, or biological parameters that may affect use, safety, or aesthetics of water resources. Federal and state agencies establish numerical and/or narrative standards that may be used as one criterion for assessing water quality. This report compares levels of selected constituents measured in streams and lakes in the Region with state and federal water-quality standards.

In Indiana, water quality standards are promulgated under Rule 1, Article 2, Title 327 of the Administrative

Table 16. Surface water standards in Indiana

All surface water resources in the state of Indiana are protected by water-quality standards established in subsection (a) of 327 IAC 2-1-6 (1992). These standards essentially state that acutely or chronically toxic chemicals and noxious substances must not be present in surface-waters at levels that will have detrimental effects on water quality.

Additional aspects of this law define standards that are preferentially applied to surface-water bodies on the basis of use. These additional standards are enforced to help assure that Indiana's surface-water resources can fulfill designated uses for humans and wildlife. Standards for protecting surface-water uses are generally specified for particular parameters which can limit or prevent the potential use of surface-water resources. For example, limits on Escherichia coli (E. coli) bacteria are enforced to protect people from disease caused by possible sewage contamination. Streams or lakes which violate E. coli standards would probably not be considered safe for body-contact recreation or water supply. A listing of fundamental surface-water uses and their corresponding water quality standards are outlined in the table below.

Designated stream-use	Specific standards defined under 327 IAC 2-1-6 (1992)
Recreational (full body contact)	E. coli may not exceed 125/100 ml as a geometric mean of 5 or more samples equally spaced over 30 days, nor exceed 235/100 ml in any single sample over a thirty day period.
Public Supply[1]	Coliform bacteria cannot exceed 5000/100 ml as a monthly average nor exceed 5000/100 ml and 20,000/100 ml in more than 20 and 5 percent, respectively, of all monthly samples. E. coli limits are the same as those established for recreational use streams. Concentrations of either sulfates or chlorides must not exceed 250 mg/L. Radiation levels due to radium-226 and strontium-90 must not exceed 3.0 pCi/L and 10.0 pCi/L, respectively (in the known absence of strontium-90 and other alpha emitters, beta particle activity of up to 1000 pCi/L is acceptable)
Industrial Supply[2]	Total dissolved solids cannot exceed 750 mg/L (subsection (f) specifies that a specific conductance of 1,200 µmhos/cm at 25°C can be considered equivalent to a TDS of 750 mg/L).
Agricultural use	Waters must meet all requirements specified in 327 IAC 2-1-6(a) (the minimum water-quality standards).
Aquatic life[3]	Allowable pH range of 6.0 - 9.0. Dissolved oxygen level must average at least 5.0 mg/L daily, without being lower than 4.0 mg/L at any time. Maximum temperature increase due to anthropogenic activity may not exceed 5.0°F (2.8°C) in streams or 3.0°F (1.7°C) in lakes and reservoirs. No substances which impart unpalatable flavor to fish or offensive odor may be discharged into designated aquatic life streams.

Table 16. Surface water standards in Indiana – Continued

Designated stream-use	Specific standards defined under 327 IAC 2-1-6 (1992)
Salmonid streams[3]	6.0 mg/L minimum dissolved oxygen level (7.0 mg/L in spawning areas during spawning season). Any temperature increases due to anthropogenic activity can not exceed 2°F (1.1°C). Maximum water temperature must not exceed 65°F (18.3°C) during spawning season, 70°F (21.1°C) during the rest of the year. The same limits on pH and the discharge of noxious substances specified for aquatic-life designated streams also apply to cold water fish streams. Designated salmonid streams in the Lake Michigan Region include Trail Creek and its tributaries, the Galena River and its tributaries, the East Fork of the Little Calumet River and its tributaries, and Kintzele Ditch downstream from Beverly Drive in Porter County.
Limited use streams	In addition to standards established in subsection (a), limited use streams must meet the standards established for recreational and industrial uses. Aerobic conditions must prevail at all times.
Exceptional use streams	Unless standards are specified on a case-by-case basis, the quality of waters designated for exceptional use shall be maintained without degradation.
Lake Michigan	The following criteria outlined in subsections (j) and (k) of 327 IAC 2-1-6 apply to all waters in the Indiana portion of Lake Michigan: minimum dissolved oxygen = 7.0 mg/L pH between 7.5 and 8.5 No human-induced temperature changes that will have adverse affects on aquatic organisms or the propagation of the aquatic community. <u>Maximum permissible values on the following chemical constituents</u> chlorides: 15 mg/L monthly average, 20 mg/L daily maximum phenols: 0.001 mg/L monthly average, 0.003 mg/L daily maximum sulfates: 26 mg/L monthly average, 50 mg/L daily maximum total phosphorus: 0.03 mg/L monthly average, 0.04 mg/L daily maximum TDS: 172 mg/L monthly average, 200 mg/L daily maximum fluorides: 1.0 mg/L daily maximum iron: 0.3 mg/L daily maximum

1 Standards apply at the point where water is withdrawn for treatment. Water distributed for public supply must also meet drinking water standards defined in 327 IAC 8-2.
2 Standards apply at the point where water is withdrawn for use.
3 Standards on excessive (above 9) pH do not apply when daily high pH values are correlated with photosynthetic activity by plants.

Code (327 IAC 2-1). Applicability of the standards depends on the presence of an in-stream mixing zone for effluent dilution, which may or may not be allocated to a discharger. The rule defines the minimum water-quality standards which apply to all waters of the state at all times, including waters in the mixing zones. Minimum standards essentially require that waters of the state be free of substances from anthropogenic sources that can have detrimental effects on water quality. Specifically, the rule extends this restriction to substances 1) that can have adverse effects on the aesthetic aspects of a water body; 2) that are in amounts sufficient to be acutely toxic to humans, aquatic life, plants or animals. The numeric criterion used to define acute toxicity for minimum water-quality protection is the *acute aquatic criterion* (AAC). The statutes also specify that all waters in the state outside the mixing zones must not contain substances at levels that can be chronically toxic, *carcinogenic*, *mutagenic* or *teratogenic* to humans, animals, plants or aquatic life. Indiana water-quality statutes define standards, such as the chronic aquatic criterion (CAC) to protect organisms from chronic toxicity. Other standards outlined in the rule are established for specific water-quality parameters and stream-use situations (table 16). The regulations also specify that when a stream is designated for more than one use, the most protective standards apply.

Water-quality standards are reviewed and revised in order to accommodate new environmental and public-health concerns, or when new data indicates the allowable level of a specific contaminant should be changed. It is thus, possible for the use-support status of a stream or lake to change even though water quality remains constant, because revisions are made in the water-quality standards. In the following section, the quality of major streams in the Region is evaluated relative to 1992 state water-quality standards. This evaluation will help illustrate progress toward contemporary wa-

Table 17. IDEM water-quality monitoring stations in the Lake Michigan Region

{Compiled from Indiana Water Quality Monitoring Station Records- Rivers and Streams, Indiana State Board of Health/Indiana Department of Environmental Management, and personal communication IDEM staff (1957-present).}

Location: Site locations are shown in figure 41.

Water Quality: Measurements of specific parameters vary with location and time during periods of record; samples collected monthly.

Plankton/algae: Samples collected monthly.

Toxics: Samples taken quarterly; measurements of specific parameters vary with location and time.

Location	IDEM code	Water Quality	Plankton/algae	Toxic compounds
Grand Calumet River				
Hohman Av bridge, Hammond	GCR 34	1958-	1959-63, 1966-72	1988-
Indianapolis Blvd, E. Chicago	GCR 36	1964-67		
Kennedy Av bridge, E Chicago	GCR 37	1964-67, 1981-		1989-
U.S. 12, Gary	GCR 41	1964-85		
Bridge St bridge, Gary	GCR 42	1986-		1989-
Indiana Harbor Canal				
Mouth of Ind. Harbor Canal	IHC 0	1973-76, 1978-	1976, 1978-79	
Dicky Road bridge, E Chicago[1]	IHC 2	1964-90	1977	1989-90
Columbus Dr, E Chicago	IHC 3S	1964-		
Indianapolis Blvd, E Chicago	IHC 3W	1964-		
Little Calumet River				
Hohman Av, Hammond	LCR 13	1958-	1959-63, 1966-72	
Bridge on State Route 149	LCR 39	1971-	1973-75	
Burns Ditch				
Near mouth of Burns Ditch	BD 0	1964-84	1974-79	
Midwest Steel truck bridge	BD 1	1966-	1971-73	1989-
Bridge on State Highway 249	BD 2E	1966-		
Portage Boat Yard dock	BD 3W	1966-		
Trail Creek				
Franklin St, Michigan City[2]	TC 0.5	1973-		
U.S. 12, Michigan City	TC 1	1969-72, 1977-	1969-72	1989-
Walker St, Michigan City	TC 1.3	1973-76		
Krueger Park, Michigan City	TC 2	1986-		
Salt Creek				
U.S. 20, Portage	SLC 1	1986-		
U.S. 6 near Valparaiso	SLC 7	1971-72		
S.R. 130 bridge, Valparaiso[3]	SLC 17	1973-		1989-

Table 17. IDEM water-quality monitoring stations in the Lake Michigan Region – Continued

Location	IDEM code	Water Quality	Plankton/algae	Toxic compounds
Lake Michigan				
East Chicago intake crib	LM EC	1969-	1971-90	
Gary intake crib	LM G	1969-	1971-90	
Hammond intake crib	LM H	1969-	1971-90	
Michigan City intake crib	LM M	1957-	1979-90	
Whiting intake crib	LM W	1957-	1979-90	1989-
Wolf Lake				
129th St culvert, Hammond	WL SL	1966-	1971-75	1988-

[1] Previously designated IHC 1 (1964-1985)
[2] Previously designated TC 0.3 (1973-1985)
[3] Previously designated SLC 12 (1973-1985)

ter-quality goals, but may not necessarily reflect a stream's past use-support status.

In addition to a comparison to state water-quality standards, levels of specific parameters in Lake Michigan Region streams are also compared to certain drinking water standards and guidelines. The federal criteria used for comparison in this section include the maximum contaminant level (MCL) and the secondary maximum contaminant level (SMCL). The MCLs are legally established limits for the concentrations of specific constituents to protect human health. The maximum contaminant levels are enforced for finished water that is treated and distributed specifically for public supply. The SMCLs are recommended, non-enforceable standards established to protect aesthetic properties of drinking water, such as taste and odor. Although the streams in the Region are not sources for public water supply, water quality in these streams may be compared to federal drinking-water guidelines for descriptive purposes. The established MCLs and SMCLs for certain inorganic ions are listed in appendix 6.

Water-quality monitoring and data collection

Long-term monitoring of water quality in Indiana was initially the responsibility of the Indiana State Board of Health (ISBH - now Indiana State Department of Health). In 1957, the ISBH began collecting and analyzing surface-water samples from a network of 49 stations located along streams throughout the state. The ISBH maintained and expanded the system until 1986, when the Office of Water Management of the Indiana Department of Environmental Management (IDEM) assumed responsibility for the stream monitoring network. The IDEM-managed system presently consists of over 100 water-quality monitoring stations located throughout the state.

Near-surface *grab samples* are collected on a monthly or quarterly basis at most IDEM monitoring stations. The grab samples are analyzed in the field and laboratory to quantify the values of numerous water-quality parameters. The data obtained in the process are used to detect changes in surface-water quality, evaluate pollution-abatement strategies, estimate background levels of various chemical constituents, determine if a stream can meet designated uses, and help document compliance with state and federal pollution-control mandates.

At present, the IDEM collects samples at 22 active monitoring stations in the Lake Michigan Region (figure 41 and table 17). Five of the active stations sample water from Lake Michigan through municipal-supply intakes. One station monitors water quality in the Indiana portion of Wolf Lake. The remaining 16 active monitoring stations are located along various rivers, creeks and drainage ditches in the Region. Water-quality information from six discontinued Region stations is also on record with the State.

Stream-water samples are analyzed for a variety of physical parameters, chemical constituents, and biological-quality indicators. Levels of total suspended solids (TSS), *biochemical oxygen demand* (BOD),

Table 18. Stream-quality monitoring stations with radiation measurements

{Compiled from Indiana Water Quality Monitoring Station Records-Rivers and Streams, Indiana State Board of Health/Indiana Department of Environmental Management (1957-1985).}

Location: Site locations are shown in figure 41.

Period of Record: Samples analyzed monthly until 1978. After 1978, three consecutive monthly samples were combined and analyzed as a quarterly sample.

Location	IDEM code	Period of Record
Lake Michigan		
East Chicago intake crib	LM EC	1973-85
Gary intake crib	LM G	1973-85
Hammond intake crib	LM H	1972-85
Michigan City intake crib	LM M	1957-85
Whiting intake crib	LM W	1957-85
Tributaries to Lake Michigan		
Near mouth of Burns Ditch	BD 0	1973-84
Mouth of Ind. Harbor Canal	IHC 0	1973-76, 1978-85
Dickey Road bridge, E. Chicago[1]	IHC 2	1972-73, 1976-77
Trail Creek[2]	TC 0.5	1981

[1] Previously designated IHC 1 (1964-1985)
[2] Previously designated TC 0.3 (1973-1985)

dissolved oxygen (DO), ammonia, bacteria and certain inorganic ions are determined for samples from most of the active monitoring stations in the Region. Many samples are also analyzed for certain toxic substances such as arsenic, cyanide, phenols and heavy metals.

The IDEM also tests stream waters for the presence of certain toxic organic compounds. Quarterly, water samples from some stations are analyzed for detectable concentrations of organic compounds including *polychlorinated biphenyls* (PCBs), pesticides, herbicides, *volatile organic compounds* (VOCs) and benzene-based compounds. At present, quarterly water samples from eight of the monitoring stations in the Lake Michigan Region are analyzed for toxic organic compounds (table 17).

Samples of fish tissue and streambed sediment are also analyzed by the IDEM for potential contamination by PCBs, heavy metals and pesticides. In the Lake Michigan Region, fish and sediment samples from the Grand Calumet River, Trail Creek, Burns Ditch, the Indiana Harbor Canal, the Lake George Canal, and the Marquette Park Lagoons have been tested for potential contamination. The results of these analyses were utilized in the development of IDEM fish advisories for the Region (see page 127).

Plankton data of Lake Michigan Region waters were collected monthly at certain monitoring stations from 1959 until 1990 (see figure 41 and table 17). Algae can clog filters and cause taste and odor problems. The reported data consists of the relative proportions of blue-green algae, green algae and *diatoms* detected in a 125 ml sample.

Regular measurements of radiation levels in water samples were made by the ISBH at select monitoring stations in the Lake Michigan Region (table 18 and figure 41). Radiation quality is expressed as measured alpha particle and beta particle activities in both the suspended sediment load and dissolved solids load of a sample. Monthly data collection began in 1957 and continued until quarterly sampling was initiated in 1978. Regular measurement of radiation levels in samples from the monitoring network ended after 1985.

The U.S. Geological Survey (USGS) has collected water-quality data from numerous streams during its research and resource-evaluation efforts in the Region. Water samples were collected by the USGS at three gaging stations on the Little Calumet River, Trail Creek and the Galena River. Additional data for the Little Calumet River were collected at a USGS-oper-

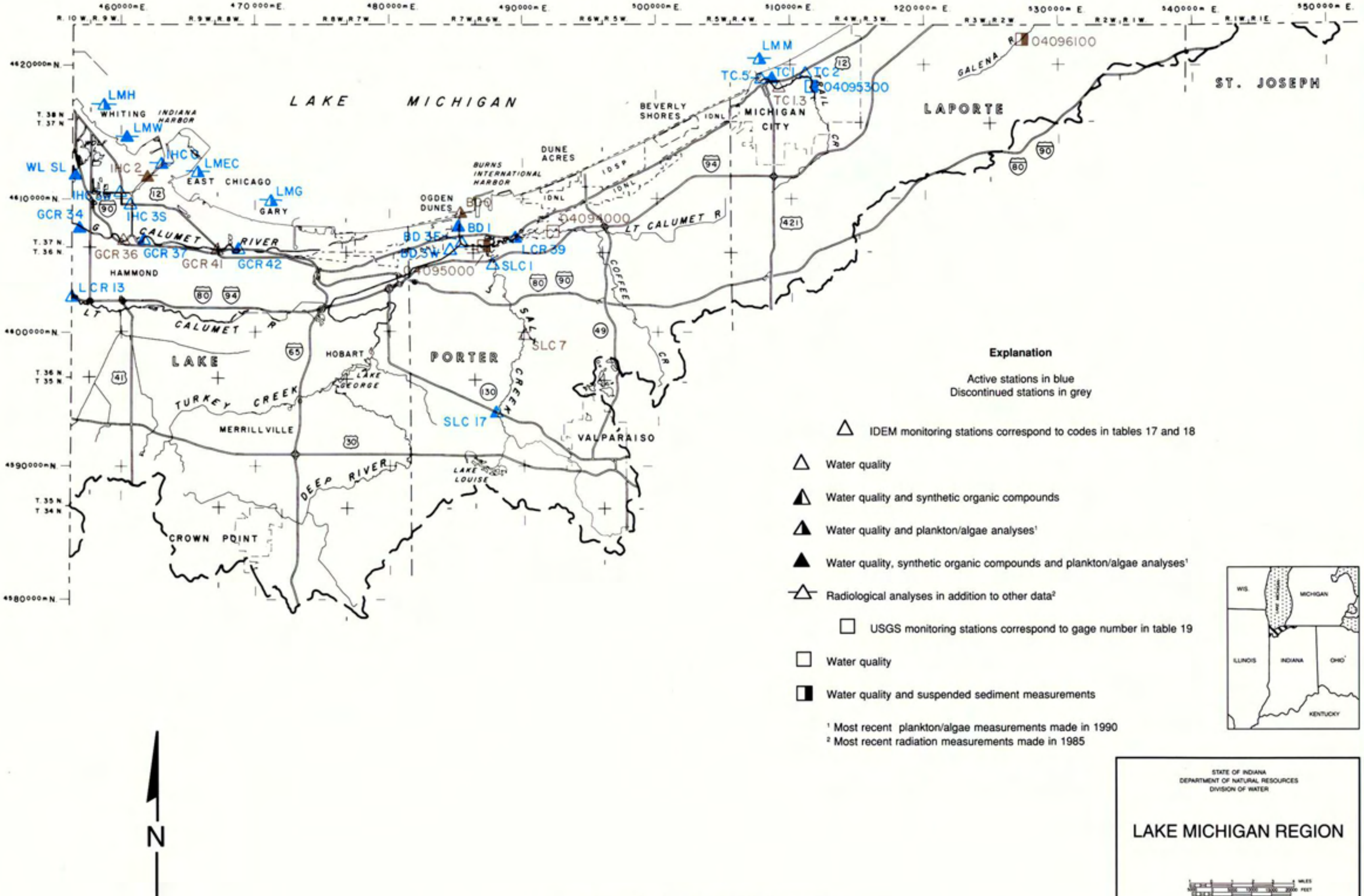


Figure 41. Water-quality monitoring sites

ated national stream quality accounting network (NASQAN) station (figure 41 and table 19). Water samples from these stations were used to determine the concentrations of various chemical constituents and total suspended sediment loads.

In October of 1984, the USGS conducted a diel (24-hour) survey of stream flow and water quality in the Grand Calumet River. Water samples were collected and flow measurements were taken at 11 stations along the Grand Calumet River and at 23 wastewater outfalls discharging into the river. Samples were analyzed for a variety of water-quality parameters, including dissolved oxygen. The water-quality and flow data obtained in the study were used to calculate chemical loads from known sources and to estimate the contribution of non-point sources to the total pollutant load in the Grand Calumet River. The results of the study are published as a USGS water-resource investigation report (86-4208) listed under Crawford and Wangsness (1987) in the **Selected References** section of this report.

The USGS has also collected data at partial-record and temporary monitoring stations along streams in and around the Indiana Dunes State Park and National Lakeshore. Data collected from these stations include ion concentrations and nutrient levels in stream samples and trace-element and synthetic hydrocarbon levels in sediments. Streams in the Indiana Dunes State Park/ National Lakeshore sampled by the USGS include the Little Calumet River, Kintzele Ditch, Dunes Creek, Derby Ditch, Markowitz Ditch, and Striebel Arm. The data have been used in USGS water-resource investigation reports prepared by Arihood(1975) and Hardy (1984).

Additional sampling efforts have been recently undertaken by the National Biological Survey on three small streams in the Region. During part of 1993 and 1994, a total of 21 sites have been sampled monthly on Dunes Creek, Derby Ditch, and Kintzele Ditch. Water quality, diatoms, and macroinvertebrates have been sampled. Mapping of land use and wetland plant distribution and abundance has also occurred. In addition to the monthly sampling on the small streams, sampling for E. coli has also been undertaken during storm events for Deep River, Salt Creek, East and West Branches of the Little Calumet River, and Burns Ditch.

In February and May of 1977, the Michiana Area Council of Governments (MACOG) conducted sampling on Trail Creek and the Galena River to quantify levels of dissolved oxygen, suspended solids, BOD, ammonia and phosphate. Their results were used to describe quality conditions in these streams, and were included in a water-quality assessment report for LaPorte, Saint Joseph, Elkhart and Marshall Counties

Table 19. Stream-quality data from USGS gaging stations

{Compiled from Water Resources Data, Indiana (1978-80), U.S. Geological Survey, and personal communication, David Cohen, U.S. Geological Survey, Water Resources Division, Indianapolis.}

Location: Site locations are shown in figure 41.

Water quality: Measurements of specific parameters vary with location and time.

USGS river gage location	Gage number	Water Quality	Suspended sediments
Little Calumet River 200 ft. upstream from bridge on U.S. Hwy 20, Porter Ind.[1]	04094000	1973-80	NA
Little Calumet River at Samuelson Rd near McCool, Porter County[2]	04095000	1978-80	1979-80
Trail Creek downstream from bridge on Springland Av, Michigan City[1]	04095300	1977-81, 1990-93	1979-93
Galena River downstream from bridge on County Rd 125 E. LaPorte County[1]	04096100	1977-80	1979-80

[1] Site of USGS river-gaging station. See table 11 for period of flow records.
[2] Site of USGS national stream-quality accounting network (NASQAN) station.
NA = Not applicable - data not collected at this site.

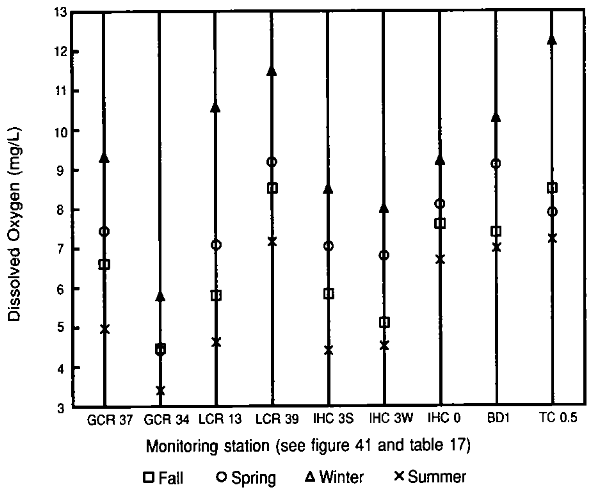


Figure 42. Seasonal median dissolved oxygen at selected stations

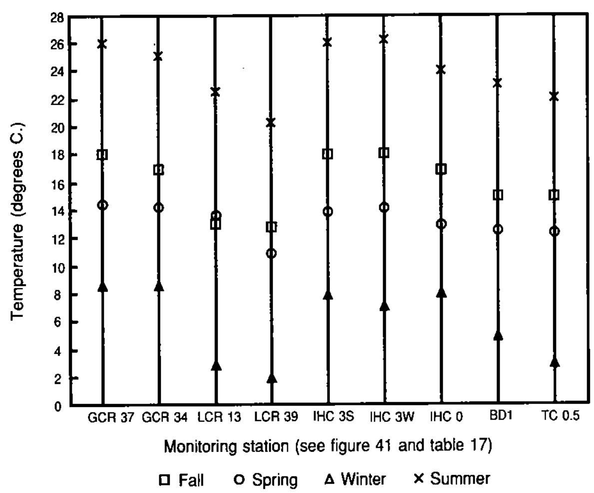


Figure 43. Seasonal median temperature at selected stations

(Michiana Area Council of Governments, 1978a).

Water quality in the Trail Creek watershed is also monitored through a cooperative effort between the LaPorte County Health Department and the Michigan City Sanitary District. The primary goal of the monitoring effort is to assess the effects of improved land-management practices on water quality in the stream of Trail Creek (Northwestern Indiana Regional Planning Commission, 1993).

Stream quality

Sources of data for analysis

Data from selected IDEM monitoring stations were used to analyze the water quality of streams in the Lake Michigan Region. Data were analyzed from monitoring stations along the Grand Calumet River (GCR 34 and GCR 37), the Little Calumet River (LCR 13 and LCR 39), the Indiana Harbor Canal (IHC 0, IHC 3S, and IHC 3W), Trail Creek (TC 0.5) and Burns Ditch (BD1).

The water-quality analyses in this section focuses on the major drainage systems in the Region, such as the Grand Calumet River, Little Calumet River, Indiana Harbor Canal, and Trail Creek. A general lack of adequate data for headwater streams in the Lake Michigan Region (figure 41) precluded a meaningful analysis of the smaller streams. Ground water is, however, the primary source of water for most head-water areas in the Region; and a comprehensive discussion of ground-water quality is presented in the **Ground-Water Quality** section of this report.

The data used for this report were collected at the above monitoring stations over a ten-year period (1982-1992 at stations LCR 39 and TC 0.5; 1983-1993 at all other selected stations). The water quality parameters examined consist of dissolved oxygen (DO), pH, *specific conductance* at 25°C, hardness, chloride, and total iron. Analysis of some water-quality parameters was not possible at certain stations because of insufficient or unavailable data.

Seasonal variations in water quality

The median values of the dissolved oxygen and specific conductance data collected during each climatic season (winter, spring, summer and fall) were compared to discern possible seasonal trends in water quality. Dissolved oxygen and specific conductance were examined for temporal trends because seasonal variations are often observed in these parameters, and specific limits for their levels have been established for certain stream-uses (table 16). Possible seasonal variations in DO concentrations and specific conductance levels could, therefore, be a factor in stream-quality assessment.

At all of the monitoring stations examined, the highest seasonal median dissolved oxygen levels are

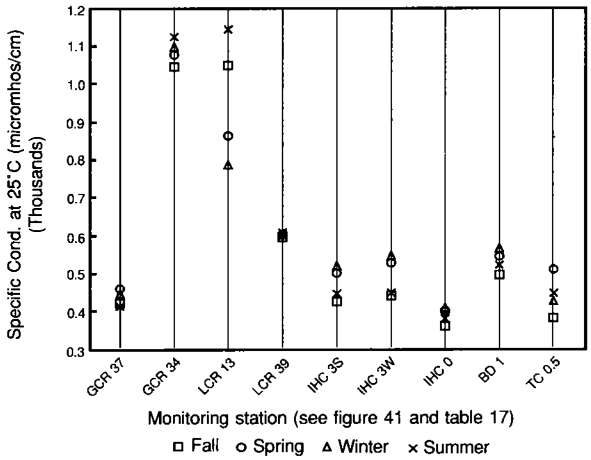


Figure 44. Seasonal median specific conductance at selected stations

observed during winter and the lowest levels occur during summer (figure 42). Because the largest contrasts in median water temperature (figure 43) are also observed between winter and summer, this trend in DO levels probably reflects changes in oxygen solubility due to seasonal variations in average water temperature. At most of the monitoring stations examined, higher median DO concentration and lower median temperatures occur during spring than during fall. This pattern, however, is not observed at certain monitoring stations (TC 0.5, GCR 34 and LCR 13). Discrepancies in the expected seasonal trends in DO concentrations may reflect other factors (see box on page 116) which influence the dissolved oxygen content of streams.

Graphs of median specific conductance in water samples from the selected monitoring stations are displayed in figure 44. The largest differences in seasonal specific conductance levels are detected in water samples from the West Branch of the Little Calumet River (monitoring station LCR 13). The median specific conductance value for samples collected during summer exceeds the median value in winter samples by approximately 350 µmhos/cm (at 25°C) at this station. In contrast, median specific conductance levels in water samples from the East Branch of the Grand Calumet River (monitoring station LCR 39) appear to be very consistent throughout the year.

Seasonal differences in specific conductance in the water samples from the other stations (GCR 34, GCR 37, IHC 0, BD 1, TC 0.5) may not be very significant (figure 44). It is possible however, that some of the annual variability in the specific conductance levels of these streams relates to seasonal influences.

Spatial variations in water quality

Box plots are a graphical device used to display the median and percentile ranges of a data set. These graphs are generally used to provide a concise visual summary of a single set of data and for comparison among different data sets. Box plots for water-quality data from the selected monitoring stations are displayed in figure 45.

Variability in the levels of dissolved oxygen are observed among different streams in the Lake Michigan Region (figure 45 and appendix 7). The highest median dissolved oxygen concentration (8.9 mg/L) is observed in water samples from the East Branch of the Little Calumet River (monitoring station LCR 39). Median dissolved oxygen levels are also relatively high (above 8.0 mg/L) in samples collected from Burns Ditch (monitoring station BD 1) and near the mouth of Trail Creek (TC 0.5). The lowest median DO level is observed in samples from the West Branch of the Grand Calumet River (monitoring station GCR 34).

In addition to variability among streams, differences in median DO levels are observed at different locations along a single stream. Lower median DO levels are observed in samples from the West Branch of the Grand Calumet River relative to samples from the East Branch (monitoring station GCR 37). A similar pattern is observed between the East and West Branches of the Little Calumet River, where median DO levels are lower in samples from the West Branch of the Little Calumet River compared to samples from the East Branch of this river. Apparent differences in median DO levels are also detected among water samples from the different monitoring stations along the Indiana Harbor Canal (figure 45 and appendix 7).

Box plots of specific conductance levels in water samples from the selected monitoring stations are displayed in figure 45. The highest median specific conductance levels are observed in samples from the West Branches of the Grand Calumet River and the Little Calumet River. Differences in median specific conductance levels among and within streams may relate to factors which affect the dissolved solute concentrations in surface waters. Some such factors include local variations in the abundance of soluble

Factors affecting surface-water quality

The efficient management of water resources requires knowledge of the naturally-occurring and human-induced processes that can influence the chemistry and quality of surface waters. Surface-water quality is influenced by numerous physical, chemical and biological factors which generally vary in time and with location. Describing the effects of these factors and variations in their influence is critical for developing strategies to protect water quality while permitting reasonable levels of water use (Hem, 1993).

Many of the current efforts to protect surface-water resources emphasize controlling degradation associated with industry, agriculture, municipal waste disposal, flow diversions and other *anthropogenic* activities. Pollutants and waste products from these and other sources can enter surface-water systems through inadequately treated wastewater discharges, runoff, soil erosion, atmospheric deposition, chemical spills, and combined sewer overflows. Human activities that alter the flow characteristics or physical state of a stream, such as dam building, dredging or channelization may affect both water chemistry and sediment transport. Surface-water quality can also be influenced by irrigation and ground-water pumping (Hem, 1993).

Any possible effects human activities have on water quality depends on the types and volumes of pollutants released, and the extent of dilution that occurs in the receiving surface-water body. Adverse affects from human activities can also be minimized by proper wastewater treatment, adequate solid-waste disposal, erosion control, and other pollution control practices. Municipalities, industry, and other water users are required to protect the quality of surface-water resources they utilize. In many cases, their specific obligations are defined in federal, state and local regulations. The effects of anthropogenic activities on water quality will also be modified by the hydrologic and chemical conditions of the receiving surface-water system.

Surface-water quality is also influenced by various natural factors in the environment. The natural factors that affect water quality can be considered, in general, the various physical, chemical and biological aspects of a watershed. Examples of these factors include climate, geology, soil type, vegetation and stream ecology. Natural influences on water-quality must be quantified to accurately describe variations in water quality, and to discern possible human-induced effects on water resources.

In many temperate areas, variations in water quality over time can be correlated with seasonal changes in the prevailing meteorological conditions. Both the temperature and the volume of precipitation influence weathering of rocks. Alternating wet and dry seasons may thus promote seasonal variability in weathering reactions which produce soluble minerals. This variability in weathering may result in seasonal differences in the volume and types of ions transported into surface waters by *direct runoff*, creating seasonal variations in solute chemistry.

Seasonal trends in the concentrations of certain anthropogenic chemicals are sometimes observed in the surface waters. Such trends are most commonly associated with chemicals used over wide areas of agricultural or urbanized watersheds and during certain months of the year. Such chemicals can be transported to streams by runoff after precipitation or snow-melting events. Examples of anthropogenic chemicals which could reach seasonal high levels in surface water include deicing salts for roads, nitrogen-based fertilizers, and pesticides.

Water temperature can be a particularly important parameter in water-quality studies. Many aquatic organisms can survive and function only within a particular range of water temperatures. These organisms may die, fail to reproduce, or suffer other adverse effects if the appropriate temperature range is exceeded.

minerals, differences in stream discharge, differences in the volume of base flow, and anthropogenic sources of dissolved constituents.

Box plots of hardness levels in samples from the selected monitoring stations are displayed in figure 45. Median hardness levels range from approximately 160 mg/L ($CaCO_3$ equivalent) in samples from the mouth of the Indiana Harbor Canal to 380 mg/L ($CaCO_3$ equivalent) in water samples from the West Branch of the Little Calumet River. This range of hardness values would classify the waters from the select monitoring stations as "hard" to "very hard" in the hardness classification scale (see page 166 of this report) of Durfor and Becker (1964).

Hardness can be an important factor in surface-water quality because the minimum water-quality criterion for certain metals are functions of hardness. Applicable criteria outlined in the Indiana minimum water-quality requirements (327 IAC 2-1-6) include the *acute aquatic criterion* (AAC) and the *chronic aquatic criterion* (CAC). The present AACs and CACs for cadmium, chromium(+3), copper, lead, nickel, silver and zinc are not defined as whole-number limits, but rather as exponential functions of hardness. It is thus, possible that different CACs and AACs may apply to different streams, or along different segments of the same stream, because of variations in hardness.

Chloride levels appear to be higher in the West Branch of the Grand Calumet River than in the other streams analyzed (figure 45 and appendix 7). The median chloride concentration in samples from the Grand Calumet River equals 165 mg/L. In contrast, median chloride levels do not exceed 50 mg/L in samples from the other selected monitoring stations. Chloride statistics were not calculated for the data sets from the East and West Branches of the Little Calumet River because relatively few chloride measurements were available from these stations for the period of study.

Violations of applicable standards for chloride were only observed in the samples from the West Branch of the Grand Calumet River. A total of eight samples collected over the 1983-1993 period had chloride levels above the current critical aquatic-life criterion of

The effect of most concern however, is probably the inverse relation between water temperature and dissolved oxygen (DO) levels. Most gases, including oxygen, become less soluble in water as temperature increases. It is therefore, possible to detect the lowest average DO levels of the year during summer and early fall when ambient water temperatures reach yearly high levels. Localized increases in water temperature and decreases in DO levels can also occur if effluents are discharged at much higher temperatures than water in the receiving stream.

Geologic conditions in a drainage basin can be a significant control on the solute chemistry of surface waters. The types and concentrations of dissolved ions in most waters is influenced by the chemical composition of minerals in contact with the water body. Soluble minerals in bedrock, soil or weathered geologic material may be the principal source of dissolved inorganic ions in unpolluted streams and lakes. Water quality will also be influenced by a variety of other geologic factors including the purity, solubility and crystal size of the minerals; rock texture and porosity; regional structure; and the presence or absence of fissures (Hem, 1985).

The aquatic biota, which consists of all plants, animals and microorganisms inhabiting a stream or lake, can be a significant influence on the chemistry of surface waters. Biological influences on water quality can result from the metabolic processes performed by organisms to maintain life functions and reproduction. These metabolic processes often influence the rates of chemical reactions, An example of reaction influenced by organisms in the aquatic environment is the oxidation of organic matter. Certain microorganisms obtain metabolic energy from organic matter through cellular reactions involving oxygen. This organism-mediated process can promote rapid decomposition of organic matter in the aquatic environment, and may have significant effects on the dissolved oxygen levels of surface waters.

Aquatic organisms also remove and redistribute certain constituents from the aquatic environment. Some constituents removed by organisms are essential nutrients required to maintain metabolic functions and physical growth. Examples of such nutrients include iron, phosphorous and nitrogen. Other constituents, such as calcium and silica, are extracted from the aquatic environment by certain organism for the development of shells and skeletons. Absorption by aquatic organisms may be a significant influence, and possibly the controlling factor, on the concentration of certain ions in unpolluted waters (Hem, 1985).

Photosynthesis by algae and aquatic plants often has discernible influence on the chemistry of surface waters. During photosynthesis by aquatic plants, dissolved carbon dioxide is removed from the water column. The removal of this gas can result in a noticeable increase in the pH of water in a lake or stream. Oxygen is a by-product of the photosynthesis process, and increases in dissolved oxygen levels may result from photosynthetic activity. Because photosynthesis requires sunlight, plants can only conduct this process during daylight hours. In some streams, this daily variation in photosynthetic activity results in discernible twenty-four hour cycles in pH and dissolved oxygen concentrations (Hem, 1985).

The types and numbers of aquatic plants and animals must also be considered in water-quality assessments because the mere presence of certain organisms can seriously limit the utility of a lake or stream. The presence of disease-causing bacteria, parasites or viruses can make a surface-water body unsafe for swimming, fishing, or use as a water supply. Algae and aquatic plants are normally vital parts of the aquatic ecosystem; however, excessive growth of these organisms due to *eutrophication* can cause serious water-quality problems. Severe problems can also result when non-indigenous species of plants and animals are introduced into a surface-water system. A discussion of some non-indigenous species in Lake Michigan is presented in the box entitled **Recently introduced aquatic species in the Great Lakes**.

230 mg/L. Furthermore, the chloride levels in three of the samples in violation of the CAC were high enough to also exceed the SMCL for chloride (250 mg/L).

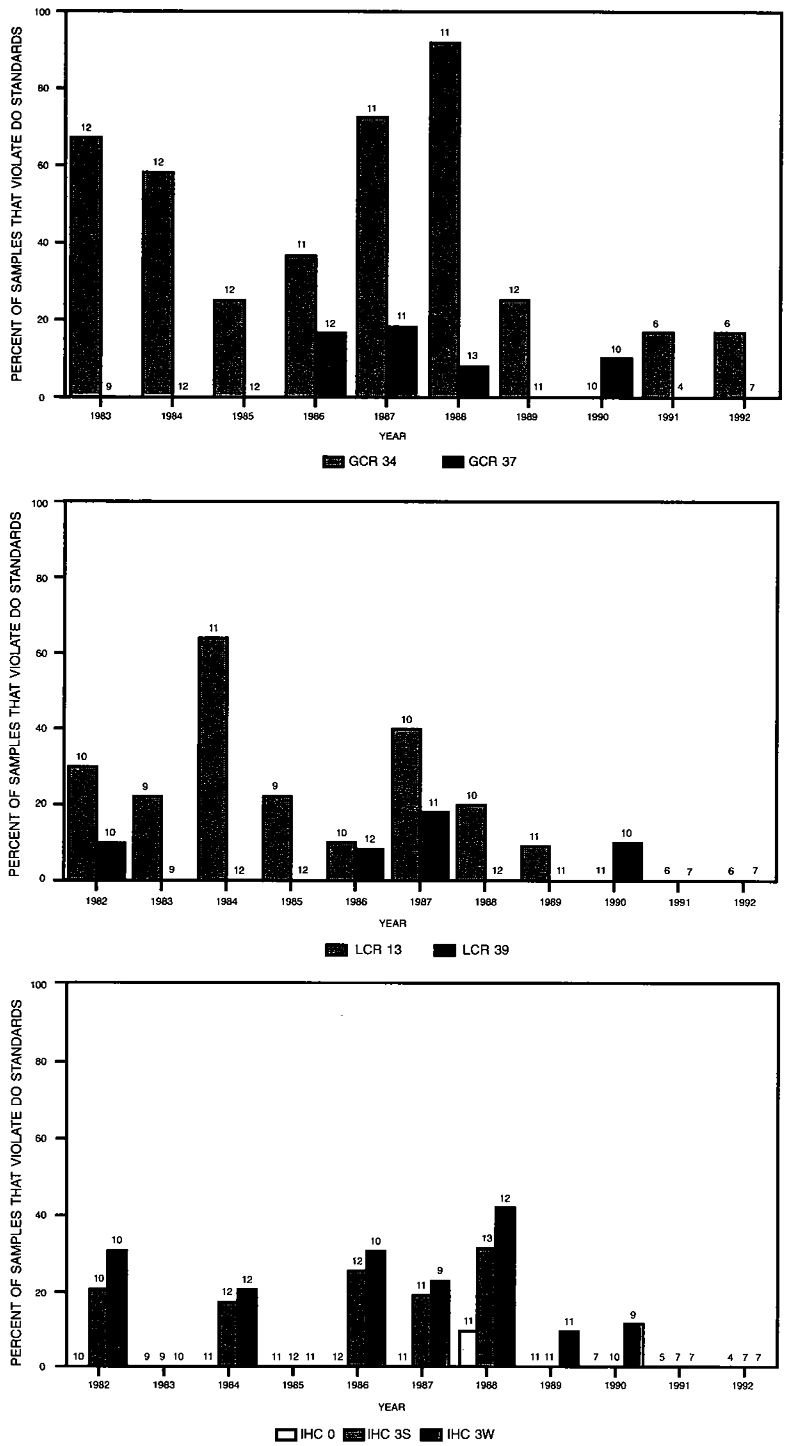
The box plots for total iron in samples from the selected monitoring are displayed in figure 45. Median total iron levels are the highest in samples from the East Branch of the Grand Calumet River and the South Branch of the Indiana Harbor Canal. Most samples from the selected streams contain iron levels that exceed the 0.3 mg/L secondary maximum contaminant level (SMCL). Specifically, iron concentrations above the SMCL are observed in 75 to almost 100 percent of samples, depending on the monitoring station under consideration.

Additional aspects of stream quality

Dissolved oxygen

Dissolved oxygen (DO) is the term used to express the quantity of oxygen gas dissolved in a unit volume of water. In most surface-water systems, the principal source of dissolved oxygen is the diffusion of atmospheric oxygen across the water surface. However, the equilibrium concentration of dissolved oxygen is also influenced by temperature, atmospheric pressure, photosynthesis by aquatic plants, and the concentration of dissolved solutes (Hem, 1985). Fish and other gill-breathing animals can only utilize oxygen dissolved in water for their respiration, thus dissolved oxygen is generally considered a fundamental surface-water quality indicator.

Dissolved oxygen concentrations can be affected by the levels of oxidizable organic matter in a lake or stream. In the aquatic environment the decay of organic matter is often facilitated by oxygen-consuming bacteria. These bacteria degrade the organic matter through oxidizing reactions in order to obtain energy for metabolic functions. In most surface-water systems, the principal source of oxygen for this process will be the dissolved oxygen in the water column. Thus, if the rate of oxygen consumption by bacteria exceeds the rate of oxygen replenishment, the DO level of the



* see figure 41 and table 17 for locations.
Minimum DO limited to 6.0 mg/L for LCR 39, 4.0 mg/L for other monitoring stations.
(number of samples for each year displayed above bars)

Figure 46. Percent of monthly samples at selected stations which violate dissolved oxygen requirements

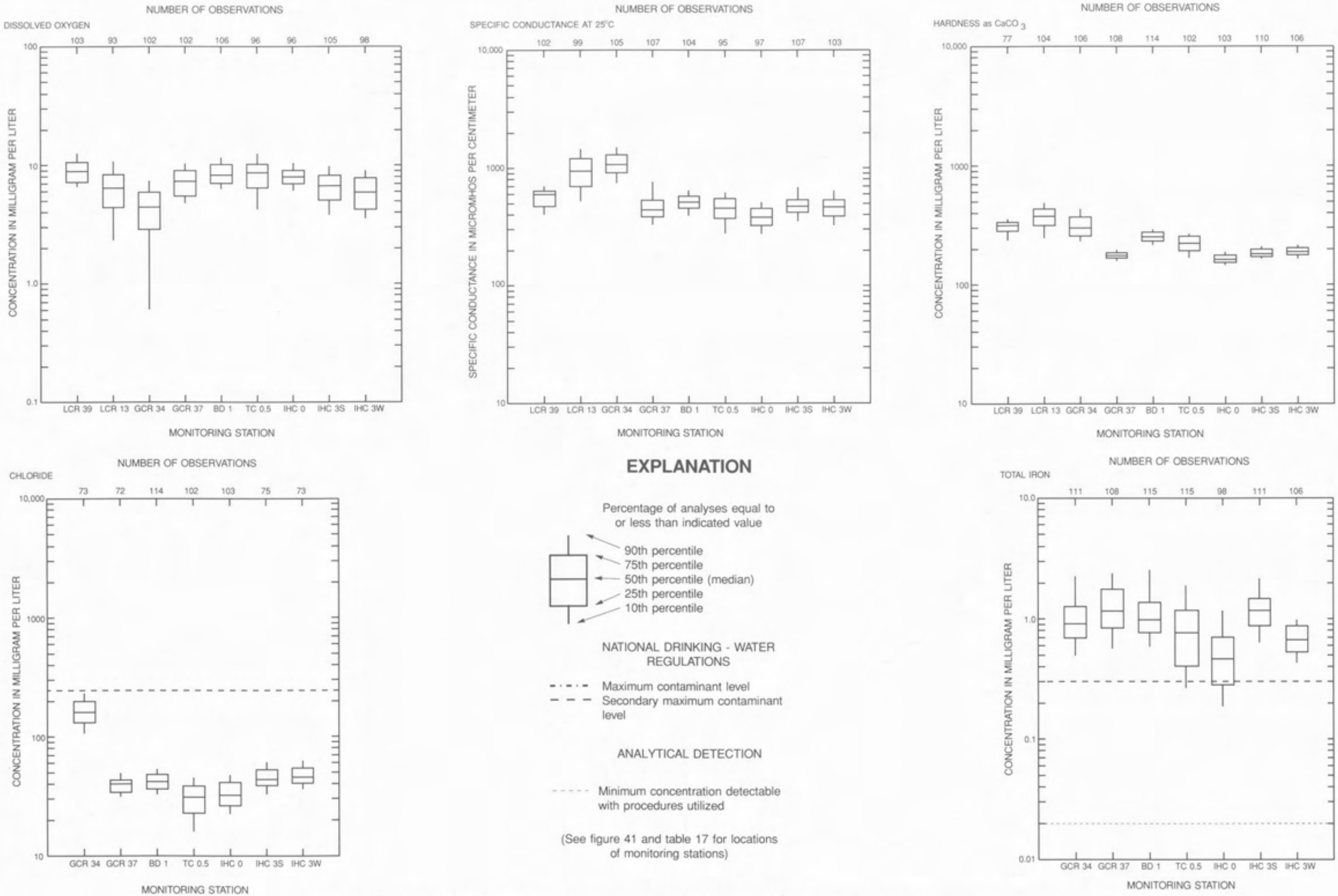


Figure 45. Statistical summary of selected water-quality constituents for selected stream monitoring stations.

water body will begin to decrease.

Large volumes of dissolved and suspended organics are often required to cause significant decreases in surface water DO levels. When high levels of oxidizable organic matter are present in a lake or stream, enough dissolved oxygen may be consumed during the decay process that a stream or lake may become uninhabitable for many aquatic species. In extreme cases, it is possible for the total biochemical oxygen demand to exceed the total volume of dissolved oxygen in a stream or lake. In such a situation, anaerobic (no available oxygen) conditions may develop. Very high levels of organic matter may develop in surface waters as a result of eutrophication, non-point source discharges, combined sewer overflows, and discharge of undertreated wastewater.

Violations of DO criteria for aquatic-life uses (table 16) has been a chronic water-quality problem in the West Branch of the Grand Calumet River. It is reported in the 1990 IDEM 305(b) report that the minimum dissolved oxygen standard was violated in 71 percent of all samples collected from the West Branch (monitoring station GCR 34) during the 1988-1989 period. During the period of time from 1991 through 1993, dissolved oxygen levels below 4 mg/L are observed in approximately nine percent of all samples from the West Branch of the Grand Calumet River and nearly five percent of all samples from the East Branch.

Over the ten-year period from 1982 to 1992, violations of the dissolved-oxygen criteria were observed in a greater percentage of samples from the West Branch of the Grand Calumet River, than in samples from the East Branch (figure 46).

Oxygen-consuming organic matter in the Grand Calumet River probably originates from numerous sources. Point-source discharges from industrial facilities and municipal water-treatment plants have long been implicated as sources of oxidizable organic materials in the Grand Calumet River (U.S. Department of Health, Education, and Welfare, 1965; Indiana Department of Environmental Management, [1988b]). Non-point sources may also contribute significant amounts of organic matter and other pollutants to the Grand Calumet River. Possible non-point sources along the Grand Calumet River include urban areas, industrial lands contiguous with the River, and contaminated ground-water (Indiana Department of Environmental Management, [1988b]).

Daily fluctuations in DO levels in the Grand Calumet River were estimated by Crawford and Wangsness (1987). Daily variations in the DO levels of water samples from the East Branch of the Grand Calumet River ranged from 1 to 2 mg/L. Variations in DO levels in the East Branch appeared to be random and unrelated to photosynthetic activity. Fluctuations of DO levels in samples from the West Branch ranged from 0.5 mg/L in samples collected in Cook County (Illinois) to 3 mg/L in samples collected near its confluence with the Indiana Harbor Canal. Large fluctuations in DO levels in samples collected near the Indiana Harbor Canal were attributed to flow reversals and mixing of waters between the West Branch and the Canal (Crawford and Wangsness, 1987).

Low dissolved oxygen levels have been a significant water-quality problem in sections of the Indiana Harbor Canal (figure 46). Over the ten-year period from 1982 to 1992, the highest percentage of DO criteria violations are observed in the Lake George Branch of the Canal (monitoring station IHC 3W). No violations of DO criteria have been observed in IDEM monthly samples collected during 1991 to 1993 at any of the monitoring stations on the Canal. However, an assessment of the fish community in the Indiana Harbor Canal/Grand Calumet River system indicates that low dissolved oxygen levels may still occur (Indiana Department of Environmental Management [1994?]).

During the 1982 to 1992 period, DO criteria violations were recorded in fewer IDEM monthly samples from the East Branch of the Little Calumet River (monitoring station LCR 39) than in samples from the West Branch (figure 46). Historically, possible sources of oxygen-consuming materials in the Little Calumet River include combined sewer overflows, stormwater discharges, and the discharge of inadequately treated wastewaters into the river or its tributaries (U. S. Department of Health, Education and Welfare, 1965). Although some sewage-related problems still exist in the Little Calumet River (Indiana Department of Environmental Management, [1994?]), no violations of minimum DO criteria were recorded in water samples from the Little Calumet River during 1991 and 1992.

Trail Creek in northern LaPorte County is a designated salmonid stream and is therefore, regulated by the aquatic-life standards specifically established for cold-water fisheries. Violations of DO standards for salmonid streams however, have been recorded in this stream. Low dissolved-oxygen levels are one factor implicated in four fish kills that occurred in Trail Creek during 1986 and 1987 (Indiana Department of Environmental Management, [1988a]). Dissolved-oxygen levels below the minimum criteria (6.0 mg/L for salmonid streams) were measured in 40 percent of all samples collected from Trail Creek during the period from 1986 to 1987. Violations of the DO criteria for cold-water fisheries are also observed in 11 percent of all IDEM monthly samples collected during the 1988-1989 period and 18 percent of samples collected during 1990 and 1991. No violations of DO criteria were observed for the 1992-1993 period (Indiana Department of Environmental Management, [1990]; [1994?]).

In order to decrease the volume of oxidizable organic matter entering Trail Creek, the Michigan City Sanitary District (MCSD) has recently plugged many CSO outfalls and constructed a stormwater detention basin. The total capacity of the Michigan City wastewater treatment plant has been increased to handle larger volumes of wastewater. The treatment plant also supersaturates its discharge effluent to 13 mg/L DO during the summer months (Indiana Department of Environmental Management, [1994?]; Northwestern Indiana Regional Planning Commission, 1993).

Several communities in the Lake Michigan Region began or completed upgrades at local treatment plants during the 1980s. Specific changes were made to individual treatment plants depending on their requirements for improving operations and effluent quality. Although some improvements in stream quality have been associated with these upgrades, many of the Region streams do not support designated uses due to DO levels (table 15).

Toxic compounds

In the past, a variety of potentially-toxic substances have been detected in the waters of the Grand Calumet River and the Indiana Harbor Canal. Chemicals such as mercury, lead, copper, cyanide and PCBs have been detected at levels considered to be toxic to aquatic organisms. Violations of applicable standards for some of these substances are still intermittently detected in the Grand Calumet River and the Indiana Harbor Canal. However, the overall levels of many toxic substances in the River and the Canal are generally lower today than during the past (Indiana Department of Environmental Management, 1991).

In July of 1988, the Indiana Department of Environmental Management conducted a water-quality survey to quantify the presence and distribution of toxic substances in the Grand Calumet River and Indiana Harbor Canal. Water samples for the study were collected at 11 different locations in the water-column and from 36 wastewater outfalls along the River and the Canal. The locations of the sampling points is presented in the IDEM 305(b) report for 1988-1989. Collected samples were analyzed for a variety of potentially-toxic constituents, including trace metals, cyanide, and a variety of synthetic organic compounds.

Various trace metals were detected in both effluent and ambient water samples collected during the 1988 IDEM study. Detectable levels of antimony, nickel and zinc were found in some samples, but no violations of minimum water-quality criteria for these metals were observed. Verifying the compliance status of other trace metals, however, was complicated by limited laboratory accuracy. The detection limits for both copper and arsenic exceeded the minimum criteria for these substances throughout the Grand Calumet River and Indiana Harbor Canal. The detection limit for lead also exceeded minimum criteria for this metal except in the harder waters of the West Branch of the Grand Calumet River (see page 116 of this report). It is therefore, possible that undetected violations of the standards for these metals occurred in some samples.

Some definite violations of minimum water-quality standards for copper, lead and arsenic were observed in the 1988 IDEM survey. The violations occurred in samples where the concentrations of these trace metals exceeded the laboratory detection limit, and were all observed in samples from the West Branch of the Grand Calumet River (Indiana Department of Environmental Management, [1990]).

The samples from the 1988 IDEM study of the Grand Calumet and Indiana Harbor Canal were screened for a variety of synthetic organic compounds. Analyses were conducted for 145 different synthetic organic compounds, but only 35 of the compounds were present at detectable concentrations in effluent or stream-water samples. The only organic compound in violation of the minimum water-quality standards was 1,2-dichloroethane. This violation was observed in a water-column sample from the West Branch of the Grand Calumet River.

The IDEM noted that only 11 of the 35 organic compounds detected in the 1988 stream-water samples were also detected in effluent samples. This may indicate that non-point sources are contributing synthetic organic compounds to the Grand Calumet River and Indiana Harbor Canal (Indiana Department of Environmental Management, [1990]).

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.

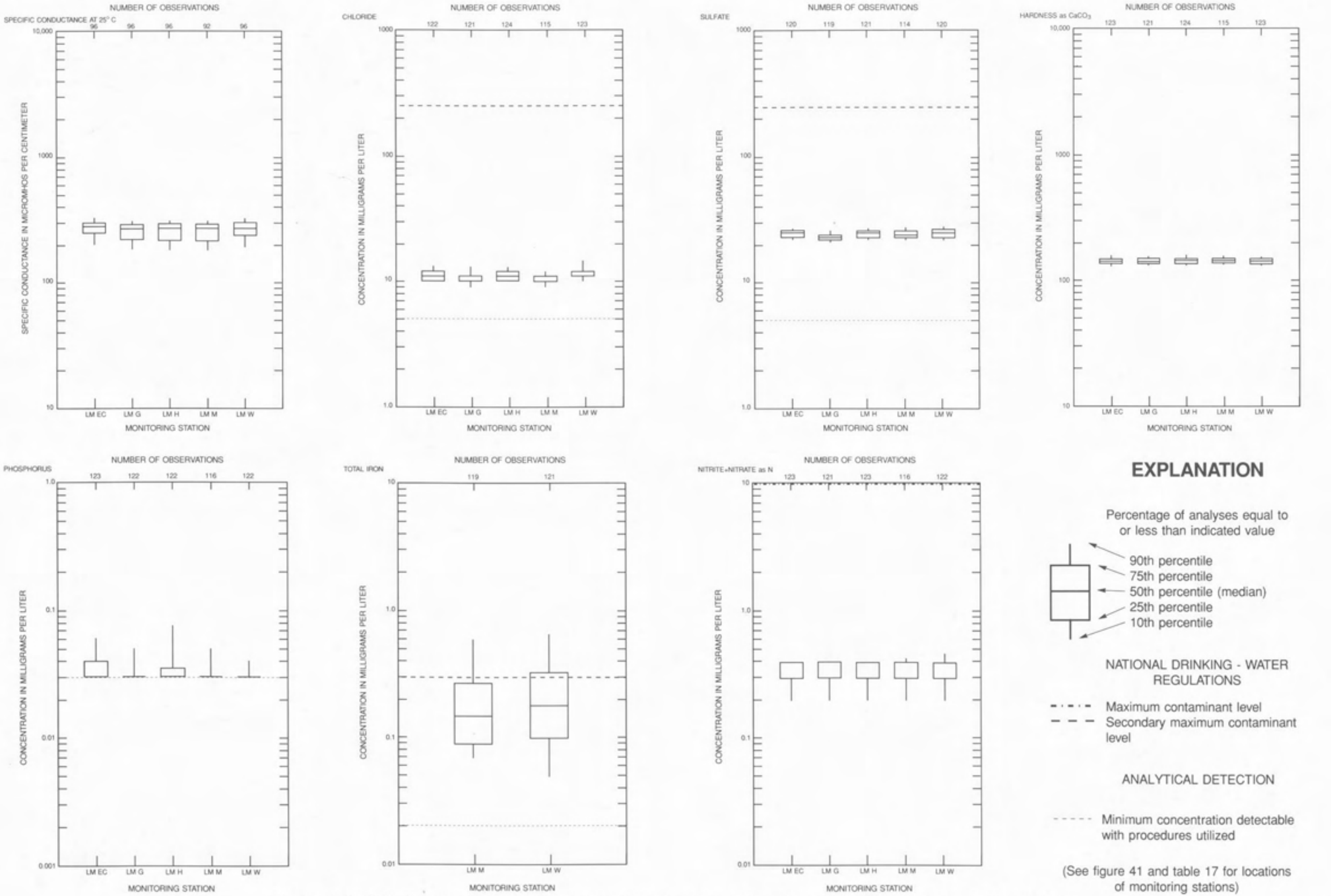


Figure 47. Statistical summary of selected water-quality constituents for selected Lake Michigan monitoring stations.

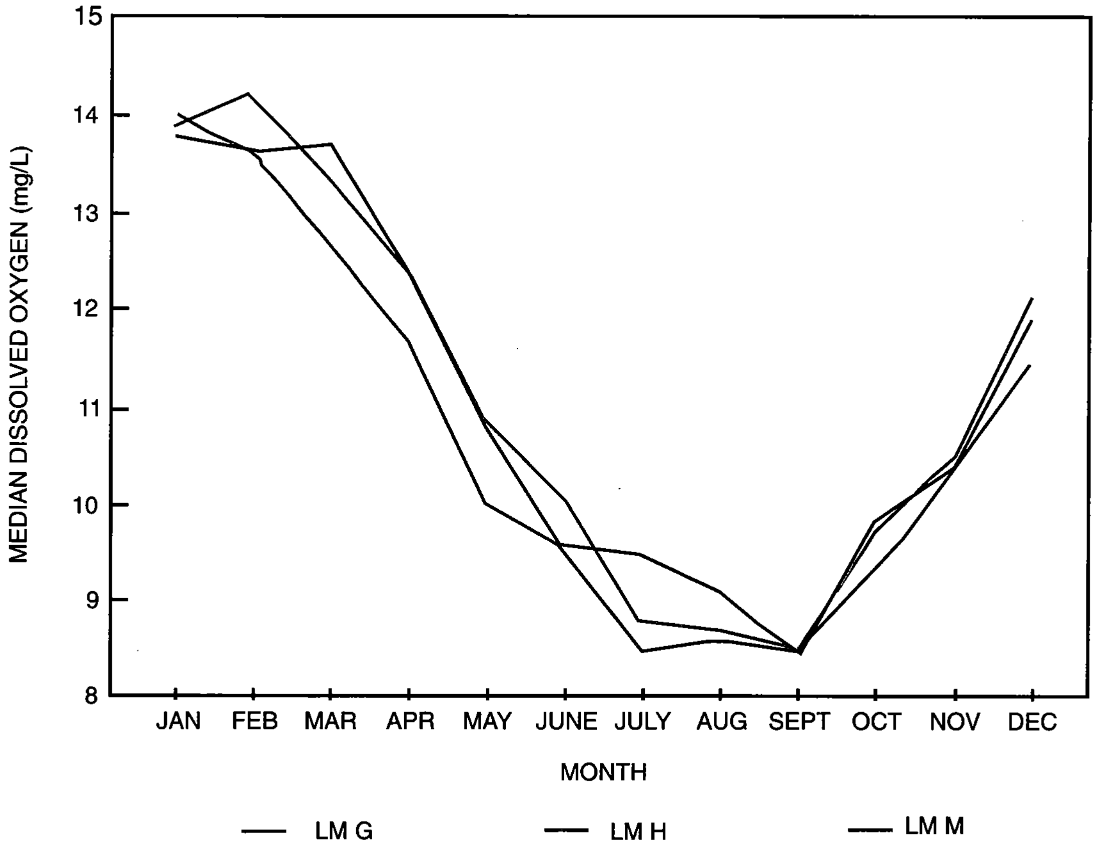


Figure 48. Median monthly dissolved oxygen values for selected Lake Michigan monitoring stations

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.

GROUND-WATER HYDROLOGY

Ground-water supplies are obtained from *aquifers*, or subsurface formations of rock saturated with water. The hydrologic characteristics of aquifers and natural chemistry of ground water determine the availability and suitability of regional ground-water resources for specific uses.

GROUND-WATER RESOURCES

Ground water is the part of precipitation which enters the ground and continues to move downward through openings in soil and bedrock until it reaches the water table (figure 49). The water table is the elevation below which all openings in the rock or soil are filled with water. Water entering the saturated zone is called *recharge*.

In a general way, the configuration of the water table approximates the overlying topography (figure 49). At a depression where the land surface intersects the water table, water is discharged from the ground-water system to become part of the surface-water system.

The interaction between ground water and surface water can moderate seasonal water-level fluctuations in both of these systems. During dry periods, ground-water discharge can help maintain water levels in streams. Conversely, surface water can recharge ground water through soils saturated by flooding or through streambeds during periods when the water table falls below the elevation of the water surface in a stream.

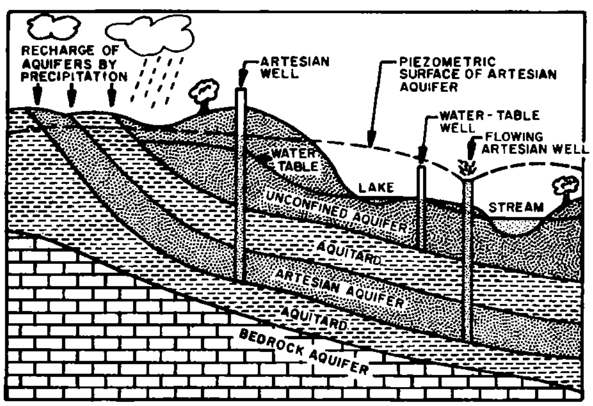


Figure 49. Aquifer types and ground-water movement

Porosity and *permeability* are the most important hydraulic properties affecting ground-water availability. Porosity is the amount of open space in rock and soil. Permeability is the degree to which pores are connected and determines how quickly water moves through the material.

In bedrock, pores occur as fractures, solution openings, and openings between grains composing the rock. In unconsolidated deposits, all of the pores are intergranular, but fine-grained deposits such as clays or silts may have secondary porosity in the form of fractures.

The size and sorting of material determines the amount and interconnection of intergranular pores. Sand and gravel deposits have a high proportion of pore space and high permeability, whereas fine-grained or clay-rich deposits have a greater proportion of pores, but a lower degree of permeability.

Aquifers have high porosity and permeability so that they may absorb, store and transmit water in usable quantities. Materials with low permeability, called *aquitards*, restrict ground-water movement. An aquitard overlying an aquifer may limit the recharge to the aquifer but may also protect an aquifer from surface contamination.

Where an aquitard overlies an aquifer, the water in the aquifer may be under *hydrostatic pressure*. The aquifer is said to be confined or artesian because the aquitard prevents or restricts upward movement of water from the aquifer. In an artesian well, the water level will rise to an elevation higher than the elevation of the top of the aquifer (figure 49). In a flowing artesian well, the water level in the well rises above the land surface. The level of water in wells in a confined aquifer is known as the potentiometric or *piezometric surface* (figure 49).

As a well discharges water from an aquifer, the water level is lowered around the well. This depression in the water level, called *drawdown*, causes ground water around the well to flow toward the well to compensate for water pumped from the aquifer. A greater pumping rate causes a greater depression in the water level and induces recharge to the aquifer; however, the recharge rate may be limited by the permeability of the aquifer and surrounding formations.

Ground-water levels

Ground-water levels fluctuate in response to rainfall, evapotranspiration, barometric pressure, and ground water recharge, discharge and pumpage. However, the response time for the ground-water level fluctuations is controlled predominantly by the local and regional geology.

To study natural or man-induced stresses in an aquifer, an observation well is completed in the aquifer of interest and the *static water level* is monitored periodically. The static water level in an observation well represents the local *hydraulic head* in the aquifer, and it may not be an indication of the hydraulic head in more shallow or deeper aquifers. Significant fluctuations in the static water level in the observation well may be an indication of natural or man-induced stresses in the aquifer.

The observation well monitoring program in the Lake Michigan Region was started in 1956 by the U.S. Geological Survey (USGS) in cooperation with the Indiana Department of Natural Resources (IDNR). By 1957, the observation well network consisted of six wells, five in Lake County and one in Porter County (table 21). At the present, the network includes six discontinued wells and one active observation well, Lake 13, which is located in northwestern Lake County (figure 50). Records on all of the active and discontinued observation wells in Indiana are kept on file at the Division of Water, IDNR. Observation wells in the Lake Michigan Region are categorized into three groups: 1) unaffected by pumping, 2) affected by pumping, and 3) special purpose. The seven observation wells in the Lake Michigan Region include two wells classified as unaffected, two wells classified as affected, and three wells classified as special purpose (table 21).

The two observation wells that are classified as unaffected by pumping are Porter 8 and Lake 13. Because the records of water levels in both wells are discontinuous, the hydrographs of the two wells, as well as pertinent hydrologic data such as river stage and precipitation are presented for **selected** water years only (figures 51 and 52). Hydrologic data are often presented in water years (October to September) instead of calender years (January to December) because the annual peak in river stage, which commonly occurs from December to June, can be interpreted as two annual peaks in two calender years if a major precipitation event occurs from late December to early January.

The hydrograph of Porter 8 for the 1960 water year (Oct. 1959 to Sep. 1960) shows static water level fluctuations during a period of average rainfall (figure 51). The static water levels in Porter 8, which corresponded to the local hydraulic head in a *confined* sand and gravel aquifer in northern Porter County, were monitored from 1956 to 1974 (table 21).

Observation well Lake 13, which has been active since 1986, has an automatic water-level recorder that monitors the local static water levels in a shallow *unconfined* aquifer. In the vicinity of the well, annual rainfall was above and below normal for the last few years. Rainfall was above average during the 1987, 1989 and 1990 water years, but was considerably less than average during the 1988 water year. For the 1990 water year (Oct. 1989 to Sep. 1990), static water level fluctuations in Lake 13 showed a correlative response to daily rainfall (figure 52). This type of response is expected and common in shallow *water-table* aquifers.

The hydrographs of both Porter 8 (figure 51) and Lake 13 (figure 52) indicate that the temporal trends in the ground-water levels are normal. Ground-water levels in the aquifers are highest during the wet season of spring, and decline during summer and fall because of increased evapotranspiration and reduced recharge. Fluctuations in the ground-water levels in both Porter 8 and Lake 13 average 3 to 4 feet annually. The fluctuations are the result of natural stresses, and thus may indicate trends in the natural rates of ground-water recharge to and discharge from the aquifers.

Observation wells Lake 4 and Lake 5, active from 1956 to 1971, and 1956 to 1961, respectively, were used to monitor the static water levels in a confined sand and gravel aquifer in northern Lake County. The static water levels in both wells were affected by nearby pumping (table 21) and the water level fluctuations could not clearly show any indication of natural recharge to and discharge from the aquifer.

Special-purpose observation wells in the Lake Michigan Region include Lake 8, Lake 9 and Lake 10. Data collected from these wells were not available, and therefore could not be analyzed.

Piezometric Surface

Water exists under different pressures in unconfined and confined aquifers. Water in unconfined aquifers exists under atmospheric pressure, and wells that are

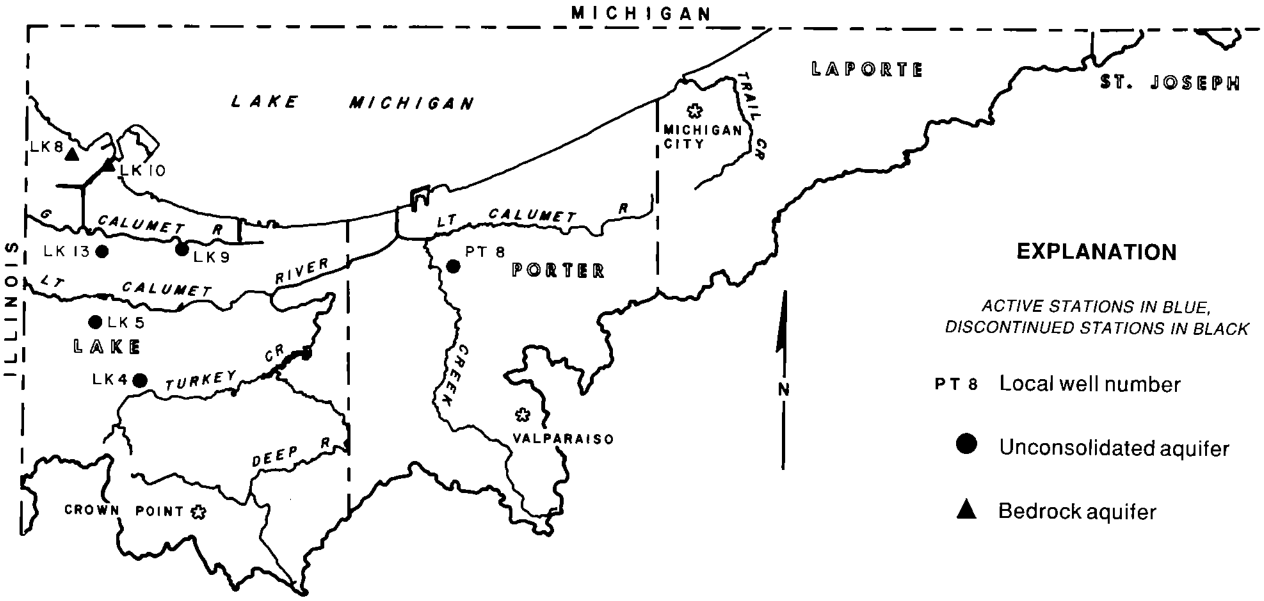


Figure 50. Location of observation wells

Table 21. Summary of active and discontinued observation wells

Well number: U.S. Geological Survey county code and well number. Well locations are shown in figure 50.
Period of record: Refers to calender year, whether or not data encompasses entire year.
Aquifer system: Cal, Calumet; LP, Lacustrine Plain; COS, Cambrian-Ordovician-Silurian carbonates and sandstones; Sil, Silurian;
Aquifer type: LS, Limestone; DOL, Dolomite; SS, Sandstone; SG, Sand and Gravel; S, Sand.
Aquifer classification: A, affected by pumpage; UA, unaffected by pumping; SP, special purpose.

County	Well no.	Period of record	Aquifer System	Aquifer Type	Aquifer Condition	Well Diameter (in.)	Well Depth (ft.)	Aquifer Class
Lake	LK13	1986-	Cal	S	Unconfined	6	23	UA
	*LK4	1956-1971	LP	SG	Confined	12	82	A
	*LK5	1956-1961	LP	SG	Confined	10	39	A
	*LK8	1957-1958	COS	LS/SS	Confined	8	1228	SP
	*LK9	1957-1967	Cal	SG	Unconfined	600	30	SP
	*LK10	1957-1968	Sil	LS/DOL	Confined	8	550	SP
Porter	* PT8	1956-1974	LP	SG	Confined	10	80	UA

* Discontinued wells

completed in these aquifers have water levels that correspond to the local water table. In contrast, water in confined aquifers exists under hydrostatic pressure which exceeds atmospheric pressure. Wells completed in confined aquifers have water levels that rise above the water-bearing formation until the local hydrostatic pressure in the well is equal to the atmospheric pressure (figure 49).

The composite piezometric surface map of the Lake Michigan Region (plate 1) shows elevations of the water table in unconfined aquifers and elevations of the static water level in wells that penetrate confined aquifers. However, depths to the piezometric surface **do not** represent appropriate depths for water wells. Instead, wells must be completed in the water-yielding formation, with depth into the aquifer based primarily

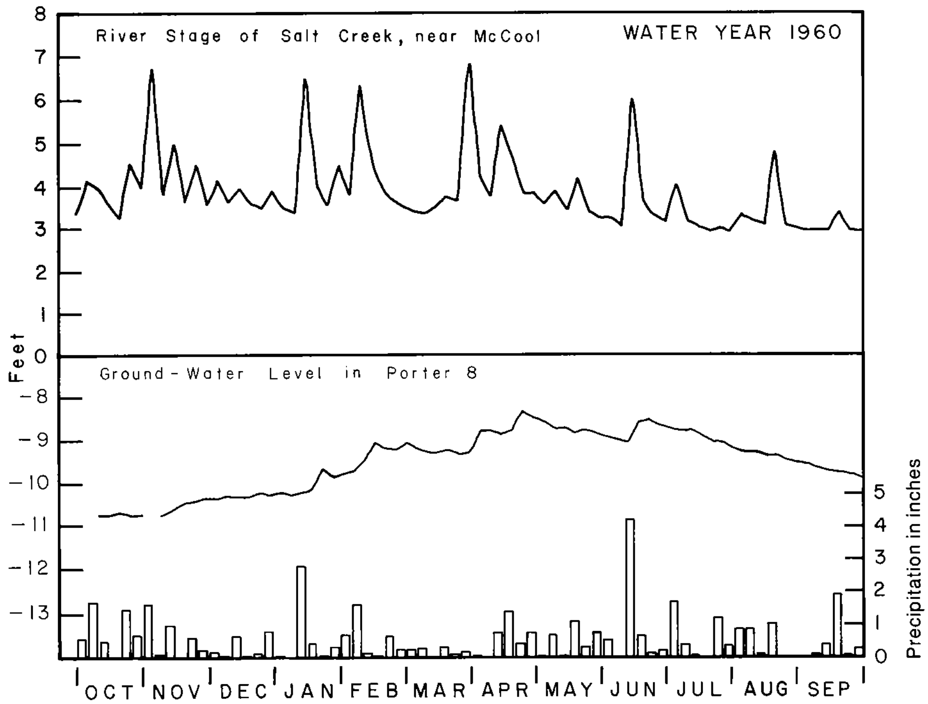


Figure 51. Comparison of river stage, precipitation, and water-level fluctuations in a confined aquifer

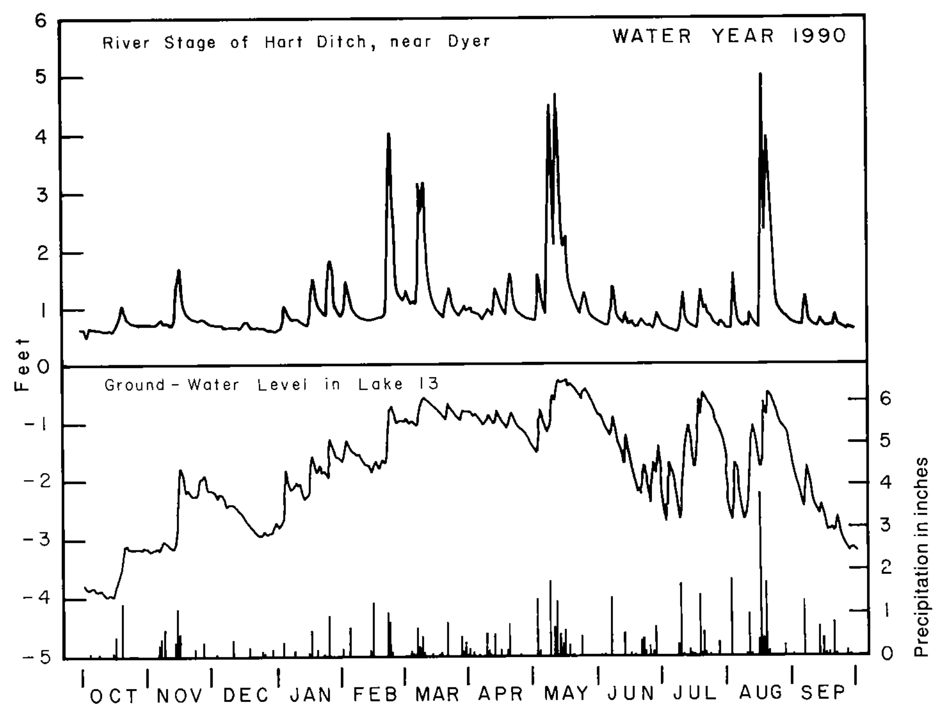


Figure 52. Comparison of river stage, precipitation, and water-level fluctuations in an unconfined aquifer

on local geologic conditions, such as thickness and lateral extent of the aquifer.

The piezometric surface map of the Lake Michigan Region (plate 1) can be used to indicate probable directions of regional ground-water flow, areas of ground-water recharge and discharge, and preferential paths for contaminant migration in regions that are dominated by horizontal ground-water flow. In natural, shallow ground-water flow systems, the piezometric surface is highest in elevation along drainage divides and lowest in elevation along *effluent streams.* Probable ground-water flow paths are perpendicular to the piezometric contour lines of decreasing values. However, heterogeneity of the deposits can affect local ground-water flow directions.

The piezometric surface in the Lake Michigan Region generally reflects the overlying topography throughout most of the region. In the eastern part of the basin in northern Porter and LaPorte Counties, the piezometric surface ranges in elevation from about 625 to 675 feet (190 to 206 meters) above m.s.l. (mean sea level) in the Lacustrine Plain *Aquifer system* and from about 675 to 775 feet (206 to 236 meters) above m.s.l. in the Valparaiso Moraine Aquifer system (plate 1).

Flowing wells (figure 49) are present in some parts of Porter and LaPorte County where the piezometric surface of the Valparaiso Moraine and the Lacustrine Plain Aquifer systems is above the land surface. The local hydrostatic pressures in these aquifer systems are generated by the high *hydraulic heads* that are present along the crest of the Valparaiso Moraine in the eastern and central parts of the Lake Michigan Region.

Hydraulic heads in the western part of the Valparaiso Moraine are not as high as in the eastern and central parts because the moraine decreases in elevation toward the west. In northern Lake County the piezometric surface ranges in elevation from about 600 to 625 feet (183 to 190 meters) above m.s.l. in the Lacustrine Plain Aquifer system and from about 625 to 675 feet (190 to 206 meters) above m.s.l. in the Valparaiso Moraine Aquifer system (plate 1).

Water-levels in most of the unconfined Calumet Aquifer system range in elevation from approximately 580 feet (177 meters) above m.s.l. at the shores of Lake Michigan to just over 600 feet (183 meters) above m.s.l. along the southern boundary of the aquifer system (plate 1). The surficial sands of the Calumet Aquifer system permit discharge of ground water from the aquifer to Lake Michigan, and the Little Calumet and Grand Calumet Rivers.

AQUIFER SYSTEMS

The ground water resources of the Lake Michigan Region are mapped and described as regional aquifer systems. Lack of data and complexity of the deposits preclude detailed aquifer mapping.

The unconsolidated and bedrock aquifer systems of the Lake Michigan Region form a single but complex hydrologic system. Three major and three minor unconsolidated aquifer systems are defined according to the hydrologic characteristics and hydrogeologic conditions of the deposits, and two bedrock aquifer systems are defined on the basis of hydrologic and lithologic characteristics. Overall, ground water supplies in the Lake Michigan Region are obtained mainly from unconsolidated aquifers, although bedrock aquifers are utilized as an important source of water in parts of Lake County.

Unconsolidated aquifer systems

The Valparaiso Moraine, Lacustrine Plain and Calumet Aquifer systems are recognized as the major unconsolidated aquifer systems in the Lake Michigan Region. Small parts of the Valparaiso *Outwash Apron*, Kankakee, and the St. Joseph Aquifer systems extend into the southern and eastern areas of the Lake Michigan Region (plate 2).

Sediments that comprise these aquifer systems were deposited in complex environments associated with the Lake Michigan lobe and ancestral Lake Michigan. Boundaries of the unconsolidated aquifer systems are gradational, and individual aquifers may extend across aquifer systems boundaries.

Unconsolidated aquifers in the Lake Michigan Region are utilized primarily in the interior portions of Porter and LaPorte Counties, and in north-central and east-central Lake County. Highly-productive zones within the unconsolidated aquifer systems are encountered where thick, coarse-grained deposits occur (figure 53).

Valparaiso Moraine Aquifer System

The Valparaiso Moraine Aquifer system consists of a heterogeneous layer of outwash sand and gravel with intermixed clay and silt lenses. The aquifer system, which lies along the central parts of Lake, LaPorte and

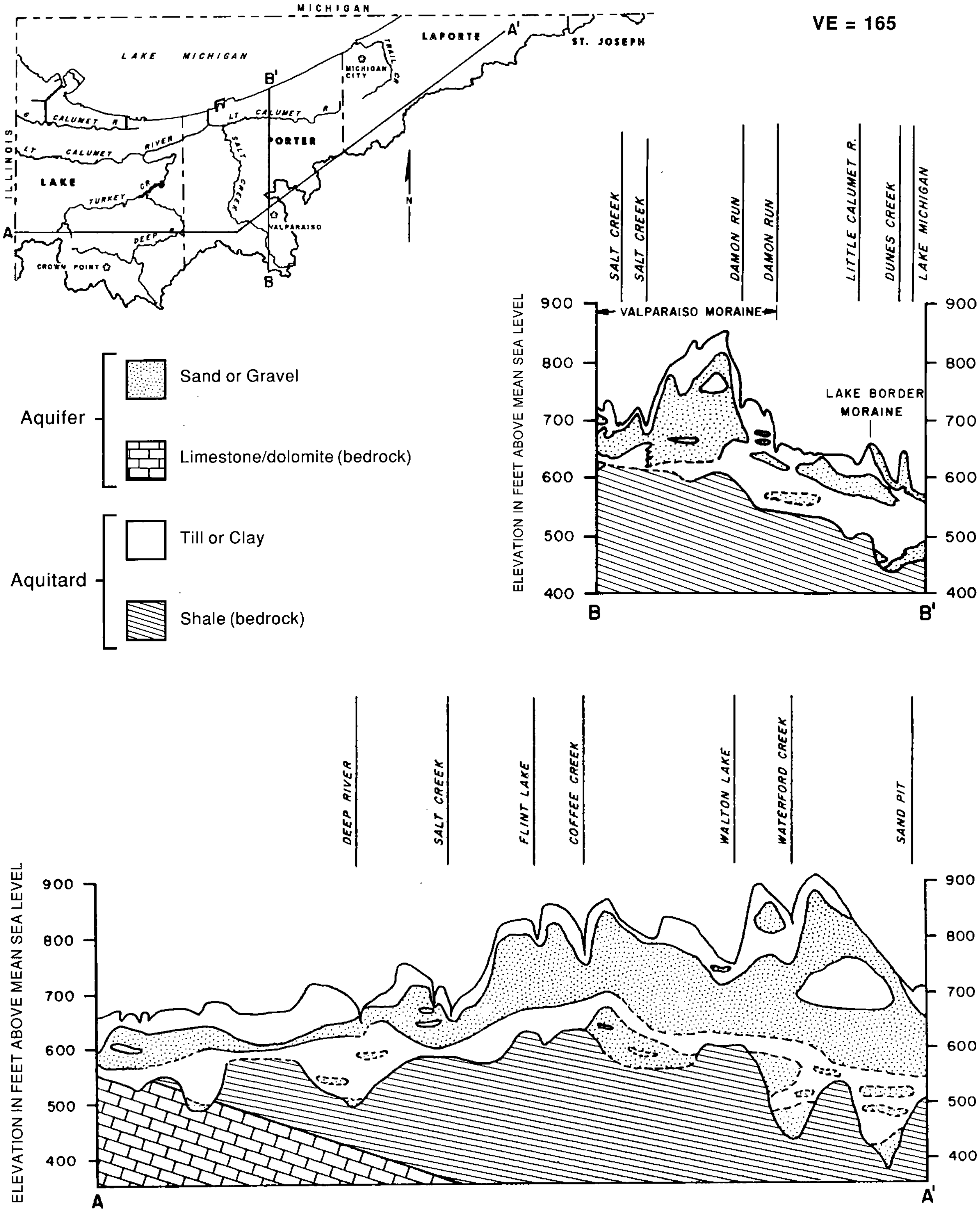


Figure 53. Generalized cross sections of unconsolidated aquifer systems

Porter Counties, is overlain by a till that is present as surficial ground and terminal moraine. The aquifer system was previously defined as the confined part of Unit 3 of the unconsolidated deposits of Lake, LaPorte and Porter Counties (Rosenshein and Hunn 1968a; 1968b). However, the aquifer system is unconfined in small isolated areas in Porter County where surficial tills are absent.

In the Lake Michigan Region, the upper surface of the Valparaiso Moraine Aquifer system lies about 10 to 100 feet (3 to 30 meters) beneath the surface of the Valparaiso Moraine. Elevations of the top of the aquifer system generally range from 638 to 700 feet (194 to 213 meters) above m.s.l. in Lake County and 675 to 740 feet (206 to 226 meters) above m.s.l. in LaPorte and Porter Counties.

The Valparaiso Moraine Aquifer system typically ranges in thickness from about 10 to 130 feet (3 to 40 meters). However, the geometry and extent of the aquifer system varies from east to west along the crest of the morainal complex (figure 53). In most of Porter County, the outwash sand body is laterally extensive, and exceeds 100 feet (30 meters) in thickness in the north-central part of the county. However, toward the western part of the Lake Michigan Region, the Valparaiso Moraine Aquifer system becomes thinner and less permeable. In some parts of western Lake County, the aquifer system is less than 10 feet (3 meters) thick or absent.

Sand-and gravel-filled outwash channels of limited saturated thickness are present in Lake and western Porter Counties at elevations ranging from 670 to 775 feet (204 to 236 meters) above m.s.l. These coarse-grained but poorly-sorted outwash channel deposits have an average thickness of about 26 feet (8 meters) and directly overlie the major aquifer body. However, the channel deposits may be locally separated from the major aquifer by a 10- to 20-foot (3 to 6 meter) thick clay.

In parts of the Valparaiso Moraine Aquifer system, artesian conditions exist because the overlying till behaves as an aquitard (figure 53). Water levels in the artesian wells that are completed in the aquifer system seldom rise to the surface, except in parts of LaPorte and Porter Counties where flowing artesian wells are found. However, despite the artesian conditions, static water levels in most of the Valparaiso Moraine Aquifer system are relatively deep, generally ranging from 25 to 80 feet (8 to 24 meters) below the morainal surface.

Production from wells that are completed in the main aquifer body are commonly more than adequate for domestic use. Yields from 2- and 4-inch domestic wells typically range from 10 to 25 gpm, although yields may vary from 5 to 60 gpm (table 22). In general, high capacity wells can produce as much as 800 gpm which is adequate for some municipal supplies. However, higher yields are possible from wells completed in the thicker portions of the Valparaiso aquifer in parts of LaPorte and Porter Counties.

The Valparaiso Moraine Aquifer system is an important source of water in the Lake Michigan Region. However, drawbacks in obtaining water from this aquifer system include the relatively deep drilling depths required and problems in obtaining adequate yields where the aquifer consists of fine- to very fine-grained sand. Where these less permeable zones are encountered, wells tap the underlying Silurian and Devonian bedrock aquifers.

Surficial outwash sands along the southern margin of the Lake Michigan Region in parts of LaPorte and Porter Counties are not considered part of the Valparaiso Moraine Aquifer system. Instead, these areas are mapped as the Kankakee and the Valparaiso Outwash Apron Aquifer systems (plate 2). Hydraulic connections among these aquifer systems are considered good.

Valparaiso Outwash Apron Aquifer System

The Valparaiso Outwash Apron Aquifer system is a wedge of outwash sediments that form the southern slope of the Valparaiso Moraine. The outwash apron consists of interbedded sand and fine gravel, and has clay lenses and zones of shale-rich gravel. In the Lake Michigan Region, these deposits are present near the crest of the Valparaiso Moraine just south of the town of Valparaiso in Porter County and exceed 100 feet (30 meters) in thickness.

Lacustrine clays and channel sands are present beneath the outwash apron. The clays are of unknown lateral extent and vary up to 20 feet (6 meters) in thickness. The thickness of the channel deposits ranges from zero where the lacustrine clays rest on bedrock to more than 100 feet (30 meters) in deep bedrock valleys. Although the lacustrine clays separate the outwash apron deposits and the deeper channel deposits in places, the two permeable units are considered to be one aquifer system.

Most wells are completed in the upper aquifer unit

Table 22. Hydrologic characteristics of unconsolidated aquifer systems

Aquifer System	Aquifer thickness (ft)		Range of pumping rates (gpm)		Expected high-capacity yield(gpm)	Hydrologic condition
	Range	Common	Domestic	High-capacity		
Valparaiso Moraine	0 - 100+	40 - 60	5 - 60	100 - 800	100 - 600	Confined Unconfined
Valparaiso Outwash Apron	10 - 100+	50	15 - 60	100 - 1100	150 - 600	Unconfined
Kankakee	20 - 150	30	15 - 50	100 - 1500	100 - 1200	Unconfined
St. Joseph	10 - 100+	10 - 60	8 - 60	500 - 1500	500 - 1000	Unconfined Confined
Lacustrine Plain	0 - 90+	20 - 30	5 - 50	80 - 500	50 - 150	Confined
Calumet	0 - 40	20 - 30	5 - 20	30 - 150	20 - 100	Unconfined

and have depths ranging from 30 feet (9 meters) to more than 100 feet (30 meters). Wells completed in the lower aquifer unit have depths that typically exceed 50 feet (15 meters), but may also exceed 150 feet (46 meters). Static water levels are typically less than 20 feet (6 meters) deep, but can exceed 40 feet (12 meters) in depth in areas of higher surface elevation.

Yields in the upper and lower aquifer units are similar, typically ranging from 15 to 60 gpm for domestic wells and 100 to 600 gpm for large-diameter wells (table 22). Yields up to 1100 gpm are reported for some areas. However, special well construction techniques may be necessary because of the dominance of fine-grained sand.

Kankakee Aquifer System

The Kankakee Aquifer system is an unconfined deposit of sand in the floodplain of the Kankakee River and some of its tributaries. Almost all of the aquifer lies within the Kankakee River Basin, but small parts of the aquifer extend into the Lake Michigan Region along glacial drainageways which dissected the Valparaiso Moraine just east and west of the community of Rolling Prairie in LaPorte County (Indiana Department of Natural Resources, 1990a). Some of the glacial drainageways are presently occupied by tributaries of the Kankakee River.

The Kankakee Aquifer system overlies clay or bedrock. Most of the sediments of the aquifer system that lie in the tributary valleys are well-sorted fine- to medium-grained sands that are interbedded with gravel. The aquifer is as much as 150 feet (46 meters) thick in the Little Kankakee River valley. In the tributary valleys, depths to the water table may exceed 50 feet (15 meters), and well depths may exceed 150 feet (46 meters).

Domestic wells usually produce from 15 to 50 gpm, and high-capacity wells may produce 100 to 1200 gpm (table 22). Yields up to 1500 gpm may be possible in areas which have thick, coarse-grained deposits such as the Little Kankakee River valley in LaPorte County.

St. Joseph Aquifer System

The St. Joseph Aquifer system consists of thick deposits of outwash sand and gravel. Large meltwater rivers sorted and deposited thick beds of coarse-grained sand and gravel. These deposits are as much as 129 feet (39 meters) thick, but are commonly from 10 to 60 feet (3 to 18 meters) thick.

In the small part of St. Joseph County that lies in the Lake Michigan Region, the St. Joseph Aquifer system is interbedded with outwash deposits of the Kankakee

Aquifer system. Locally interspersed with the deposits that comprise the St. Joseph Aquifer system are thin clay or till units of limited areal extent.

Shallow wells ranging from 40 to 90 feet (12 to 27 meters) in depth are common in this aquifer system because of the presence of thick, near-surface sands and gravels. Overall, well depths range from 30 to 145 feet (9 to 44 meters). Static water levels range from 4 to 70 feet (1 to 21 meters) deep, but commonly are between 10 and 30 feet (3 and 9 meters) deep.

Aquifer yields in the part of the St. Joseph Aquifer system that lies in the Lake Michigan Region are not reliably known. Reported yields from the aquifer system range from 100 to 1500 gpm.

Lacustrine Plain Aquifer System

The Lacustrine Plain Aquifer system consists of a series of confined aquifers present beneath the Calumet Lacustrine Plain (figure 16). The southern boundary of the aquifer system is only an approximation (plate 2) and aquifers that comprise the Lacustrine Plain Aquifer system may interconnect with and be hydraulically connected to the Valparaiso Moraine Aquifer system. The northern part of the Lacustrine Plain Aquifer system contains aquifers that are separated from the surficial Calumet Aquifer by a clay and till unit that in places exceeds 100 feet (30 meters) in thickness.

The Lacustrine Plain Aquifer system consists of fine-to medium-grained glaciolacustrine sand, and coastal sand and gravel capped by either lacustrine clay or till. Thickness of the individual aquifers averages 24 feet (8 meters), but frequently ranges from 7 feet (2 meters) to as much as 90 feet (27 meters) in areas where sediment accumulations were localized in bedrock valleys.

Of the many individual aquifers that comprise the Lacustrine Plain Aquifer system, two aquifers of significant areal extent have been identified beneath the Lake Border Moraine. Although one aquifer underlies the central part of the Lake Border Moraine and the other aquifer underlies the western part of the moraine, both aquifers may be hydraulically connected near the Porter-LaPorte County line (Dave Cohen, U.S. Geological Survey, personal communication, 1993).

The aquifer that underlies the central part of the Lake Border Moraine is located in northwestern LaPorte County at depths ranging from 40 to 60 feet (12 to 18 meters) below the surface. The aquifer consists of fine- to medium-grained sand with minor amounts of silt and gravel. Aquifer thickness is variable but exceeds 150 feet (46 meters) in the vicinity of Michigan City's municipal airport.

The aquifer beneath the western part of Lake Border Moraine in northeastern Porter County lies about 25 to 70 feet (8 to 21 meters) below the surface. The aquifer has a common thickness of about 40 feet (12 meters) but thins to the east. Fine- to medium-grained sands comprise most of the aquifer, but gravel is present in appreciable amounts in the central and eastern extent of the aquifer.

Depths to static water levels are highly variable in the many aquifers of the Lacustrine Plain Aquifer system. In western Lake County, static water levels can be more than 60 feet (18 meters) below the surface, but in some parts of La Porte County flowing artesian wells are present. Artesian heads in the eastern part of the Lacustrine Plain Aquifer system strongly suggest local hydraulic connection between the Lacustrine Plain and Valparaiso Moraine Aquifer systems.

Wells completed in the Lacustrine Plain Aquifer system can typically produce about 5 to 20 gpm (table 22), more than sufficient for domestic use. In areas where wells penetrate coarse sand and gravel, yields of 40 to 50 gpm have been reported. Yields from high-capacity wells range from 80 to as much as 500 gpm for some municipal well systems. However, because of variations in thickness, lateral extent and localized hydraulic connections of the individual aquifers, sustained yields from the Lacustrine Plain Aquifer system vary.

Calumet Aquifer System

The Calumet Aquifer system is mainly a water-table aquifer located in the northern parts of Lake, LaPorte and Porter Counties (plate 2). The aquifer system is bordered to the north by Lake Michigan, and roughly to the south by the Little Calumet River in Lake County and the northern slopes of the Lake Border Moraine in northwestern LaPorte and northeastern Porter Counties.

The Calumet Aquifer system consists of fine- to medium-grained sand with dispersed lenses of beach gravel. The aquifer system is capped by dunal sands in many places. However, beds of interlaminated silt and clay, and deposits of peat and muck confine the aquifer system in small areas across the Lake Michigan Region. The aquifer system is underlain by a relatively impermeable clay and till unit that in places exceeds 100 feet (30 meters) in thickness. Aquifers that lie beneath the clay and till unit are considered part of the Lacustrine Plain Aquifer system.

Static water levels in the Calumet Aquifer system vary accordingly to surface elevation. Areas of subdued relief in northern Lake and northwestern Porter Counties have static water levels that are frequently less than 15 feet (5 meters) below the surface. However, static water levels can be as much as 100 feet (30 meters) below the crests of high dunes in northern LaPorte and northeastern Porter Counties. Ponds and marshes in the interdunal depressions define areas where the water-table intersects the ground surface.

Saturated thickness of the Calumet Aquifer system ranges from less than 5 feet (2 meters) along its southwestern extent to about 40 feet (12 meters) in areas containing broad water-table mounds. Watson and others (1989) identified water-table mounds between the Little Calumet and Grand Calumet Rivers, and between Gary Harbor and the Indiana Harbor Canal.

Development of the Calumet Aquifer system has not been significant because of the proximity of Lake Michigan, an abundant surface-water source. However, the aquifer system is utilized as a source of water by a few domestic and small commercial facilities. Domestic wells typically produce about 5 to 20 gpm, and high-capacity wells can be expected to produce up to 100 gpm (table 22). Higher sustained-withdrawal rates are difficult to achieve in many parts of the aquifer system because of the predominance of fine-grained sand.

Bedrock aquifer systems

The occurrence of bedrock aquifers in the Lake Michigan Region depends on the original composition of rocks and post-depositional changes which can influence hydraulic properties. Erosion has removed layers of bedrock in the Lake Michigan Region, which lies along the northeastern flank of the Kankakee arch (figure 19). Subsequent weathering and solution activity have increased the permeability of the rocks at the bedrock surface.

In bedrock aquifers, the upper units are usually the most productive zones because permeability is greatest at the bedrock surface. Rock types present at the bedrock surface in the Lake Michigan Region (plate 2) range from poorly productive shales to fairly productive carbonates. The yields of bedrock aquifers depend on the hydraulic characteristics of the bedrock units and the nature of the overlying deposits. Recharge rates to bedrock aquifers are largely influenced by the overlying strata.

Where shale or till overlies a bedrock aquifer, recharge to the underlying aquifer is generally limited by the overlying material of low permeability.

In general, bedrock aquifers are not utilized in the central and eastern parts of the Lake Michigan Region because of the predominance of unproductive shales at the bedrock surface and the availability of water from the overlying glacial deposits. In parts of Lake County, the unconsolidated deposits do not contain significant aquifers and therefore bedrock aquifers are utilized. Carbonate aquifers are used in parts of western Lake County, and shale is used as a source of water in some areas in central Lake County despite low yields.

Silurian-Devonian Carbonate Aquifer System

Silurian and Devonian carbonate rocks form the most utilized bedrock aquifer system in the Lake Michigan Region. However, water-yielding capabilities of this aquifer system are not uniform throughout its extent. Differences in *porosity* and variations in the degree of enhanced permeability have made it necessary to subdivide the Silurian-Devonian Carbonate Aquifer system into the Silurian Aquifer and the Devonian Carbonate Aquifer.

The **Silurian Aquifer** in the Lake Michigan Region consists of reef and interreef carbonate rocks of the Salina Group. Pre-middle Devonian chemical and physical weathering have produced considerable solution features in the rocks of the Wabash Formation which form the upper part of the bedrock aquifer.

Permeability of the Silurian carbonates decreases significantly with depth and only the upper 100 feet (30 meters) of the unit can be considered transmissible (Rosenshein and Hunn, 1968a). Reef rocks of the Salina Group have porosity values ranging from 5 to 25 percent and are quite permeable, but bank and interreef rocks have significantly lower porosities and permeabilities. Reefcore rocks may be less permeable than rocks of the inner flanks (John Rupp, Indiana Geological Survey, written communication, 1988).

Approximately 80 to 170 feet (24 to 52 meters) of unconsolidated material overlies Silurian bedrock in western Lake County. Water wells are drilled to an average depth of about 230 feet (70 meters) and the static water levels range from about 11 to 70 feet (3 to 21 meters) below the land surface. Most wells penetrate the upper 50 feet (15 meters) of bedrock.

The Silurian Aquifer is the most utilized bedrock aquifer in the Lake Michigan Region. The aquifer can be a reliable source of water for users requiring about 10 to 200 gpm. However, large-diameter wells drilled into the most tranmissible zones of the Silurian carbonates can produce as much as 500 gpm if constructed and developed optimally.

The **Devonian Carbonate Aquifer** overlies the Silurian Aquifer subsystem in most of the Lake Michigan Region, except in western Lake County where Silurian rocks are present at the bedrock surface (plate 2). The Devonian Carbonate Aquifer is comprised of limestone and dolomitic rocks of the Muscatatuck Group. The aquifer is utilized as a minor source of water in the western part of the Lake Michigan Region where it forms the bedrock surface. However, shale overlies Muscatatuck rocks in some areas. Porosity of the Devonian carbonates ranges from 0 to 14 percent, but permeability is highly variable (John Rupp, Indiana Geological Survey, written communication, 1988). The following hydrogeologic information on the Devonian Carbonate Aquifer is based on the records of water wells that are completed in areas where the Devonian carbonates are present at the bedrock surface. However, in areas where the Devonian carbonates are thin, some of the water wells may be completed in the underlying Silurian carbonates. The Devonian Carbonate Aquifer is overlain in most places by about 125 feet (38 meters) to more than 230 feet (70 meters) of unconsolidated material. The majority of water wells that penetrate the Devonian Carbonate Aquifer are completed in the upper 70 feet (21 meters) of bedrock, which is the most transmissible part of the aquifer. In general, static water levels in the Devonian Carbonate Aquifer are highly variable, ranging from about 25 to 90 feet (8 to 27 meters) below the surface.

Compared to water removal from Silurian carbonates, sustained yields from water wells that penetrate Devonian carbonates are much lower. The Devonian carbonates in the Lake Michigan Region can be used as a possible source of water for domestic and farm purposes requiring no more than 100 gpm. For maximum yields, wells should have large diameters (at least 8 inches or 20 centimeters) and should be properly developed. Low-yield wells are not uncommon and may be unavoidable in areas where shale is present at the bedrock surface.

Devonian Shale Aquifer

The Devonian-age Antrim Shale is used as the primary source of water in a few isolated areas in the Lake Michigan Region. These localities lie to the immediate north and north-east of the town of Crown Point, where the unconsolidated deposits do not contain any significant aquifers and the Antrim Shale forms the bedrock surface. In some instances, wells are completed in the underlying carbonate rocks in areas where the Antrim Shale is relatively thin, but the water may be of poorer quality.

Water wells that tap the Antrim Shale penetrate approximately 100 to 150 feet (30 to 46 meters) of unconsolidated material, and some of the wells are completed into more than 50 feet (15 meters) of shale. However, only the upper 25 feet (8 meters) of the shale has been made permeable due to post-Devonian weathering, jointing and fracturing. Static water levels in the shale range from 40 to 80 feet (12 to 24 meters) below the surface.

The Antrim Shale can be a possible source of water for users requiring about 10 gpm or less, which is adequate for most domestic and farm supplies. Water extracted from the Antrim Shale has been reported to contain a slight amount of natural gas.

The Upper Devonian to Lower Mississippian Ellsworth Shale is present at the bedrock surface along the southern boundary of the Lake Michigan Region (plate 2). However, the Ellsworth is not utilized as a source of water in the Lake Michigan Region because unconsolidated aquifers are abundant in the overlying deposits.

GROUND-WATER DEVELOPMENT POTENTIAL

The development or potential yield of an aquifer depends on aquifer characteristics (*transmissivity, hydraulic conductivity*, and storage), aquifer thickness, areal extent, ground-water levels and recharge. The aquifer system in the Region which has the greatest potential for ground-water development is the Valparaiso Moraine along the southern boundary in eastern Porter and western LaPorte Counties where permeable deposits are thick and extensive (figure 53). Of the Region's bedrock aquifers, the Silurian reef rocks which are overlain directly by outwash deposits have the highest potential for development.

Transmissivity

Transmissivity is a measure of the water-transmitting capability of an aquifer. It is defined as the product of the hydraulic conductivity and thickness of an aquifer. Each of the various methods developed to compute aquifer transmissivity establishes a mathematical relationship between the pumping rate and the resultant *drawdown* in the aquifer. The three methods used to estimate aquifer transmissivity in the Lake Michigan Region, listed in order of decreasing reliability, include the use of 1) graphical plots based on aquifer-test data, 2) specific capacity data based on adjusted drawdown, and 3) specific capacity data based on unadjusted drawdown.

The graphical approach can only be used when extensive data have been collected from aquifer tests. In most aquifer tests, water levels are recorded simultaneously at observation wells while the test well is being pumped. The response of the aquifer is monitored over an areal extent that is determined by the spatial distribution of the observation wells. Graphical plots of time versus drawdown and distance versus drawdown can yield reliable estimates of the hydraulic parameters of the aquifer. However, unless an extensive well field is being developed, an aquifer test is not warranted because the cost of installing observation wells is too high.

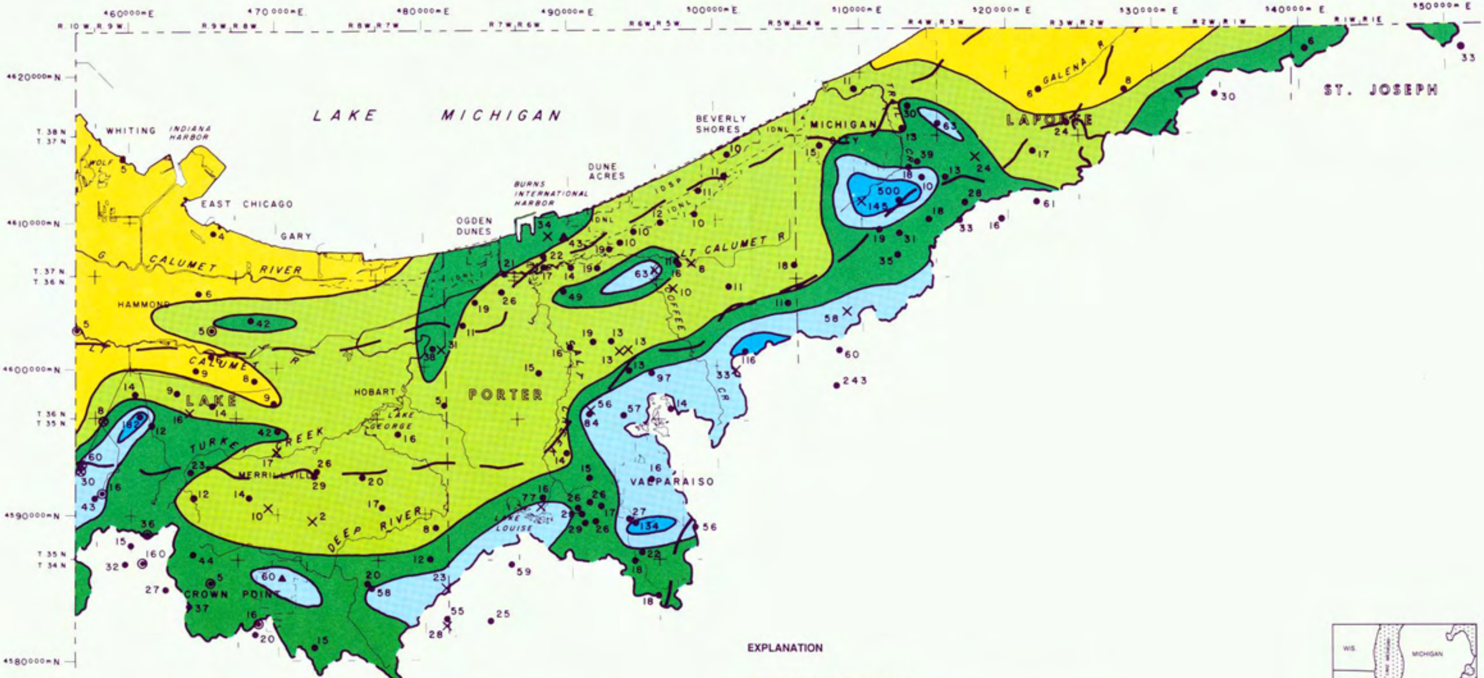
Specific capacity tests are less expensive than aquifer tests because drawdown is measured only at the test well while it is being pumped. After the completion of a water well, the driller conducts a specific capacity test to determine the potential yield of the well. As the length of the test increases, continued drawdown in the well causes a decrease in specific capacity, which is defined as the rate at which water can be pumped from a well under unit decline in drawdown. In reconnaissance ground-water investigations, useful estimates of aquifer transmissivity can be based on specific capacity data (Walton, 1970).

Consistent estimates of aquifer transmissivity in the Lake Michigan Region were efficiently generated from specific capacity data by using a computer program called "Tguess" (Bradbury and Rothschild, 1985). The computer program can adjust drawdown values from specific capacity tests to accommodate for well loss, partial penetration and dewatering of the aquifer. In most cases, these factors tend to cause lower estimates of specific capacity (Walton, 1970). However, if a well penetrates an aquifer of unknown thickness, drawdowns from specific capacity tests cannot be accurately adjusted. In this case, aquifer thickness is assumed to be equal to the thickness of aquifer that is penetrated by the well. The computed transmissivity of the aquifer, which is referred to as transmissivity based on unadjusted drawdown, can be considered to represent a local minimum transmissivity of the aquifer.

Regional estimates of aquifer transmissivity in the Lake Michigan Region (figure 54) were based on specific capacity tests that were conducted predominantly at high-capacity wells. At most of these facilities, wells fully penetrate the aquifer and are developed properly. However, in areas where regional hydrogeologic information was sparse or unreliable, transmissivity estimates based on unadjusted drawdown were used as supplemental data for the regional transmissivity map of the Lake Michigan Region (figure 54).

Estimates of transmissivity in the Lake Michigan Region typically range from 10,000 to 25,000 gallons per day per foot (124 to 311 square meters per day) in the Calumet Aquifer system, 10,000 to 50,000 gpd/ft (124 to 621 sq. meters/day) in the Lacustrine Plain Aquifer system, and 25,000 to 50,000 gpd/ft (311 to 621 sq. meters/day) in the Valparaiso Moraine Aquifer system (figure 54). Variations in transmissivities are probably the result of local changes in the lithofacies, thickness, and depth of the aquifer, and local differences in the nature of the surficial deposits. In the northwestern part of the Calumet Aquifer system, where fine-grained sands are predominant, transmissivity estimates are commonly much less than 10,000 gpd/ft (124 sq. meters/day) (figure 54). In contrast, thick coarse-grained deposits occur in localized areas within the Lacustrine Plain and Valparaiso Moraine Aquifer systems. In some of these areas, transmissivities exceed 100,000 gpd/ft (1242 sq. meters/day) (figure 54).

Bedrock aquifers in the Lake Michigan Region are utilized in small areas in Lake County, and therefore transmissivities of the bedrock systems could not be mapped on a regional scale. Transmissivities of the Silurian-Devonian Carbonate Aquifer system are highly



EXPLANATION

	< 10,000 gpd/ft
	10,000 - 25,000 gpd/ft
	25,000 - 50,000 gpd/ft
	50,000 - 100,000 gpd/ft
	> 100,000 gpd/ft

Transmissivity estimates based on

- ● Specific capacity of a domestic well completed in unconsolidated deposits
- × Specific capacity of a high-capacity well completed in unconsolidated deposits
- ▲ Pump test conducted in unconsolidated deposits
- ⊙ Specific capacity of a domestic well completed in bedrock
- ⊗ Specific capacity of a high-capacity well completed in bedrock
- Aquifer boundary

Regional estimates of transmissivity are based on specific capacity tests conducted in both high-capacity and domestic wells. In areas containing few water wells, regional estimates of transmissivity were based on the thickness and extent of the major aquifers interpreted from maps showing bedrock topography, saturated thickness, and surficial geology.

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STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

LAKE MICHIGAN REGION

Figure 54. Regional estimates of aquifer transmissivity
(unconsolidated materials only)

variable, but commonly range from 1,000 to 10,000 gpd/ft (12 to 124 sq. meters/day). In general, the Silurian carbonates are more transmissive than Devonian carbonates in the Lake Michigan Region. Localized transmissivities of the Silurian carbonates are as much as 60,000 gpd/ft (745 sq. meters/day) near Dyer in Lake County. In the few areas of the Lake Michigan Region where the Antrim Shale is used as a source of water, transmissivities of the shale are less than 5,000 gpd/ft (62 sq. meters/day).

Recharge

Aquifer yield is dependent upon aquifer permeability and saturated thickness and on the number, spacing and diameter of the wells that tap the aquifer. Although the development potential of an aquifer is determined by the total recharge to the aquifer, water quality, and well yields must be considered when ground-water systems are being appraised.

The ground-water development potential of the aquifer systems in the Lake Michigan Region is based on the rate of recharge (derived chiefly from *infiltration* of direct precipitation) and areal extent of the aquifer systems (figure 55). Estimates of natural recharge rates to the aquifer systems of the Lake Michigan Region were based on the permeability, areal extent and thickness of the deposits overlying the aquifer systems, and on regional climate (mainly precipitation and temperature).

Estimated recharge rates to the aquifers in the Lake Michigan Region are highest in the unconfined Calumet Aquifer system (figure 55). Infiltration of direct precipitation to the Calumet Aquifer system is high because of thinly developed soils on the thick surficial sands. The Calumet Aquifer system, which has an average recharge rate of about 500,000 gallons per day per square mile (26.7 centimeters per year), accounts for more than 50 percent of the total recharge to aquifers in the Lake Michigan Region despite occupying only 21 percent of the areal extent of the region (figure 55). However, estimates of recharge to the Calumet Aquifer must be viewed with caution because the high degree of industrialization and urbanization affect the local surface and subsurface hydrology to a considerable extent.

Rates of recharge to the Valparaiso Moraine Aquifer system are considerably lower than rates of recharge to the Calumet Aquifer system (figure 55) because the surficial tills and steeper gradient of the Valparaiso morainal surface promote runoff. Rates of recharge to the Valparaiso Moraine Aquifer system vary from 125,000 gpd/sq mi (6.7 cm/yr) in the west to 200,000 gpd/sq mi (10.7 cm/yr) in the east. Recharge rates to the western part of the aquifer system are lower because the surficial tills are thicker and finer grained than to the east.

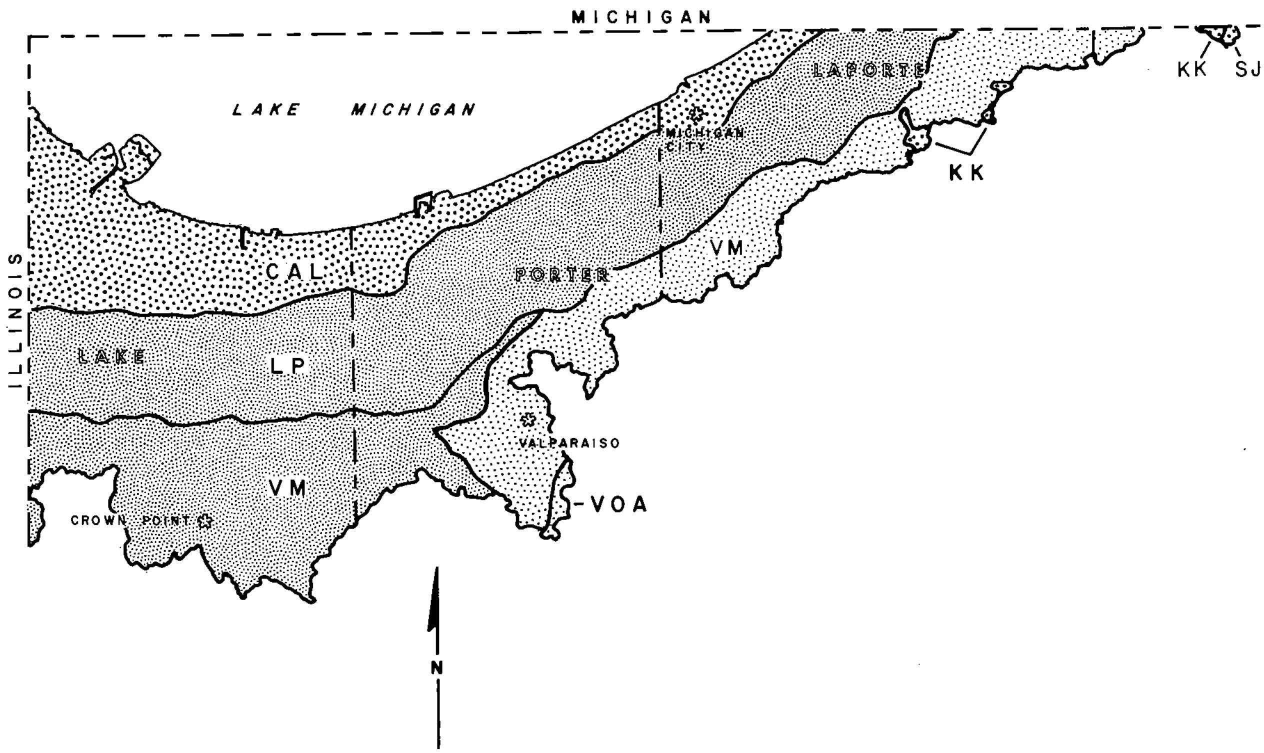
The Lacustrine Plain Aquifer system has the lowest recharge rates of the major aquifer systems in the Lake Michigan Region, averaging about 100,000 gpd/sq mi (5.3 cm/yr) (figure 55). Recharge to the many individual aquifers that comprise the aquifer system is limited by tills and fine-grained lacustrine sediments that surround the aquifers.

Recharge to the bedrock aquifers of the Lake Michigan Region is difficult to determine accurately because of the complex geology of the overlying glacial and lacustrine deposits. Rosenshein (1963) estimated an average recharge rate of 20,000 gpd/sq mi (1.1 cm/yr) for till-covered Silurian carbonates in Lake County. Higher recharge rates to the Silurian and Devonian carbonates are expected in areas where the carbonate bedrock is overlain directly by outwash deposits.

GROUND-WATER QUALITY

Water quality is an important and occasionally deciding factor in determining the utility of the ground-water resources in a given region. The concentrations of various naturally-occurring and artificial chemical constituents define ground-water quality and determine whether the resource, without prior treatment, is suitable for drinking water supplies, industrial purposes, irrigation, livestock watering, or other uses.

The dissolved constituents discussed in the following section are often detected in unpolluted ground waters, where their concentrations are primarily controlled by the composition and physical properties of the geological materials through which the waters circulate. However, under certain circumstances, the concentration of these chemicals in the water of an aquifer can be substantially increased by human activities. Elevated levels of certain naturally-occurring constituents in some areas of the Lake Michigan Region cannot be reconciled with the local geology and may reflect human-induced pollution of the ground-water systems. Chemicals such as organic compounds and heavy metals can also be introduced into ground



Aquifer System	Area (sq. mi)	Area (sq. km)	Recharge rate (gpd/sq. mi)	Recharge rate (cm/yr)	Recharge (mgd)	Recharge (cu. m/day)
Valparaiso Moraine (VM)	230.0	595.7	125,000 - 200,000	6.7- 10.7	37.38	141,651
Valparaiso Outwash Apron (VOA)	2.5	6.5	300,000	16.0	0.75	2,843
Kankakee (KK)	2.4	6.2	500,000	26.7	1.20	4,548
St. Joseph (SJ)	0.5	1.3	500,000	26.7	0.25	948
Lacustrine Plain (LP)	239.8	621.0	100,000	5.3	23.98	90,884
Calumet (CAL)	128.8	333.6	500,000	26.7	64.40	244,076

Figure 55. Estimated recharge rates of unconsolidated aquifer systems

water by human activities. In some areas of the Lake Michigan Region, human-induced aquifer pollution has locally diminished the quality and utility of ground-water resources.

Sources of ground-water quality data

Inorganic chemical analyses of water samples from 297 wells in the Lake Michigan Region were used to characterize the ground-water quality of the aquifer systems defined in this Region. An additional 36 chemical analyses from wells in the adjacent Kankakee River Basin were used to assist in constructing concentration maps of chemical constituents; but the additional data were not included in the statistical analyses. Major data sources include: 1) domestic, commercial and public-supply wells sampled during the fall of 1987 in a cooperative effort between the Division of Water (DOW) and the Indiana Geological Survey (IGS); 2) municipal and other public-supply wells sampled periodically by the Indiana State Board of Health (ISBH) which is now the Department of Health; 3) the Ground-water Strategy Study in Lake and Porter Counties published by ISBH; 4) public supply, industrial, industrial, domestic, and observation wells sampled by the U.S. Geological Survey (USGS); 5) dunes studies published by the USGS.

The intent of the water-quality analysis is to provide a realistic characterization of the natural ground-water chemistry of the Region; specific instances of ground-water contamination are not analyzed in detail. Chemical conditions are likely to be site-specific in cases of contamination, and may not be representative of typical ground-water chemistry in the Region. To minimize possible effects ground-water contamination may have on the characterization and description of the Region's ground-water, available chemical data from identified sites of contamination were excluded from the water-quality data set analyzed in this report. Excluding this data should provide a more reasonable assessment of natural water-quality conditions in the Region.

The location of ground-water chemistry sites used in the analysis are displayed on plate 3. Plate 3 also displays the reported use of the sampled wells, and the group or agency that performed the sampling and chemical analysis. Appendix 9 lists selected data for individual wells used in the analysis for this report.

A ground-water quality study conducted by Indiana University, School of Public and Environmental Affairs (1985) and funded by the U.S. Environmental Protection Agency (USEPA) provided additional nitrate-nitrogen analyses.

A private Indiana cooperative well-water testing program sponsored by the Farm Bureau, Soil and Water Conservation Districts, County Health Departments, Extension Service, and Resource Conservation and Development Districts provided additional information on nitrates, pesticides and herbicides in rural wells in LaPorte County. Information is not yet available for Lake and Porter Counties from this program, but should be in the near future.

Factors in the assessment of ground-water quality

Major dissolved constituents in the ground water of the Lake Michigan Region include calcium, sodium, chloride, sulfate, and bicarbonate. Less abundant constituents include potassium, magnesium, iron, manganese, fluoride and nitrate. Other chemical parameters that are discussed in this report are pH, alkalinity, hardness and total dissolved solids (TDS).

Although the data from well-water samples in the Lake Michigan Region are treated as if they represent the chemistry of ground water at a distinct point, they actually represent the average concentration of an unknown water volume in the aquifer. The extent of aquifer representation depends mostly on the depth of the well, hydraulic conductivity of the aquifer, and rate of pumping. For example, the chemistry of water sampled from high-capacity wells may represent average ground-water quality for a large cone of influence (Sasman and others, 1981). Also, water collected from deep bedrock wells can be a mixture of water from different production zones.

The chemistry of original aquifer water may be altered by contact with plumbing, residence time in a pressure tank, method of sampling and laboratory analysis. Because the degree to which these factors affect original aquifer water is unknown, ground-water analyses generally typify the quality of water at the tap rather than the composition of in-situ aquifer water. In spite of these limitations, results of sample analyses can provide basic information on ground-water quality characteristics of aquifer systems.

Analysis of data

Graphical and statistical techniques were used to analyze the available ground-water quality data from the Lake Michigan Region. Graphical analysis is used to display the areal distribution of dissolved constituents over the Region and to determine the general chemical character of the ground water of each aquifer system. Statistical analysis can provide some useful generalizations about the water quality of the Region, such as the average concentration of a constituent and

FACTORS AFFECTING GROUND-WATER CHEMISTRY

The chemical composition of ground water varies because of many complex factors that change with depth and over geographic distances. Ground-water quality can be affected by the composition and solubility of rock materials in the soil or aquifer, water temperature, partial pressure of carbon dioxide, acid-base reactions, oxidation-reduction reactions, loss or gain of constituents as water percolates through clay layers, and mixing of ground water from adjacent strata. The extent of the effect will be determined in part by the residence time of the water within the different environments.

Rain and snow are the major sources of recharge to ground water. They contain small amounts of dissolved solids and gases such as carbon dioxide, sulfur dioxide, and oxygen. As precipitation infiltrates through the soil, biologically-derived carbon dioxide reacts with the water to form a weak solution of carbonic acid. The reaction of oxygen with reduced iron minerals such as pyrite is an additional source of acidity in ground water. The slightly acidic water dissolves soluble rock material, thereby increasing the concentrations of chemical constituents such as calcium, magnesium, chloride, iron, and manganese. As ground water moves slowly through an aquifer the composition of water continues to change, usually by the addition of dissolved constituents (Freeze and Cherry, 1979). A longer residence time will usually increase concentrations of **dissolved solids**. Because of short residence time, ground water in recharge areas often contains lower concentrations of dissolved constituents than water occurring deeper in the same aquifer or in shallow discharge areas.

Dissolved carbon dioxide, bicarbonate, and carbonate are the principal sources of **alkalinity**, or the capacity of solutes in water to neutralize acid. Carbonate contributors to alkalinity include atmospheric and biologically-produced carbon dioxide, carbonate minerals, and biologically-mediated sulfate reduction. Noncarbonate contributors to alkalinity include hydroxide, silicate, borate, and organic compounds. Alkalinity helps to buffer natural water so that the **pH** is not greatly altered by addition of acid. The pH of most natural ground waters in Indiana is neutral to slightly alkaline.

Calcium and **magnesium** are the major constituents responsible for **hardness** in water. Their presence is the result of dissolution of carbonate minerals such as calcite and dolomite.

The weathering of feldspar and clay is a source of **sodium** and **potassium** in ground water. Sodium and **chloride** are produced by the solution of halite (sodium chloride) which can occur as grains disseminated in unconsolidated and bedrock deposits. Chloride also occurs in bedrock cementing material, connate fluid inclusions, and as crystals deposited during or after deposition of sediment in sea water (Hem, 1985). High sodium and chloride levels can result from upward movement of brine from deeper bedrock in areas of high pumpage.

Cation exchange is often a modifying influence of ground-water chemistry. The most important cation exchange processes are those involving sodium-calcium, sodium-magnesium, potassium-calcium, and potassium-magnesium. Cation exchanges occurring in clay-rich semi-confining layers can cause magnesium and calcium reductions which result in natural softening.

Concentrations of **sulfide, sulfate, iron**, and **manganese** depend on geology and hydrology of the aquifer system, amount of dissolved oxygen, pH, minerals available for solution, amount of organic matter, and microbial activity.

Mineral sources of sulfate can include pyrite, gypsum, barite, and celestite. Sulfide is derived from reduction of sulfate when dissolved oxygen concentrations are low and anaerobic bacteria are present. Sulfate-reducing bacteria derive energy from oxidation of organic compounds and obtain oxygen from sulfate ions (Lehr and others, 1980).

Reducing conditions which produce hydrogen sulfide may occur in deep wells completed in carbonate and shale bedrock. Oxygen-deficient conditions are more likely to occur in deep wells than in shallow wells because permeability of the carbonate bedrock decreases with depth, and solution features and joints become smaller and less abundant (Rosenshein and Hunn, 1968a; Bergeron, 1981; Basch and Funkhouser, 1985). Deeper portions of the bedrock are therefore not readily flushed by ground water with high dissolved oxygen. Hydrogen sulfide gas, a common reduced form of sulfide, has a distinctive rotten egg odor which can be detected in water containing only a few tenths of a milligram per liter of sulfide (Hem, 1985).

Oxidation-reduction reactions constitute an important influence on concentrations of both iron and manganese. High dissolved iron concentrations can occur in ground water when pyrite is exposed to oxygenated water or when ferric oxide or hydroxide minerals are in contact with reducing substances (Hem, 1985). Sources of manganese include manganese carbonate, dolomite, limestone, and weathering crusts of manganese oxide.

Sources of **fluoride** in bedrock aquifer systems include fluorite, apatite and fluorapatite. These minerals may occur as evaporites or detrital grains in sedimentary rocks, or as disseminated grains in unconsolidated deposits. Ground waters containing detectable concentrations of fluoride have been found in a variety of geologic settings (Hem, 1985).

Natural concentrations of **nitrate-nitrogen** in ground water originate from the atmosphere and from living and decaying organisms. High nitrate levels can result from leachates of industrial and agricultural chemicals or decaying organic matter such as animal waste or sewage.

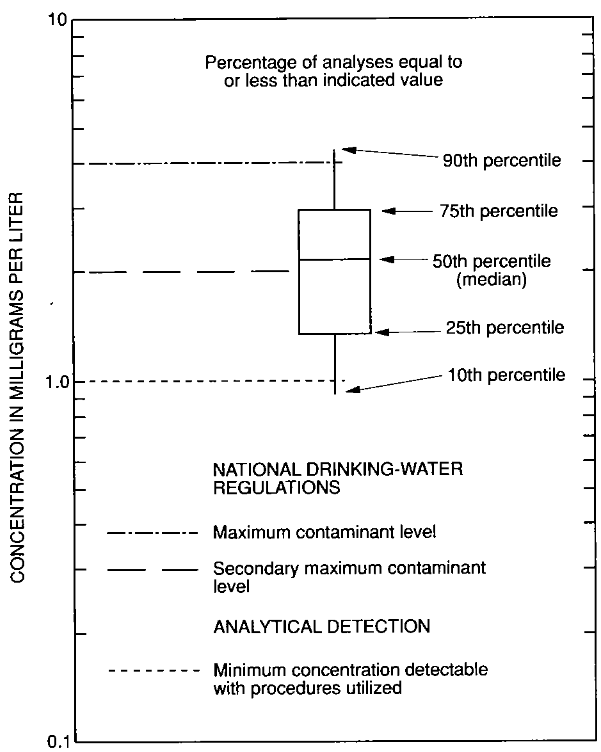
The chemistry of **strontium** is similar to that of calcium, but strontium is present in ground water in much lower concentrations. Natural sources of strontium in ground water include strontianite (strontium carbonate) and celestite (strontium sulfate). Naturally-occuring **barium** sources include barite (barium sulfate) and witherite (barium carbonate). Areas associated with deposits of coal, petroleum, natural gas, oil shale, black shale, and peat may also contain high levels of barium.

the variability that can be expected.

Only wells screened deeper than 25 feet below the surface are included in the data analysis. Most of the wells screened below 25 feet are developed for domestic use, municipal supply, or other water-supply purposes. The majority (83 percent) of wells less than 25 feet deep are USGS monitoring wells in the Calumet Aquifer system, which do not provide water for domestic or municipal use.

Major regional trends in ground-water chemistry were determined by developing trilinear diagrams for the larger aquifer systems in the Lake Michigan Region. Trilinear plotting of ground-water chemistry was popularized by Piper (1944) as a graphical technique to chemically classify ground waters and to compare chemical trends in aquifer systems (see insert, page 165).

In order to graphically represent variability in ground water chemistry, box plots (figure 56) were prepared for selected ground-water constituents. Box plots are useful for depicting descriptive statistics, showing the overall variability in constituent levels occurring in an aquifer system, and making general chemical comparisons among aquifer systems. Unfortunately, statistical analyses of some aquifer systems in the Lake Michigan Region are complicated by a limited number of samples. This is especially true of the Lacustrine Plain Aquifer system underlying the Calumet and the Silurian and Devonian Bedrock Aquifer system, from which only 11 and 12 samples were available, respectively. This limited sampling may not be representative of the chemistry



CAL	Calumet Aquifer system
LAC	Lacustrine Plain Aquifer system
LPC	Lacustrine Plain Aquifer system underlying the Calumet
VM	Valparaiso Moraine Aquifer system
SD	Silurian and Devonian Bedrock Aquifer system

Figure 56. Explanation and legend for box-and-whisker plots

of these two aquifer systems; moreover, the possibility exists that variations in the box plots for the two systems are exaggerated by a few abnormally high or low measurements.

The areal distribution of most major constituents is mapped according to aquifer systems using Arc/Info, a Geographic Information System (GIS) (figures 57 to 66). The maps are shown with box plots of corresponding chemical parameters. Several sampling and geologic factors complicate the development of chemical concentration maps for the Region. The locations of sampling sites are not evenly distributed in the Region, but are clustered around towns, industry and developed areas (plate 3). Data points are also scarce in areas utilizing surface water supplies. Lateral and vertical variations in geology can also influence the chemistry of subsurface water. Therefore, the maps presented in the following discussion represent only approximate concentration ranges.

Where applicable, ground-water quality is assessed in the context of National Primary and Secondary Drinking-Water Standards (see box on next page). The secondary drinking water standard referred to in this report is called the secondary maximum contaminant level (SMCL). The SMCL reflects the maximum concentration limit of a constituent that may adversely affect aesthetic properties, such as taste, odor or color, of drinking water. Some chemical constituents (such as fluoride and nitrate) are also considered in terms of their *maximum contaminant level* (MCL); the concentration at which a constituent represents a threat to human health. The MCL is a legally enforceable primary drinking water standard for public water supplies. General water-quality criteria for irrigation and livestock and standards for public supply are given in appendix 6. Note that MCLs and SMCLs are not defined for every dissolved constituent commonly encountered in ground water.

Trilinear diagram analysis

The trilinear diagrams developed from the Lake Michigan Region ground-water chemistry data are presented in appendix 10. The water chemistry of Lake Michigan Region aquifers, excluding the Lacustrine Plain Aquifer system underlying the Calumet and the Silurian and Devonian Bedrock Aquifer system, is shown by the trilinear analyses to be dominated by bicarbonate, calcium and magnesium.

NATIONAL DRINKING-WATER STANDARDS

National Drinking Water Regulations and Health Advisories (U. S. Environmental Protection Agency, 1993) list concentration limits of specified inorganic and organic chemicals in order to control amounts of contaminants in drinking water. Primary regulations list maximum contaminant levels (MCLs) for inorganic constituents considered toxic to humans above certain concentrations. These standards are health-related and legally enforceable. Secondary maximum contaminant levels (SMCLs) cover constituents that may adversely affect the aesthetic quality of drinking water. The SMCLs are intended to be guidelines rather than enforceable standards. Although these regulations apply only to drinking water at the tap for public supply, they may be used to assess water quality for privately-owned wells. The table below lists selected inorganic constituents of drinking water covered by the regulations, the significance of each constituent, and their respective MCL or SMCL. Fluoride and nitrate are the only constituents listed which are covered by the primary regulations.

Constituent	Secondary Maximum Contaminant Level (SMCL) (ppm)	Maximum Contaminant Level (MCL) (ppm)	Remarks
Total Dissolved Solids (TDS)	500	*	Levels above SMCL can give water a disagreeable taste. Levels above 1000 mg/L may cause corrosion of well screens, pumps, and casings.
Iron	0.3	*	More than 0.3 ppm can cause staining of clothes and plumbing fixtures, encrustation of well screens, and plugging of pipes. Excessive quantities can stimulate growth of iron bacteria.
Manganese	0.05	*	Amounts greater than 0.05 ppm can stain laundry and plumbing fixtures, and may form a dark brown or black precipitate that can clog filters.
Chloride	250	*	Large amounts in conjunction with high sodium concentrations can impart a salty taste to water. Amounts above 1000 ppm may be physiologically unsafe. High concentrations also increase the corrosiveness of water.
Fluoride	2.0	4.0	Concentration of approximately 1.0 ppm help prevent tooth decay. Amounts above recommended limits increase the severity and occurrence of mottling (discoloration of the teeth). Amounts above 4 ppm can cause adverse skeletal effects (bone sclerosis).
Nitrate**	*	10	Concentrations above 20 ppm impart a bitter taste to drinking water. Concentrations greater than 10 ppm may have a toxic effect (methemoglobinemia) on young infants.
Sulfate	250	*	Large amounts of sulfate in combination with other ions (especially sodium and magnesium) can impart odors and a bitter taste to water. Amounts above 600 ppm can have a laxative effect. Sulfate in combination with calcium in water forms hard scale in steam boilers.
Sodium	NL	NL	Sodium salts may cause foaming in steam boilers. High concentrations may render water unfit for irrigation. High levels of sodium in water have been associated with cardiovascular problems. A sodium level of less than 20 ppm has been recommended for high risk groups (people who have high blood pressure, people genetically predisposed to high blood pressure, and pregnant women).
Calcium	NL	NL	Calcium and magnesium combine with bicarbonate, carbonate, sulfate and silica to form heat-retarding, pipe-clogging scales in steam boilers. For further information on calcium and magnesium, see hardness.
Magnesium	NL	NL	
Hardness	NL	NL	Principally caused by concentration of calcium and magnesium. Hard water consumes excessive amounts of soap and detergents and forms an insoluble scum or scale.
pH	-	-	USEPA recommends pH range between 6.5 and 8.5 for drinking water.

NL No Limit Recommended.
* No MCL or SMCL Established by USEPA.
** Nitrate concentrations expressed as equivalent amounts of elemental nitrogen (N).
(Adapted from USEPA, 1993a)
Note: 1 part per million (ppm) = 1 mg/L.

CHEMICAL CLASSIFICATION OF GROUND WATERS USING TRILINEAR DIAGRAMS

Trilinear plotting systems were used in the study of water chemistry and quality as early as 1913 (Hem, 1985). The type of trilinear diagram used in this report, independently developed by Hill (1940) and Piper (1944), has been used extensively to delineate variability and trends in water quality. The technique of trilinear analysis has contributed extensively to the understanding of ground water flow, and geochemistry (Dalton and Upchurch, 1978).

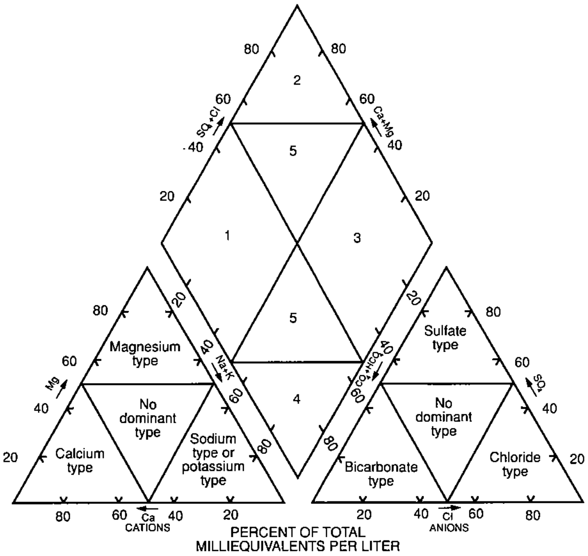
On conventional trilinear diagrams sample values for three cations (calcium, magnesium and the alkali metals- sodium and potassium) and three anions (bicarbonate, chloride and sulfate) are plotted relative to one another. Because these ions are generally the most common constituents in unpolluted ground waters, the chemical character of most natural waters can be closely approximated by the relative concentration of these ions (Hem, 1985; Walton, 1970).

Before values can be plotted on the trilinear diagram, the concentrations of the six ions of interest are converted into milliequivalents per liter (meq/L), a unit of concentration equal to the concentration in milligrams per liter divided by the equivalent weight (atomic weight divided by valence). Each cation value is then plotted, as a percentage of the total concentration (meq/L) of all cations under consideration, in the lower left triangle of the diagram. Likewise, individual anion values are plotted, as percentages of the total concentration of all anions under consideration, in the lower right triangle. Sample values are then projected into the central diamond-shaped field. Fundamental interpretations of the chemical nature of a water sample are based on the location of the sample ion values within the central field.

Distinct zones within aquifers having defined water chemistry properties are referred to as hydrochemical facies (Freeze and Cherry, 1979). Determining the nature and distribution of hydrochemical facies can provide insights into how ground-water quality changes within and between aquifers. Trilinear diagrams can be used to delineate hydrochemical facies, because they graphically demonstrate relationships between the most important dissolved constituents in a set of ground-water samples.

A simple but useful scheme for describing hydrochemical facies with trilinear diagrams is presented by Walton (1970) and is based on methods used by Piper (1944). This method is based on the "dominance" of certain cations and anions in solution. The dominant cation of a water sample is defined as the positively charged ion whose concentration exceeds 50 percent of the summed concentrations of major cations in solution. Likewise, the concentration of the dominant anion exceeds 50 percent of the total anion concentration in the water sample. If no single cation or anion in a water sample meets this criterion, the water has no dominant ion in solution. In most natural waters, the dominant cation is either calcium, magnesium, or alkali metals (sodium and potassium), and the dominant anion is either chloride, bicarbonate, or sulfate (see figure above).

Distinct hydrochemical facies are defined by specific combinations of dominant cations and anions. These combinations will plot in certain areas of the central, diamond-shaped part of the trilinear diagram. Walton (1970) described a simple but useful classification scheme which divides the central part of the diagram into five subdivisions (see figure above). Five basic hydrochemical facies can be defined with this criteria:



1. Primary Hardness; Combined concentrations of calcium, magnesium and bicarbonate exceed 50 percent of the total dissolved constituent load in meq/L. Such waters are generally considered hard and are often found in limestone aquifers or unconsolidated deposits containing abundant carbonate minerals.

2. Secondary Hardness; Combined concentrations of sulfate, chloride, magnesium and calcium exceed 50 percent of total meq/L.

3. Primary Salinity; Combined concentrations of alkali metals, sulfate and chloride are greater then 50 percent of the total meq/L. Very concentrated waters of this hydrochemical facies are considered brackish or (in extreme cases) saline.

4. Primary Alkalinity; Combined sodium, potassium and bicarbonate concentrations exceed 50 percent of the total meq/L. These waters generally have low hardness in proportion to their dissolved solids concentration (Walton, 1970).

5. No specific cation-anion pair exceeds 50 percent of the total dissolved constituent load. Such waters could result from multiple mineral dissolution or mixing of chemically distinct ground waters.

This chemistry reflects the dissolution of carbonate minerals and is typical of waters in limestone terranes and common in ground waters from midwestern glacial deposits (Freeze and Cherry, 1979). In the Lacustrine Plain Aquifer system underlying the Calumet, bicarbonate is the dominant *anion* in 73 percent of all samples, but sodium and potassium appear to be the dominant *cations* in this aquifer. In the Bedrock Aquifer system, approximately 50 percent of all water samples were dominated by calcium, magnesium and bicarbonate, while the remaining samples were either sodium-potassium-bicarbonate dominated or had no dominant cation-anion pair.

Although waters in the Region are predominately calcium and bicarbonate dominated, numerous samples are chemically dominated by other anions or cations. That is, the concentrations of these ions exceed 50 percent of the sum of cation or anion concentrations. This indicates that, locally, there can be considerable variation in the nature of water chemistry in the Lake Michigan Region. The amount of chemical variability in an aquifer system is reflected in the scatter of points within the trilinear diagram.

The least amount of chemical variability is observed in the Valparaiso Moraine Aquifer system (appendix 10). The majority of samples from this aquifer are calcium-bicarbonate dominated, but some samples contain considerable amounts of sulfate (as high as 49 percent of total anion concentration).

A large degree of variation is observed in the ground-water chemistry of the Calumet Aquifer system (appendix 10). Forty-one percent of all samples have no dominant cation, and 24 percent have no dominant anion. Some samples from the Calumet Aquifer system are sodium dominated (3 percent); and a considerable number of samples have chloride or sulfate as the dominant anion (13.5 percent and 11 percent, respectively). Other samples from the Calumet Aquifer system plot within the fields of secondary hardness, primary salinity or no dominant chemistry (see insert on preceding page).

The Lacustrine Plain Aquifer system underlying the Calumet and the Silurian and Devonian Bedrock Aquifer system both display variability in water chemistry (appendix 10). However, since only a small number of samples are available from each system, these diagrams may not reflect all chemical conditions in these aquifers.

Assessment of ground-water quality

Alkalinity and pH

Alkalinity, the capacity of water to neutralize acid, is determined from levels of bicarbonate, carbonate, hydroxide, borates, and certain organic compounds in the water. In the Lake Michigan Region, alkalinity is due primarily to the presence of bicarbonate (HCO_3), the dominant anion in most samples from wells completed in both unconsolidated deposits and bedrock. Rosenshein and Hunn (1968a, 1968b) have noted that bicarbonate concentrations are generally higher in aquifers confined between thick tills, where water generally has more contact with carbonate minerals dispersed within the till sediments.

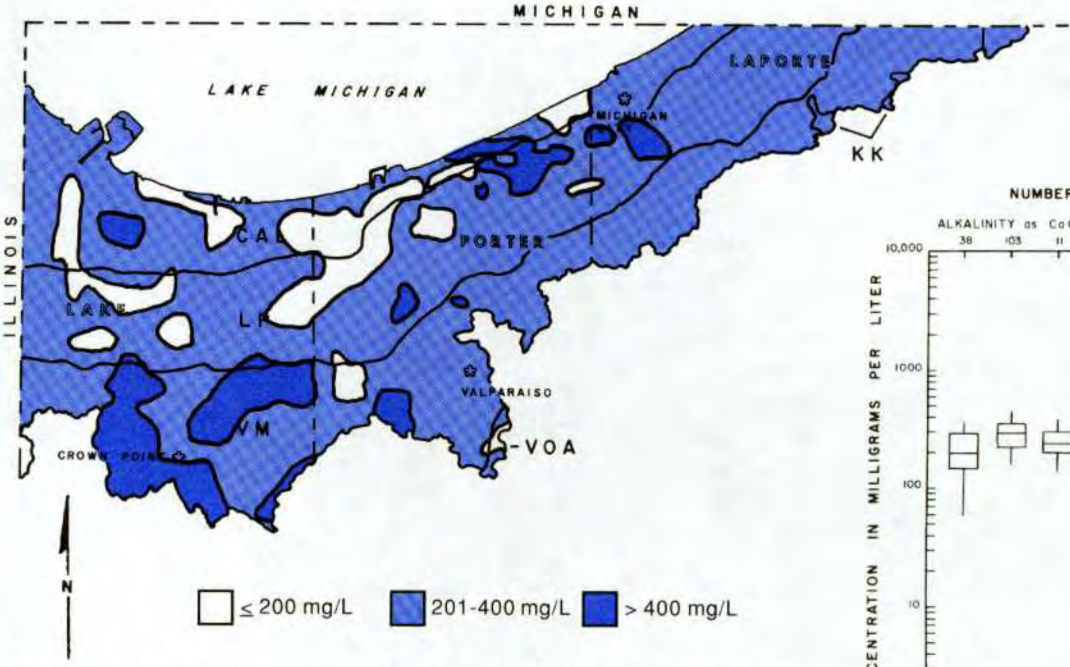
The highest median alkalinity level (330 mg/L) is detected in the Valparaiso Moraine Aquifer system (figure 57). The high median value for this aquifer system may reflect a relatively long ground-water residence time in low-permeability tills overlying the aquifer system. The lowest median alkalinity level (195.5 mg/L) was measured in the Calumet Aquifer system, which may reflect relatively short residence time in this permeable, sandy aquifer.

The median alkalinity concentration of ground water in the Silurian and Devonian Bedrock Aquifer system (382 mg/L) is considerably higher than median ground-water alkalinity in the unconsolidated aquifer systems. The higher alkalinity may be due to: 1) the limestone and dolomite composition of the bedrock units; 2) bicarbonate production from biochemical sulfate reduction (Freeze and Cherry, 1979); and/or 3) longer residence time in bedrock units.

The pH, or hydrogen ion activity, is expressed on a logarithmic scale (0 to 14), and represents the negative base-10 log of the hydrogen-ion concentration. The neutral value of pH is set at 7. Water is considered acidic when the pH is less than 7 and basic when the pH is greater than 7. Overall, the data indicate that ground water in the Region is predominantly near-neutral; pH values generally occur within the 6-8 range.

Hardness, calcium, and magnesium

"Hardness" is a term relating to the concentration of certain ions in water, particularly magnesium and calcium, and is usually expressed as an equivalent concentration of dissolved calcite ($CaCO_3$) in milligrams per liter. Durfor and Becker (1964) developed the following classification of water hardness which is useful for discussion purposes: soft water, 0 to 60 mg/L (calcite equivalent); moderately hard water, 61 to 120 mg/L; hard water, 121 to 180 mg/L; and very hard water, more then 180 mg/L. Hardness is a water-quality concern because hard water consumes excessive amounts of soap and detergents, forms an insolu-



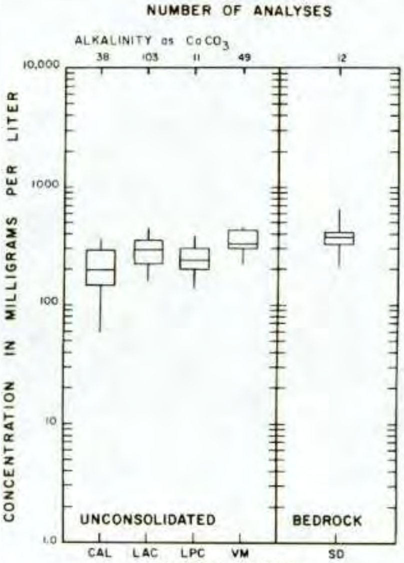
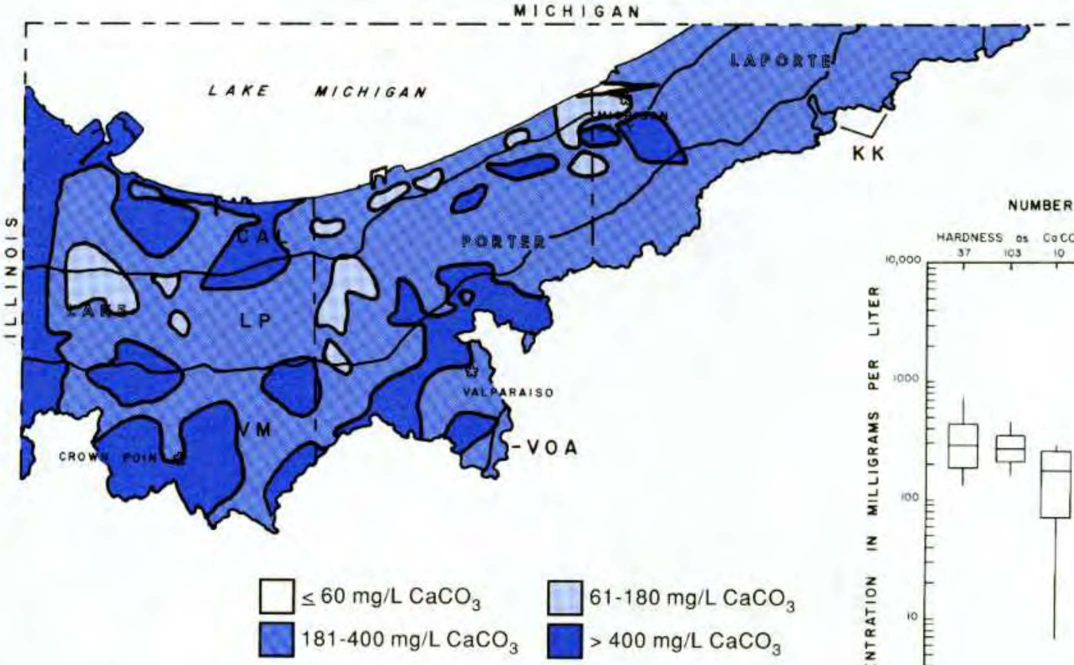


Figure 57. Generalized areal distribution of **Alkalinity** in ground water from unconsolidated aquifers and statistical summary for Alkalinity in ground water from all aquifer systems.



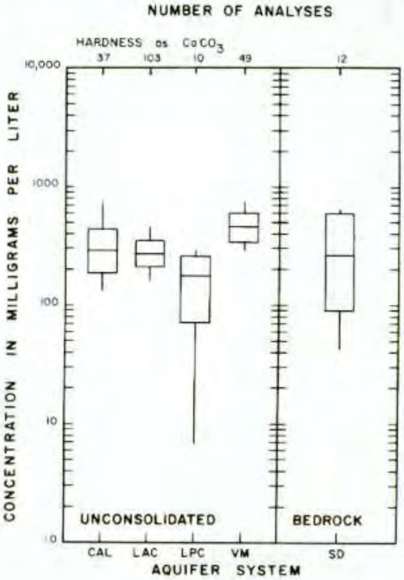


Figure 58. Generalized areal distribution of **Hardness** in ground water from unconsolidated aquifers and statistical summary for Hardness in ground water from all aquifer systems.

ble scum, and causes scale to encrust water heaters, boilers, and pipes, thus decreasing their capacity and heat-transfer properties.

Wells in the unconsolidated aquifers of the Lake Michigan Region generally contain hard to very hard water (figure 58). Very hard water is common in the Valparaiso Moraine Aquifer system, which has a median hardness of 464 mg/L (figure 58). The lowest median hardness, 175 mg/L calcite equivalent, is found in the Lacustrine Plain Aquifer system underlying the Calumet. The hard water in the Valparaiso Moraine Aquifer system may originate from the dissolution of calcium-carbonate and calcium-sulfate minerals.

Having a median hardness of 263 mg/L calcite equivalent, the Silurian and Devonian Bedrock Aquifer system generally contains very hard waters. Some hardness levels in excess of 500-600 mg/L calcite equivalent have been reported in bedrock wells around the town of Dyer in west-central Lake County. The water samples from the Silurian and Devonian Bedrock Aquifer system also have relatively high sulfate concentrations, which may indicate that gypsum ($CaSO_4\{H_2O\}$) dissolution is a factor in the elevated hardness.

The hard waters of the Silurian and Devonian Bedrock Aquifers are used in the Dyer area because of changes in the overlying Valparaiso Moraine Aquifer system. This unconsolidated aquifer becomes thinner and less permeable just east of Dyer, which limits its use as a ground-water source in some parts of the southwestern Lake Michigan Region.

Because calcium and magnesium are the major constituents responsible for hardness in water, high concentrations of these ions are generally found in waters with hardness levels above 180 mg/L $CaCO_3$ equivalent. The lowest median calcium concentration (31 mg/L) is present in the Lacustrine Plain Aquifer system underlying the Calumet; in contrast, the highest median concentration (115 mg/L) is found in the Valparaiso Moraine Aquifer system (appendix 11). The median magnesium concentrations in the unconsolidated aquifer systems ranged from 21.5 mg/L in the Calumet Aquifer system to 41 mg/L in the Valparaiso Moraine Aquifer system (appendix 11).

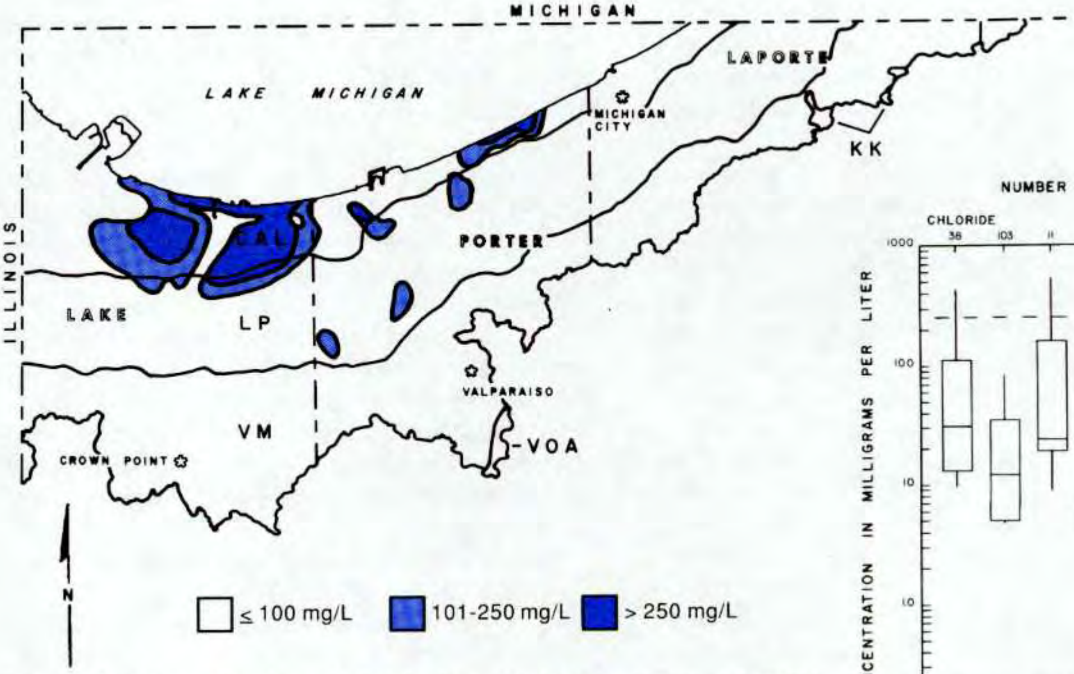
In the Silurian and Devonian Bedrock Aquifer system, median calcium and magnesium concentrations are 60 mg/L and 31 mg/L, respectively. These ions also appear to have a wider range of concentrations in bedrock wells relative to concentrations in the unconsolidated aquifer systems (appendix 11). High concentrations of magnesium and calcium probably result from the dissolution of carbonate minerals. Some ground-water samples from bedrock wells near Gary and Crown Point, however, have low hardness, calcium and magnesium levels. Compared to other bedrock well samples, these ground waters are sodium-potassium-bicarbonate dominated, have more chloride as part of their total anion percentage, and higher concentrations of fluoride.

Chloride, sodium and potassium

Wide variation in chloride concentrations are found among the unconsolidated aquifer systems of the Lake Michigan Region (figure 59). The highest median concentration of 31 mg/L is detected in the Calumet Aquifer system. The lowest median chloride concentration (7.0 mg/L) is observed in the Valparaiso Moraine Aquifer system. Some chloride concentrations above the SMCL of 250 mg/L are present in all unconsolidated aquifer systems, except for the Valparaiso Moraine Aquifer system.

The box plots in figure 60 indicate that sodium also has fairly wide concentration ranges in the unconsolidated aquifers. The lowest median concentration of 7.1 mg/L is detected in the Valparaiso Moraine Aquifer system; whereas, the highest median value (76 mg/L) is found in water from the Lacustrine Plain Aquifer system underlying the Calumet. The high sodium content of some waters from the latter aquifer may originate from natural softening. Natural softening is the replacement of calcium and magnesium in solution for sodium and potassium on the surface of a mineral substrate, such as clay particles, by *ion exchange*.

Many chloride concentrations which exceed the SMCL are detected in wells located in or near urban areas and screened at depths from 25 to 65 feet. The high chloride in these wells could originate from anthropogenic sources, such as landfills, industrial chemicals, or deicing salt. Another possible source of this ion could be the upwelling of chloride-dominated waters from the deeper flow system. A few chloride concentrations greater than the SMCL are detected in deep wells (96 to 212 feet) drilled into the Lacustrine Plain Aquifer system underlying the Calumet. The high chloride concentrations in the deeper wells may not reflect contamination, since they occur in isolated, deep wells. Explanations for the high chloride concentrations in water from the deep wells include older,



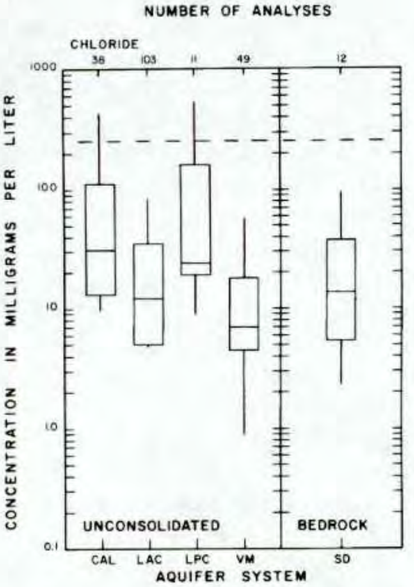
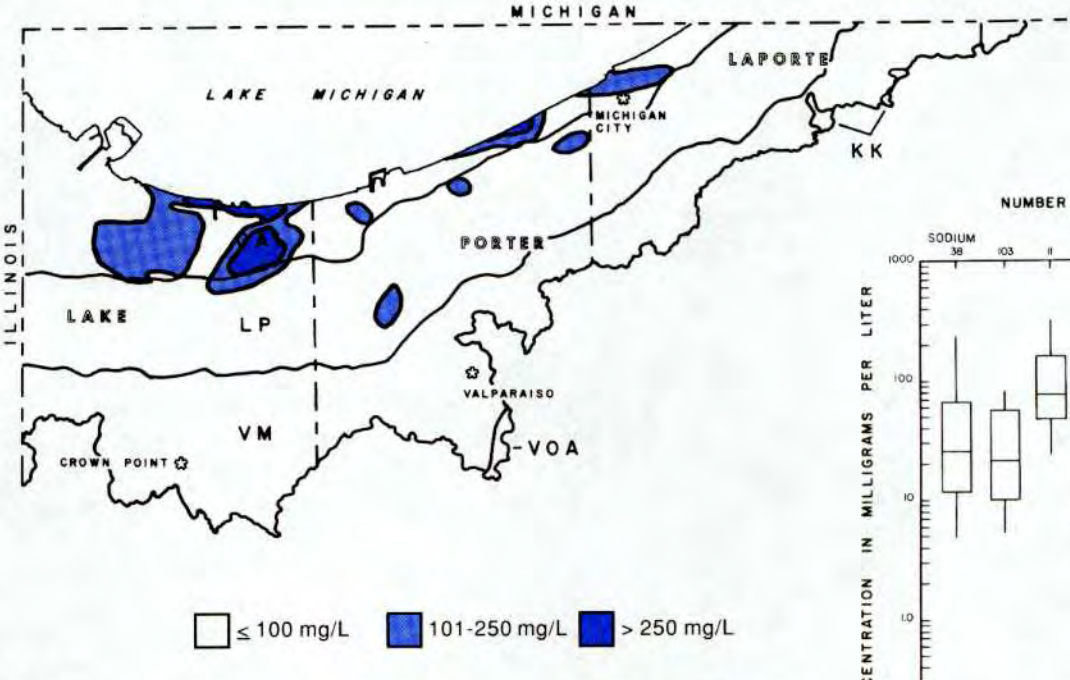


Figure 59. Generalized areal distribution of **Chloride** in ground water from unconsolidated aquifers and statistical summary for Chloride in ground water from all aquifer systems.



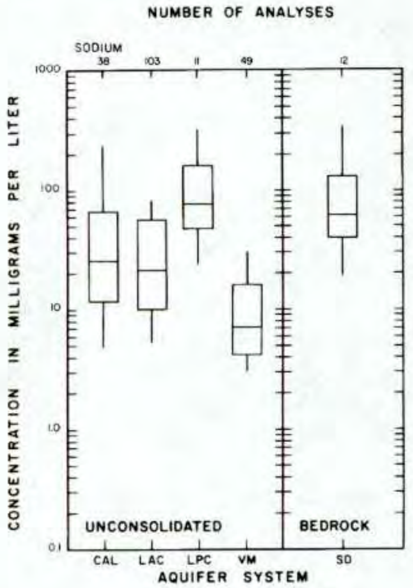


Figure 60. Generalized areal distribution of **Sodium** in ground water from unconsolidated aquifers and statistical summary for Sodium in ground water from all aquifer systems.

more saline waters within the aquifer, and the possibility that these wells are being influenced by more saline waters upwelling from depth into Lake Michigan (William J. Steen, Indiana Department of Natural Resources, personal communication, 1992).

In the Silurian and Devonian Bedrock Aquifer system, the median chloride and sodium levels are 13.5 and 62.1 mg/L, respectively. These values are higher than median values for all unconsolidated aquifers, except the Lacustrine Plain Aquifer system underlying the Calumet. It is important to note that the median value of sodium is nearly five times that of chloride in the Bedrock Aquifer system. The median sodium concentration also exceeds the median chloride concentration in the Lacustrine Plain Aquifer system (figures 59 and 60). The higher sodium concentrations may indicate that salt dissolution is not the only factor affecting sodium concentrations in the Bedrock Aquifer system. Additional sodium could originate from ion-exchange processes in the clay layers of the Lacustrine Plain Aquifer system or in shales overlying the Silurian and Devonian Bedrock Aquifer system.

Relatively little variation is seen in the potassium concentrations of the unconsolidated aquifers (appendix 11). Median values range from 1.7 mg/L in the Valparaiso Moraine Aquifer system to 3.2 mg/L in the Calumet Aquifer system and Lacustrine Plain Aquifer system underlying the Calumet. The median potassium concentration in the Silurian and Devonian Bedrock Aquifer system equaled 5.65 mg/L, which is generally higher than concentrations in the unconsolidated aquifers. Although some potassium concentrations in excess of 10 mg/L are detected, the majority (96.8 percent) of samples from all aquifers have potassium concentrations below this level.

Sulfate and sulfide

Sulfur generally occurs naturally in ground water in the oxidized form of sulfate (SO_4) and the reduced form of sulfide (S). Sulfate concentrations in the Lake Michigan Region display wide variations throughout the unconsolidated aquifer systems (figure 61). Considerable variability in sulfate concentrations is observed in the Calumet, Lacustrine Plain and Lacustrine Plain Aquifer underlying the Calumet Aquifer systems. The highest median concentration is observed in the Valparaiso Moraine Aquifer system. Every aquifer system in the Region, except the portion of the Lacustrine Plain Aquifer system underlying the Calumet, has samples in which sulfate concentrations exceed the SMCL of 250 mg/L.

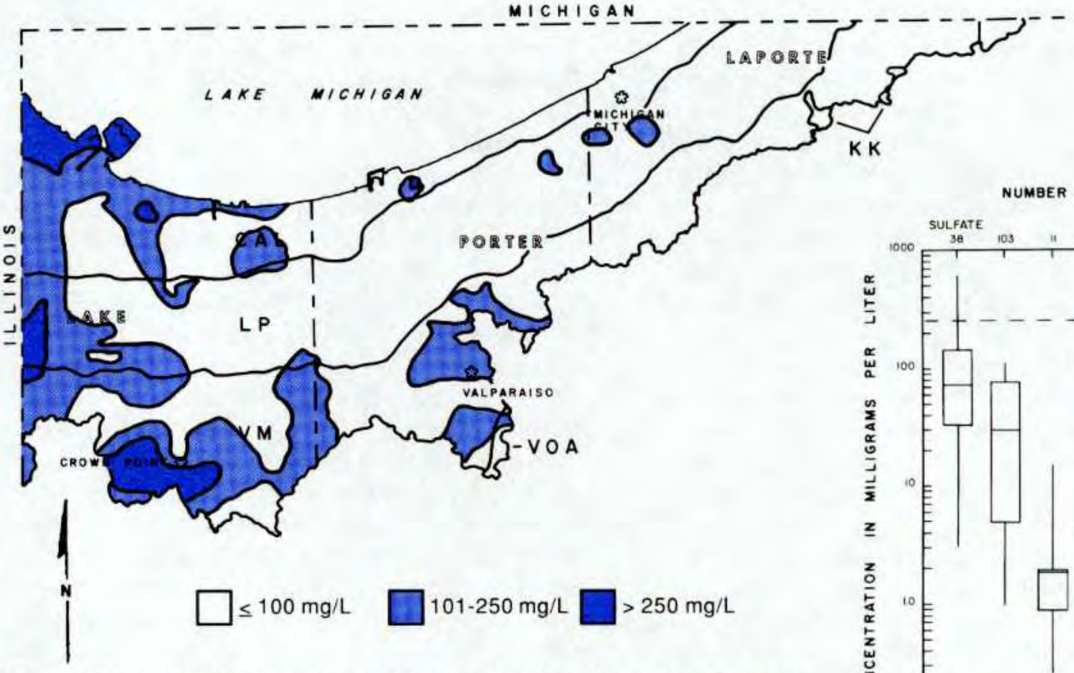
The sulfate values in the Valparaiso Moraine Aquifer system may reflect interactions between percolating ground water and sulfur-based minerals in overlying tills (Hartke and others, 1975). The low permeability of the tills would tend to increase contact time between ground waters and sulfur-based minerals, producing higher overall sulfate concentrations.

There are no apparent depth-related trends in sulfate concentrations, since high and low levels of sulfate are found in both shallow and deep wells. High concentrations could thus, be a result of multiple sources such as dissolution of sulfur minerals, the upward discharge of waters from the bedrock, and possible human-induced contamination.

Very low sulfate concentrations are detected in the Lacustrine Plain Aquifer system underlying the Calumet. As the trilinear diagram for this aquifer demonstrates (appendix 10), sulfate forms an almost negligible percentage of total anions in solution. Sulfate concentrations range from 0.2 to 17 mg/L and have a median value of 1.9 mg/L in the aquifer system. The low sulfate concentrations may result from the reduction of sulfate to sulfide in this deep aquifer.

An extensive degree of variability is observed in the sulfate concentrations of water samples from the Silurian and Devonian Bedrock Aquifer system. Sulfate concentrations range from 3.0 to 343 mg/L and have a median value of 105.5 mg/L in the aquifer system. Approximately 25 percent of all bedrock samples exceed the sulfate SMCL. Many of the samples which have high sulfate concentrations are located in southern Lake County near the Silurian and Devonian bedrock contact. The higher concentrations could result from interactions between ground water and gypsum and anhydrite beds that may be present locally near the Silurian and Devonian contact (Shaver and others, 1986; Doheny and others, 1975; and Curtis Ault, Indiana Geological Survey, personal communication, 1993).

Under reducing, low-oxygen conditions, sulfide is usually the dominant species of sulfur in ground water. Sulfide in ground water can be produced by anaerobic bacteria, which will reduce sulfate during the metabolism of organic matter (Freeze and Cherry, 1979). The form of sulfide in ground water is dependent on pH. In acidic environments (pH less than 7), sulfide generally occurs as dissolved, uncharged hydrogen-sulfide gas



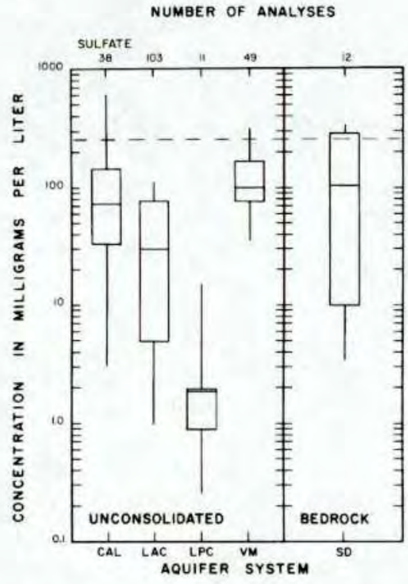
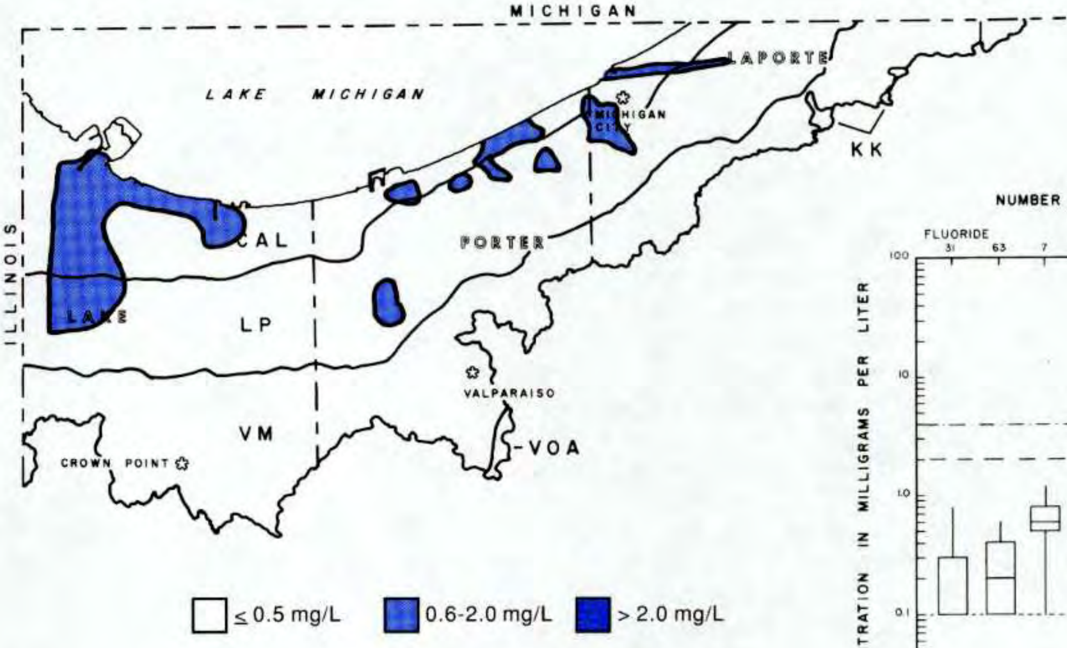


Figure 61. Generalized areal distribution of **Sulfate** in ground water from unconsolidated aquifers and statistical summary for Sulfate in ground water from all aquifer systems.



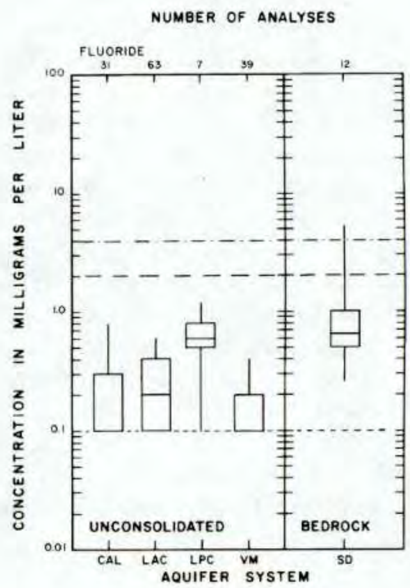


Figure 62. Generalized areal distribution of **Fluoride** in ground water from unconsolidated aquifers and statistical summary for Fluoride in ground water from all aquifer systems.

(H_2S) while under basic conditions (pH greater than 7) hydrogen-sulfide will disassociate into bisulfide (HS^-) and hydrogen ions (Freeze and Cherry, 1979; Konrad J. Banaszak, Geraghty and Miller, Inc., personal communication, 1993). Since median pH values in the Region are generally above 7, HS^- would be the expected form of reduced sulfur in solution. Once out of solution, however, bisulfide and hydrogen recombine to form hydrogen-sulfide gas. (Konrad J. Banaszak, Geraghty and Miller, Inc., personal communication, 1993).

In the Lake Michigan Region, hydrogen sulfide has been encountered in some bedrock wells, particularly in central Lake County (Northwestern Indiana Regional Planning Commission, 1981); however, the occurrence of this gas may not be well documented since disclosure of its presence is voluntary. Hydrogen sulfide is well-known for causing a rotten-egg odor in well water. No SMCL exists for the constituent, but concentrations as low as 1.0 mg/L can render water unfit for human consumption because of odor (Freeze and Cherry, 1979). Hydrogen sulfide is corrosive to metals, and if oxidation to sulfuric acid has occurred, also to concrete pipes. Damage to plumbing and introduction of metals into water supplies are possible results of hydrogen sulfide-induced corrosion.

Fluoride

The concentration of fluoride in natural waters is usually below 1.0 mg/L (Hem, 1985). This generalization is consistent with the median fluoride levels found in the aquifer systems of the Lake Michigan Region (figure 62). A few samples in the Calumet Aquifer system and the Silurian and Devonian Bedrock Aquifer system, however, exceed the SMCL of 2.0 mg/L; and one sample in the Silurian and Devonian Bedrock Aquifer system exceeds the MCL of 4.0 mg/L.

In the unconsolidated aquifer systems, the highest median fluoride concentration (0.6 mg/L) is detected in the Lacustrine Plain Aquifer system underlying the Calumet. The lowest median concentration was measured in the Calumet Aquifer system (0.1 mg/L). Fluoride in the unconsolidated aquifers of the Lake Michigan Region may originate from weathering of fluoride-based minerals, such as apatite and fluorapatite, in tills and moraine deposits.

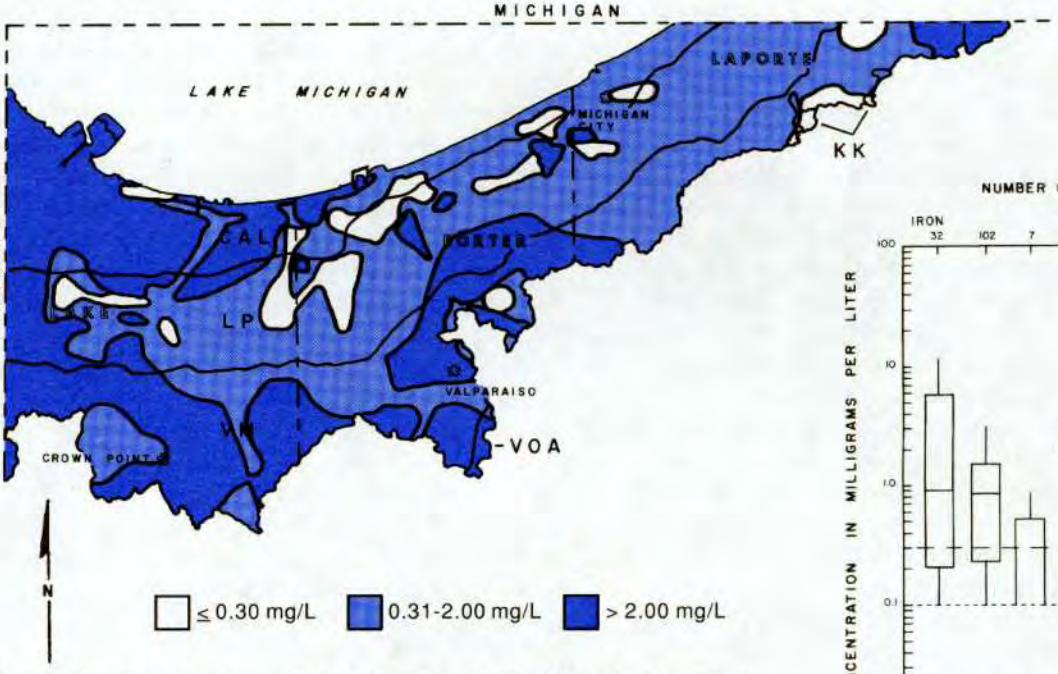
In general, higher levels of fluoride are detected in waters from the bedrock aquifer relative to waters from the unconsolidated aquifer systems. The median concentration of fluoride in waters from the Silurian and Devonian Bedrock Aquifer system is 0.65 mg/L, and the highest observed fluoride concentration (6.0 mg/L) is detected in ground water from a bedrock well near Crown Point in Lake County. Fluoride in the Silurian and Devonian Bedrock Aquifer system probably originates from the dissolution of fluorite in the bedrock or fluorapatite in evaporite deposits.

Problems with excessive fluoride in the water supply of an area near the Region have resulted in disputes over water diversion out of the Lake Michigan Region. In Lake County, just south of the Lake Michigan Region boundary, high concentrations of naturally-occurring fluoride are found in bedrock wells which provide the town of Lowell with its municipal water supply. Because fluoride levels have, at times, exceeded the MCL, the USEPA has imposed an Administrative Order on the town to reduce the levels of fluoride in the public water supply. A recent attempt was made, through the "prior approval" process of the Great Lakes Charter discussed in **Water Resource Development, Legal and political constraints**, to divert water from the Lake Michigan Region to supply Lowell with water. The diversion effort failed, however, because agreement could not be reached among the negotiating parties.

Iron and manganese

Excessive iron is undesirable in ground water because it can stain clothing and bathroom fixtures, cause taste problems, and result in clogged well screens if precipitated. The box plots in figure 63 indicate that a percentage of ground-water samples from each aquifer system have iron concentrations that exceed the SMCL of 0.3 mg/L. In the Lacustrine Plain Aquifer system underlying the Calumet, the calculated median iron concentration is below the detection limit, and cannot be readily quantified. The highest median iron concentration of 2.4 mg/L is detected in the Valparaiso Moraine Aquifer system. Median iron concentrations in all other aquifer systems in the region exceed the SMCL.

High, naturally-occurring iron concentrations in ground water can originate from several potential sources (see box on page 162). The weathering of iron-bearing minerals in surficial tills is probably a significant source of iron in the Valparaiso Moraine Aquifer



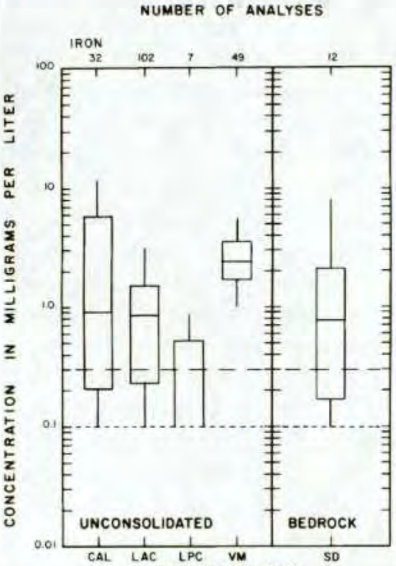
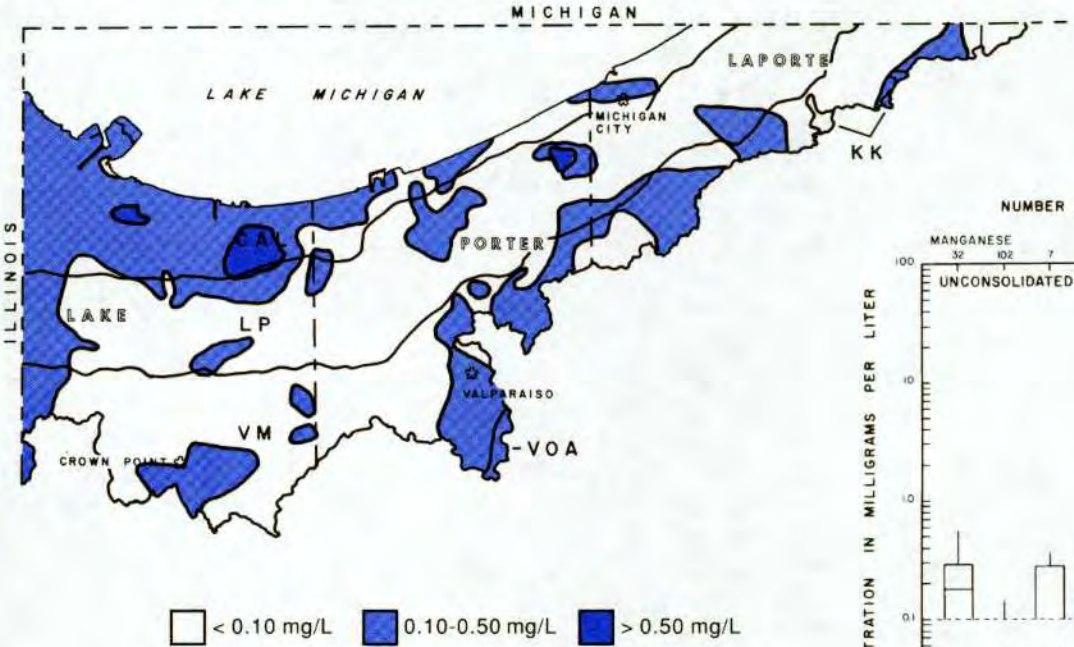


Figure 63. Generalized areal distribution of **Iron** in ground water from unconsolidated aquifers and statistical summary for Iron in ground water from all aquifer systems.



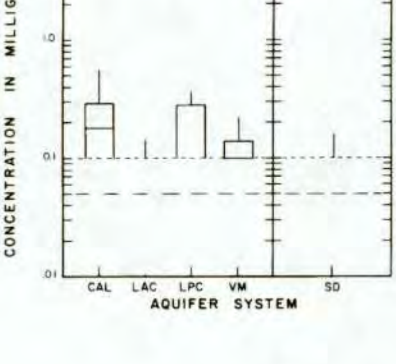


Figure 64. Generalized areal distribution of **Manganese** in ground water from unconsolidated aquifers and statistical summary for Manganese in ground water from all aquifer systems.

system. Lower iron concentrations may result from a scarcity of iron minerals in the aquifer material or metabolic reduction of iron by bacteria.

Manganese is undesirable in drinking water because even small quantities can cause objectionable taste and deposition of black oxides. The SMCL of manganese is 0.05 mg/L, which is only half the detection limit of DOW-IGS analytical techniques. Therefore, the percent of samples exceeding the SMCL in this data set cannot be readily quantified. However, all of the aquifers in the Lake Michigan Region have some samples with manganese concentrations above the detection limit (figure 64 and appendix 9).

The concentration map for manganese is displayed in figure 64. Note that the lowest contour interval indicates areas where the concentration is inferred to be below the detection limit. It is therefore, possible that ground water with manganese concentrations above the 0.05 mg/L SMCL may be encountered in areas delineated by these contours. Manganese in Lake Michigan Region ground water can originate from several different sources. Manganese oxide tends to accumulate in bog or wetland environments (Hem, 1985). In the eastern portion of the Valparaiso Moraine Aquifer system and the Calumet Aquifer system in the vicinity of Indiana Dunes National Lake Shore, relatively high manganese concentrations of 0.10 mg/L or greater appear to be partially associated with bogs or poorly-drained, organic soils. Higher manganese in the northwest portion of the Calumet Aquifer system may also reflect the influence of poorly-drained, organic soils as well as possible anthropogenic influences. Additional sources of manganese in Lake Michigan Region ground waters include manganese oxides associated with stream and lake deposits (Hem, 1985) and manganese-rich Antrim shale gravels which have been identified in the Valparaiso Moraine Aquifer system.

Nitrate-nitrogen

Nitrate (NO_3) is the most common contaminant found in Indiana drinking water (Indiana Department of Environmental Management, [1990]), as well as the prevalent form of naturally-occurring nitrogen in most ground waters (Freeze and Cherry, 1979). In order to delineate the possible origin of ground-water nitrate, Madison and Brunett (1984) presented a concentration criteria for determining if nitrate (as an equivalent amount of nitrogen) originates from natural or potentially, anthropogenic sources; Using these criteria, nitrate levels of less than 0.2 mg/L are considered to represent natural or background levels. Concentrations ranging from 0.21 to 3.0 mg/L are considered to represent a transition between natural and human influences. Concentrations between 3.1 and 10.0 mg/L are interpreted to indicate possible human influences, such as agricultural runoff or seepage from septic tanks and livestock corrals. Above 10 mg/L, the MCL for this constituent, nitrate can cause *methemoglobinemia* in infants.

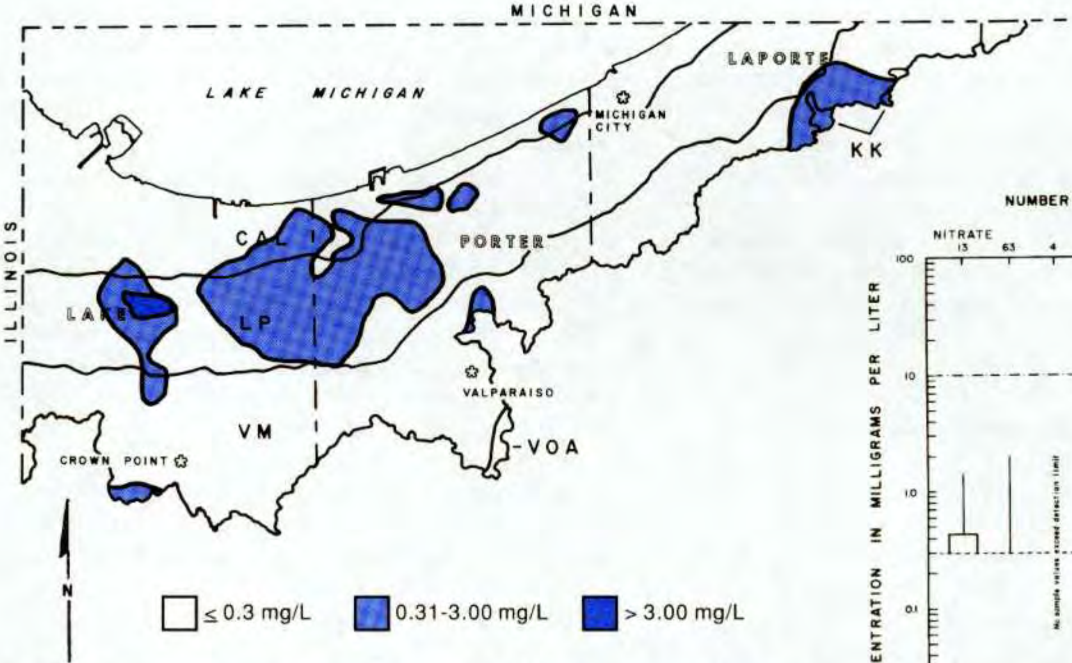
The sample detection limit for DOW-IGS samples in this study is 0.3 mg/L, so the occurrence of "background" nitrate levels, based on the criteria above, cannot be readily quantified. Fortunately, the detection limit is far below the MCL.

In addition to the nitrate data obtained from the joint DOW-IGS sampling project, data from a nitrate study by the Indiana University School of Public and Environmental Affairs (SPEA) were used for the analyses of nitrate in this study.

The median concentration of nitrate in ground water from Lake Michigan Region Aquifers can not be accurately determined, because many samples have nitrate levels below the detection limit. In the unconsolidated aquifer systems, some concentrations in excess of 3.1 mg/L are present in the data (appendix 9), possibly indicating contamination of the aquifer by septic tank leakage, nitrate fertilizers or other sources. Median nitrate concentrations in the Silurian and Devonian Bedrock Aquifer system are also below the detection limit, and the maximum concentration detected in the bedrock wells is only 0.8 mg/L. None of the ground-water samples in the DOW-IGS data set had nitrate concentrations exceeding the 10 mg/L MCL.

Aquifers and depths were not delineated in the ground-water nitrate data from the Indiana University SPEA study, and most of the data are limited to the eastern part of the Lake Michigan Region. However, concentration patterns are similar to those of the DOW-IGS data set, with most concentrations at or near 0.3 mg/L. Therefore, the majority of nitrate concentrations in the Lake Michigan Region appear to be in the transition range between natural and human-influenced levels.

Data from a private well testing program sponsored by the Farm Bureau, Soil and Water Conservation Districts, County Health Departments, Extension Service, and Resource Conservation and Development



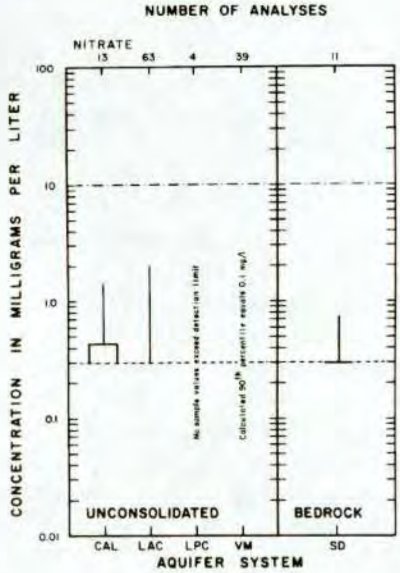
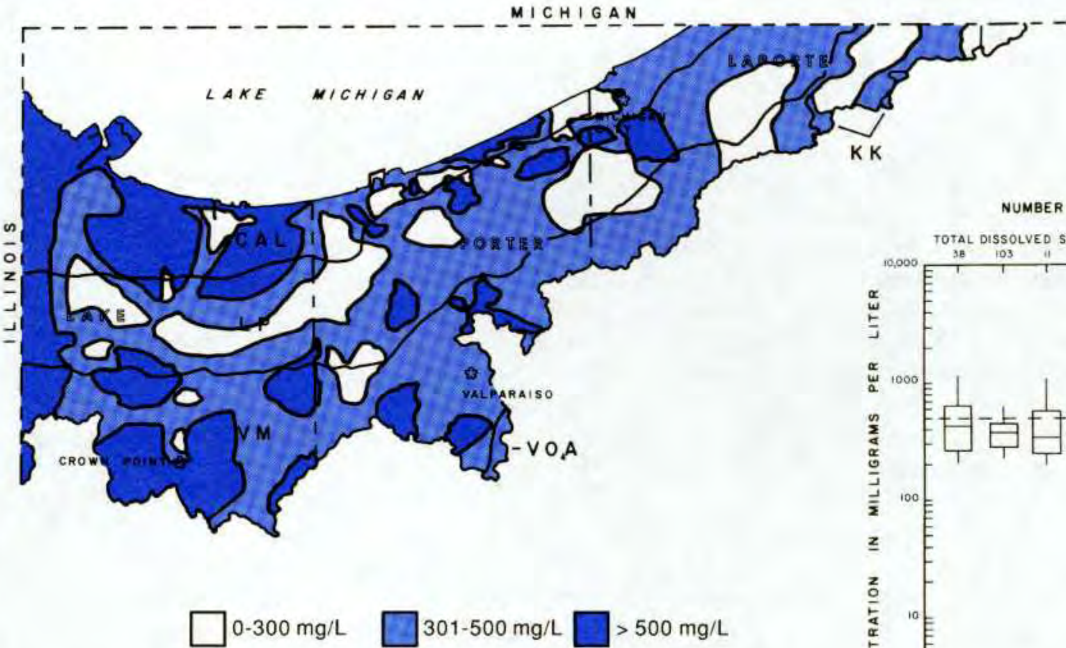


Figure 65. Generalized areal distribution of **Nitrate** in ground water from unconsolidated aquifers and statistical summary for Nitrate in ground water from all aquifer systems.



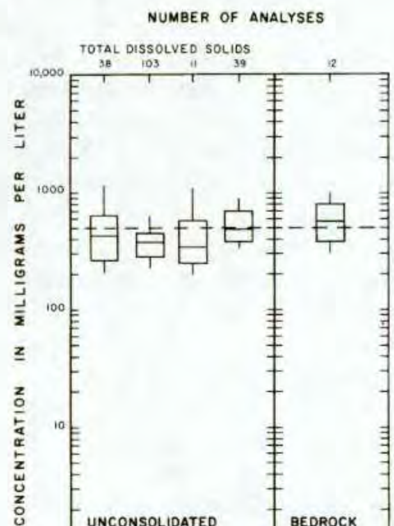


Figure 66. Generalized areal distribution of **Total Dissolved Solids** in ground water from unconsolidated aquifers and statistical summary for Total Dissolved Solids in ground water from all aquifer systems.

Districts indicate that a few nitrate concentrations in excess of 10 mg/L are present in Lake Michigan Region wells in northwest LaPorte County. Nitrate concentrations above the MCL are also detected in nearby Kankakee River Basin wells. In general, however, the data for the Lake Michigan Region seem to indicate that nitrate concentrations above 3.1 mg/L are found in a few, widely-scattered wells. Therefore, the higher concentrations are probably isolated occurrences that are not indicative of regional nitrate contamination.

Total dissolved solids

Total dissolved solids (TDS), the sum of concentrations of all detected ions in solution, are a measure of the concentration of dissolved mineral constituents in water. In general, if the ground water has a high TDS concentration, the levels of the major constituents such as calcium, sodium, chloride, sulfate and bicarbonate, are usually high. Some DOW-IGS samples from all Lake Michigan Region aquifer systems exceed the SMCL of 500 mg/L for TDS.

Total dissolved solids levels in ground water are influenced by various natural and anthropogenic processes. In general, ground waters with long residence times have high TDS levels. Longer residence times result in more interaction between ground water and soluble minerals; thus, high concentrations of dissolved minerals are often found in old ground waters. High TDS levels can also result from the dissolution of very soluble minerals, such as halite or gypsum, and from anthropogenic influences on an aquifer.

Because different factors can influence TDS in ground water, the high TDS levels in some Lake Michigan Region Aquifers (figure 66) are probably the result of several distinct processes. The high median TDS concentrations in the Valparaiso Moraine Aquifer system may be a result of slow infiltration through the Valparaiso Moraine till cap. High TDS levels in some areas of the Calumet Aquifer system wells may reflect discharge from the bedrock or deeper unconsolidated deposits (Shedlock and others, 1992) or local anthropogenic impacts on the water chemistry.

Total dissolved solids can be increased on a local scale by ground-water contamination. In the western portion of the Calumet Aquifer system, some of the areas which have TDS levels greater than 500 mg/L appear to be clustered in urban areas (figure 66), and several shallow wells (less than 50 feet deep) in this area have TDS levels exceeding 1000 mg/L (appendix 9). These elevated TDS levels may reflect local impacts of industrial and municipal activities on water chemistry.

The median TDS concentration of waters from the Silurian and Devonian Bedrock Aquifer system is 573 mg/L. In addition to exceeding the median levels of all Lake Michigan unconsolidated aquifer systems, this concentration exceeds the SMCL. The higher average TDS concentration in the Silurian and Devonian Bedrock Aquifer system probably reflects longer residence time and the dissolution of soluble evaporite minerals such as gypsum and anhydrite.

Beneath the Silurian limestones, highly mineralized, saline waters in Cambrian and Ordovician sandstones are detected. TDS levels as high as 30,000 mg/L are noted by Hartke and others (1975) in these formations. In general, TDS concentrations in these sandstones increase with greater depth and further distance from their inferred recharge areas in northern Illinois. The high TDS concentration and depth to these aquifers makes them impractical ground-water sources at the present.

Ground-water contamination

A ground-water supply that, under natural conditions, would be acceptable for a variety of uses can be adversely affected by contamination from human activities. Contamination, as defined by the Indiana Department of Environmental Management [1988a], occurs when levels of contaminants are in excess of public drinking-water standards, proposed standards, or health protection guidance levels promulgated by the USEPA.

Over the past 100 years, the intensive settlement and the industrial and agricultural practices that accompany development have created ample opportunity for ground-water contamination in the Lake Michigan Region. In the Area of Concern alone (see page 99 for a discussion on Areas of Concern), there are five sites which are on the EPA's National Priorities List (NPL) of "Superfund" sites and 150 known leaking underground storage tanks (Indiana Department of Environmental Management, 1991).

Numerous potential sources of ground-water contamination exist in the Lake Michigan Region, including sanitary landfills, sewage treatment plants, industrial facilities, septic and underground storage tanks, and road-salt storage facilities. Some cases of actual or potential ground-water contamination have already been identified in the Region. For example, in four of five NPL sites in the northwest portion of the Region, ground-water contamination was considered severe enough to justify treatment of the contaminated aquifers (Indiana Department of Environmental Management, 1991).

Ground-water sampling studies

Inorganic and organic substances contaminating ground water in Indiana can include petroleum and petroleum products; metals; chlorides and salts; nitrates; pesticides; and *chlorinated, non-halogenated,* or *aromatic volatile organic compounds* (VOCs). Numerous cases of ground-water contamination within the Lake Michigan Region have been documented by the Indiana Department of Environmental Management (IDEM). A registry of case histories is maintained by the IDEM and provides additional details on chemical contamination.

In the early eighties, concern about ground-water quality in northwest Indiana led to development of a ground-water strategy study for Lake and Porter Counties (Indiana State Board of Health, 1983b). The purpose of the study was to collect and analyze ground-water quality information, delineate aquifer systems, and review the adequacy of Indiana's existing ground-water laws, regulations, and policies for ground-water protection.

Ground water in eight different areas in Lake and Porter Counties was sampled, including water from five areas within the Lake Michigan Region. One ground-water sampling site within the Region is located adjacent to an industrial complex near the lakeshore; the other four sites are near landfills close to the towns of Gary, Griffith, Pines, and Valparaiso. Ninety of the 155 total samples were included in the strategy document for the in-basin portion of the two counties. Ground-water samples were tested for total organic carbon (TOC), chemical oxygen demand (COD), and common inorganic constituents and physical parameters.

The sampling revealed several areas of potential or actual ground-water contamination. Of the 83 in-basin COD samples reported in the ground-water strategy document, seven contained elevated levels, ranging from 17 to 72 mg/L. Eight of the 90 in-basin TOC samples contained more than 5 mg/L TOC; the highest level was reported to be 19.5 mg/L (Indiana State Board of Health, 1983b). No cause for the elevated levels was obvious from the chemical tests conducted, and several areas were recommended for additional study. The data from Gary and the lakeshore area showed extensive areas of actual or potential ground-water contamination. The highest chloride, COD, TOC, and barium levels reported in the document were found in water from wells near the Wheeler area (Indiana State Board of Health, 1983b).

The detection of barium concentrations exceeding 1 mg/L in several domestic water wells near Wheeler prompted a detailed area-wide investigation into the impact of a nearby landfill on ground-water quality in 1990 (Koelpin and Duncan, 1992). Evaluation of more than 130 domestic and monitoring-well samples revealed a statistically significant association between well depth and water quality. No barium concentrations in excess of the MCL were detected in water from wells less than 100 feet deep. High barium concentrations were, however, detected in samples from deep wells completed in glaciofluvial deposits just above the Antrim Shale. The Wheeler site ground-water samples were subsequently analyzed by Stiff diagram; a graphical technique which can demonstrate similarities and differences in solute chemistry among water samples (Walton, 1970; Hem, 1985). The Stiff diagram analysis revealed that water samples with high barium concentrations were chemically similar to samples from deep bedrock wells and dissimilar to wells completed in shallow unconsolidated deposits. In addition, tritium dating revealed that the barium contamination in the samples pre-dated landfill activities. Bedrock was, therefore, implicated in the study as the most probable source of barium in ground water near Wheeler (Koelpin and Duncan, 1992).

Volatile organic compounds (VOCs) have been the focus of numerous monitoring activities within recent years. VOC occurrences in ground water in Indiana have been detected through monitoring efforts and studies conducted by the USEPA, the IDEM, and Indiana University.

Since 1981, the USEPA has been conducting a survey in Indiana on the occurrence of 26 volatile organic compounds in the ground-water supplies of more than 400 community water systems each serving more than 25 persons year-round. In the Lake Michigan Region, detectable levels of at least one VOC were found in *raw water* of four public supplies for in-basin portions of Lake, Porter, and LaPorte counties (Gregg LeMasters IDEM, personal communication, 1993). If VOC levels were above USEPA standards in both raw and *finished water*, corrective action was taken such as well abandonment, mixing of water supplies, or use of treatment systems. For other water supplies, the water utilities were advised to continue monitoring if there were detectable levels of VOCs.

Beginning in 1989, the USEPA has required communities serving more than 3300 residents to monitor their finished water supplies for 59 VOCs and other organics. In the future, results from this monitoring could provide information on the occurrence of VOCs in some ground-water supplies.

While VOCs often are associated with point-source pollution, pesticides and herbicides are more typically involved in nonpoint-source impacts on ground water. In Indiana, however, there is generally less information on pesticide and herbicide contamination than for other substances in ground water.

A major focus of a recent private well-water testing program in Indiana is to collect information on the effects of two widely-used agricultural chemicals, atrazine and alachlor, on rural water supplies. LaPorte County is the only county within the Lake Michigan Region which currently has available data from this program. In addition, nitrate levels in rural water supplies were also examined; a brief discussion of findings for LaPorte County may be found on previous pages of this section under the heading of **Nitrate-nitrogen**.

The private testing program, which is sponsored by the Farm Bureau, Soil and Water Conservation Districts, County Health departments, Resource Conservation and Development Districts, County Extension and other local entities, makes use of *immunoassay* techniques to screen for triazine and alachlor.

The results of the triazine and alachlor screening were assessed in terms of two standards; the *detection limit* (DL) and the *health advisory* (HA). Samples were categorized into one of the following four groups: 1) no triazine or alachlor detected; 2) concentrations above DL, but less than one-half HA; 3) concentrations above one-half HA, but less than HA; 4) concentrations above HA. The detection limits for triazine and alachlor for this study are reported at 0.05 micrograms per liter (μg/L) or parts per billion (ppb) and 0.2 μg/L, respectively.

The triazine immunoassay screen indicates the presence of common triazine herbicides including atrazine (AAtrex), cyanozine (Bladex), and simazine (Princep). Atrazine is the herbicide most often found in private water supplies. Triazine is not considered by EPA to be a carcinogen (cancer-causing agent); but because of other health effects related to triazine, EPA has set a lifetime health advisory (HA) level for Atrazine in drinking water at 3.0 μg/L.

One well in the Lake Michigan Region contained detectable levels of atrazine which were below one-half the Health Advisory level. All the wells sampled in LaPorte County that had triazine detected in them were less than 50 feet deep, and most wells were driven, not drilled.

The alachlor screen indicates the presence of alachlor (Lasso), metalachlor (Dual), or metalaxyl (Ridomil). The test for pesticides provides a relatively low-cost, highly sensitive technique to detect the presence of various groups of pesticides in water. The procedure does not indicate which specific pesticide(s) within a group is (are) present, but it will confirm the absence of pesticides within the group tested at concentrations above the method of detection limit (MDL). The immunoassays may also indicate the presence of some of the breakdown products (metabolites) of pesticides within a particular group.

Alachlor is considered to be a probable human carcinogen. EPA has set a Lifetime Health Advisory level for alachlor in drinking water at 2.0 micrograms per liter. EPA has estimated that if an individual consumes water containing alachlor at the Health Advisory level over a lifetime, there is a theoretical chance of not more than five-in-a-million of the individual developing cancer as a direct result of drinking water containing this pesticide.

Most of the wells within the Region that were sampled as part of the cooperative water well testing project had no detectable concentrations of alachlor or metabolite. One well within the Region did contain alachlor or a metabolite at detectable levels, but not in excess of the Health Advisory levels. Some ground-water samples from LaPorte County did contain alachlor or metalolite concentrations above the Health Advisory level. However, these samples originated from wells located south of the Lake Michigan Basin boundary.

Throughout the entire state, most ground waters from wells sampled as a part of this study contain no detectable amounts of alachlor. Only a small percentage of all well samples had alachlor or metabolite concentrations above the Health Advisory level. As with triazine, most of these samples with excessive alachlor originated from wells less than 50 feet deep that were driven, not drilled. This could indicate that shallow, poorly-constructed wells are more vulnerable to pesticide contamination.

Recent ground-water quality studies in the Grand Calumet River/Indiana Harbor Canal Area of Concern (AOC) have been conducted by the United States Geological Survey. These studies were performed to characterize the general quality of ground water in the Calumet aquifer, assess the extent of aquifer contamination in the AOC, and quantify the effects of ground-water seepage on surface-water resources. Some of the information and interpretations from these studies were utilized by IDEM in developing the Stage 1 RAP for this Area of Concern (Indiana Department of Environmental Management, 1991).

Although relatively few people in northwest Indiana depend on the Calumet aquifer for drinking water, ground-water contamination is a major concern in the AOC because of the subsequent impacts it may have on local streams and wetlands (Indiana Department of Environmental Management, 1993). Computer modeling studies (Watson and Fenelon, 1988; Watson and others, 1989) determined that the Calumet aquifer often discharges ground water into the Indiana Harbor Canal, a large reach of the Grand Calumet River, Lake Michigan, the Silurian bedrock, local wetlands and municipal sewers. Ground-water discharge from the Calumet aquifer is believed to contribute a significant portion of the total pollutant load in some area streams (Indiana Department of Environmental Management, 1991; Fenelon and Watson, 1993).

Ground-water samples for chemical analysis were obtained from a network of 35 USGS wells located along the Grand Calumet River, the Indiana Harbor Canal and Lake Michigan. Fifteen wells were screened at the mid-section or near the bottom of the aquifer to increase the likelihood of intercepting dense contaminant plumes. Some of the wells were emplaced in the discharge zones of flow from suspected sources of contamination; providing information on the extent ground-water seepage could contaminate surface-water resources (Banaszak and Fenelon, 1988).

In July and August 1987, ground-water samples from the well network were collected for chemical analysis. Field analysis was used to determine temperature, alkalinity, dissolved oxygen levels, pH, and *specific conductance* of the samples. Laboratory analysis was subsequently conducted for twenty-four inorganic and eighty-eight organic chemicals. For a complete list of all water quality variables considered in this study, see Banaszak and Fenelon (1988).

Correlations between ground-water quality and land use were interpreted from the 1987 chemistry data. Specific conductance, which is generally proportional to TDS (Hem, 1985), was found to be higher in some wells screened in steel mill slag or contaminated by petroleum products. A few wells had concentrations of mercury, arsenic, lead, chromium or fluoride which exceeded their respective MCLs (see appendix 6). All but one of these wells were located on or near land used for heavy industry (Banaszak and Fenelon, 1988).

The analysis also revealed apparently higher average concentrations of certain organic chemicals in wells around industrial land. Twenty-one of the eighty-eight organic chemicals under consideration were detected in at least one sample, but only phenols and benzene were present in enough samples to facilitate statistical comparisons of concentration between groups of wells. This comparison indicated that the median concentrations of phenols and benzenes were significantly higher in samples from wells in or near industrial areas. Benzene in ground water is often associated with two other organic compounds: toluene and xylene. Two, or all three of these chemicals were simultaneously detected in some samples from industrial areas. This was interpreted by the authors as possibly indicating multiple anthropogenic sources for these VOCs (Banaszak and Fenelon, 1988).

Apparent relations between well depth and certain chemical constituents were also detected. Ground-water temperatures were significantly higher in wells screened in the upper part of the aquifer, while barium concentrations were significantly higher in deeper wells screened in the lower part of the aquifer (Banaszak and Fenelon, 1988).

A second USGS study of ground-water quality in the AOC was recently concluded by Fenelon and Watson (1993). This study includes a more detailed analysis of water-quality and land use relationships, and an assessment of the impact ground-water discharge has on surface water resources in the AOC. Data came from additional chemical analyses, for volatile organic chemicals and cyanide, of ground-water samples gathered in 1988 from the well network used in the 1987 study. This new data was analyzed along with the data from the 1987 water-quality study (Joseph M. Fenelon, U.S.Geological Survey, personal communication, 1993).

Land use and ground-water quality in the Calumet Aquifer system

The Indiana Dunes State Park and Indiana Dunes National Lakeshore (IDSP-IDNL) are two of the most popular nature preserves in the State. These parks protect some unique natural features on the Lake Michigan coast of Indiana, including sand beaches, active sand dunes, and dune ridges that mark former shorelines of ancient glacial lakes. The beaches in the IDSP-IDNL are utilized for recreational purposes, and the forests and interdunal wetlands within the parks provide habitats for various forms of wildlife.

The IDSP-IDNL parks are protected by various state and federal conservation statutes designed to minimize human impacts on the environment of designated nature preserves. However, extensive industrial and municipal development has significantly altered the environment of some areas adjacent to the IDSP-IDNL. This development has consequently created various potential sources of pollution in close proximity to the IDSP-IDNL.

One possible environmental threat to the IDSP-IDNL is ground-water pollution because most of the IDSP-IDNL area is underlain by the Calumet Aquifer system. The unconfined Calumet Aquifer is relatively susceptible to contamination, because it is composed predominately of sand which provides relatively little resistance to ground-water flow. The parks are also down-gradient from several potential contaminant sources including industrial sites, residential communities and highways. Because the Calumet Aquifer is hydraulically connected to interdunal wetlands, streams and ditches in some areas of the Region (Rosenshein and Hunn, 1968b; Arihood, 1975; Shedlock and others, 1992), ground-water pollution in these areas could eventually threaten aquatic ecosystems and wildlife.

Considering the differences in land-use practices, it appears more probable that human-induced changes in water quality of the Calumet Aquifer will be observed in water-quality data collected outside the IDSP-IDNL boundaries than in water-quality data from inside the IDSP-IDNL boundaries. To assess possible differences of ground-water quality related to land use practices inside and outside park boundaries, median values of relevant chemical constituents in ground water from Calumet Aquifer wells inside the IDSP-IDNL were compared with median values in ground water from Calumet aquifer wells outside the parks. Comparisons were made by using two separate box plots for each chemical constituent, one plot for ground water chemistry data inside the IDSP-IDNL, and the other for ground-water chemistry data outside the park boundaries (appendix 12).

Overall, higher median values of TDS, hardness, calcium, sulfate, alkalinity, fluoride, chloride, manganese, sodium and potassium are observed in ground waters from wells outside the boundaries of the IDSP-IDNL, when compared to wells within the boundaries. Median magnesium concentrations are nearly equal in both data sets; and only iron displays a higher median concentration within the IDSP-IDNL. Differences in ground-water chemistry of the two data sets examined, therefore, may reflect differences in land-use practices outside and inside the IDSP-IDNL.

Some wells inside the boundaries of the IDSP-IDNL however, have concentrations of certain constituents that exceed recommended SMCLs. The excessive concentrations of these constituents may reflect geologic and/or human influences on ground-water chemistry.

One geologic factor that can influence the chemistry of ground water is the nature of the ground-water flow patterns. Differences in flow patterns can bring ground water into contact with different geologic material which, through processes such as mineral dissolution and cation exchange, may give the water a distinct chemical character.

Shedlock and others (1992) distinguish three separate flow systems that make up the overall ground-water flow regime in the IDSP-IDNL and surrounding area. The systems vary in lateral extent and are controlled by local and regional variations in topography and geology. The ground waters in each flow system have distinct chemical characteristics which can be used to help locate the discharge areas of the different systems. However, some mixing of waters from the three flow systems occurs in certain wetland areas (Shedlock and others, 1992).

Following the classification scheme of Toth (1963), Shedlock and others (1992) describe a local, an intermediate and a regional flow system. The local flow system receives recharge in the dune-beach complexes and discharges into interdunal wetlands and streams. The ground waters in the local flow system are often calcium and bicarbonate dominated. The intermediate ground-water flow system is recharged at the Lake Border Moraine and discharges south into the Little Calumet River and north into wetlands and streams in the IDSP-IDNL. Ground waters in the intermediate flow system are chemically dominated by calcium, magnesium and bicarbonate. The intermediate flow system is not present in the western half of the region, since the Lake Border Moraine pinches out at the surface around the Burns Harbor area.

In the 1993 study, ground-water quality was compared for five different categories of land-use: heavy industry, light industry, commercial, residential and parks. The comparison determined that ground-water samples from wells in heavy industry areas generally had the highest median concentrations of inorganic ions, while ground water from wells in residential areas and parks generally had the lowest median concentrations of inorganic ions. Concentrations of organic chemicals were generally low; only twenty-four of the eighty-eight different types of organic chemicals under consideration were detected in at least one sample. However, the set of ground-water samples from the industrial areas had the most detections of organic compounds (Fenelon and Watson, 1993). Cyanide was detected in some samples, but no pattern to the distribution of cyanide in ground water could be determined (Joseph M. Fenelon, U.S.Geological Survey, personal communication, 1993).

Subsequent calculations indicate that ground-water seepage may account for some chemical loads in the Grand Calumet River. It is estimated from the data that ground-water discharge could account for 10 percent of the total load of ammonia, chromium, and cyanide; two to six percent of the total load of chloride, fluoride, sulfate, hardness, copper, iron and lead; and small

The regional flow system, which receives recharge in the Valparaiso Moraine south of the study area, flows down to the upper layers of Silurian-Devonian bedrock and discharges into interdunal wetlands and/or to Lake Michigan. In general, waters in the regional flow system are chemically dominated by sodium, calcium, magnesium and bicarbonate at wetland discharge areas, and by sodium, chloride, calcium and bicarbonate at areas closer to the Lake Michigan shore (Shedlock and others, 1992).

In the IDSP-IDNL, many ground-water samples containing low TDS levels are from wells screened at relatively shallow depths (less than 25 feet from the land surface) and in close proximity to the sand-dune complexes. Water samples from many of these wells are relatively dilute and have calcium and bicarbonate as their dominate ions in solution. These shallow wells seem to reflect influence of the local flow system.

The chemistry of shallow ground waters in the wetlands of the IDSP-IDNL appears to be influenced by the discharge of waters from the intermediate and regional flow systems. Ground waters from the intermediate and regional flow system mix with shallow ground waters in wetlands areas, which creates a variable hydrochemical environment (Shedlock and others, 1992). Shallow ground waters that are chemically dominated by magnesium or sodium are present in these wetland areas. Furthermore, these waters generally appear to have higher TDS levels than ground waters in the local flow system.

In addition to the nature of the ground-water flow system, another geologic factor that can affect ground-water chemistry is the amount of organic matter in an aquifer. In particular, organic matter can influence the chemistry of iron in ground water. Decaying plant debris can be a source of organic chemicals which can form complexes with iron that tend to retain iron in solution (Hem, 1960; Oborn and Hem, 1961; Hem, 1985). Furthermore, certain types of bacteria can utilize iron during metabolic processes under anaerobic conditions, which may increase the content of ferrous iron in solution (Oborn and Hem, 1961; Hem, 1985).

Organic matter in swamps and wetlands may account for the higher median iron concentration in waters from wells inside the IDSP-IDNL boundaries. Much of the IDSP-IDNL, especially between Burns Harbor and Michigan City, is wetland or marsh area. Many of the water samples with iron concentrations above the SMCL were taken from shallow USGS wells in or near the wetland areas. Therefore, although there may be numerous site-specific or process-related causes for high iron concentrations in ground water, interaction between ground water and organic matter is probably one of the principal causes (Shedlock and others, 1992).

Although ground-water chemistry inside the IDSP-IDNL appears to be affected by many natural geologic processes, high concentrations of certain dissolved constituents in some samples may reflect human influences on ground-water chemistry. For example, iron and sulfate concentrations in excess of SMCL and elevated levels of trace elements are detected in ground water from wells near the IDSP-IDNL boundaries and down-gradient from coal fly-ash settling ponds. A previous study (Hardy, 1981) concluded that ground waters down-gradient of these ponds were relatively enriched in iron, sulfate and other constituents. It is therefore, possible that seepage from these ponds may be contributing some iron and sulfate into the ground-water flow system up-gradient of the IDSP-IDNL. Another example of potential human impact on ground-water quality in the IDSP-IDNL sited from Shedlock and others (1992) is the occurrence of some sodium-chloride-bicarbonate dominated well samples along the southern boundary of the IDSP-IDNL. These samples may be the result of deicing salt infiltration.

As previously stated, median TDS, median hardness and median concentrations of many ions are higher in ground-water samples from outside the IDSP-IDNL boundaries relative to samples from wells inside the park boundaries (appendix). As with the ground-water quality data from inside the IDSP-IDNL, many of the high levels of chemical constituents in the developed areas may relate to natural variations in the ground-water flow regime or composition of the aquifer. However, the area outside the IDSP-IDNL includes industrialized and developed portions of the Calumet Aquifer system. Thus, the presence of higher median concentrations in the developed areas is suggestive of human-induced changes in ground-water chemistry. Anthropogenic effects would most likely be observed in the developed, western part of the Calumet Aquifer system, where sources of potential ground-water pollutants are located.

The difference in median concentrations between the two sets of wells (see appendix 12) is probably not the exclusive results of contaminatione in developed parts of the Calumet Aquifer. Natural variations in the geology and hydrology in the Calumet Aquifer system will cause local variations in water quality throughout the aquifer. However, the extent to which the differences in median concentrations reflect anthropogenic influences and the extent they represent natural factors cannot be quantified.

amounts of nitrate, mercury, zinc and phenol in the Grand Calumet River. Actual pollutant loads in the river due to contaminated ground water, however, may be much higher than calculated loads since the discharge of localized, but highly contaminated waters into the Grand Calumet River , was not accounted for in this study.

Additional estimates indicate that the East Branch of the Little Calumet River and Indiana Harbor Canal generally receive the greatest pollutant load from direct ground-water discharge. The Silurian bedrock and the sewer system receive intermediate loads, while Lake Michigan receives the smallest relative contaminant load from direct ground-water discharge (Fenelon and Watson, 1993). Contaminated ground water in the AOC, however, is still an environmental hazard to Lake Michigan because of the direct discharge of the Indiana Harbor Canal into the Lake.

Susceptibility of aquifers to contamination

Since contaminants can be transmitted to the ground-water system by infiltration from the surface, the susceptibility of an aquifer system to contamination from surface sources depends, in part, on the type of material that forms the surface layer above the aquifer. In general, sandy surficial layers can easily transmit water from the surface, but provide negligible filtering of contaminants. Clay-rich surface deposits, such as glacial till, generally have lower permeability than sand and gravel which limits the movement of contaminated water. The presence of fractures, however, can locally decrease the effectiveness of a till in protecting ground water. The different basic hydrologic properties of sands and clays make it possible to use surficial geology to estimate the potential for ground-water contamination.

Plate 2 briefly summarizes the susceptibility to contamination of the six unconsolidated aquifers in the Lake Michigan Region. The Calumet, Kankakee and Valparaiso Outwash Apron Aquifer systems are all highly susceptible to contamination from the surface, because they all generally lack surficial clay or till deposits. Susceptibility to contamination of the Valparaiso Moraine Aquifer system and Lacustrine Plain Aquifer system varies considerably with location because of variability in the thickness of overlying tills and aquifer stratigraphy.

In addition to geologic factors, the susceptibility of an aquifer to contamination also depends on local land-use practices. The particular activities occurring upgradient from or directly above an aquifer can influence the potential for contamination and determine what types of contaminants will enter the flow system. Industrial land use, as in the northwest and Burns Harbor areas of the Region, can result in an increased risk of spills or other accidents which may contaminate ground water in the area. Another concern in the industrialized areas is the wide variety of chemicals used in, or produced by, different manufacturing processes, which could result in ground-water pollution by multiple contaminants. Agriculture, a dominant activity in the eastern and southern part of the Lake Michigan Region, may result in ground-water contamination by nitrate fertilizers, pesticides and other agricultural chemicals. Transportation is another land-use activity that may result in ground-water contamination. De-icing salts used on the extensive network of interstate and state highways in the region could contaminate ground- and surface-waters. Furthermore, other chemicals could enter the aquifer systems if accidentally spilled in transit. Despite present environmental regulations and practices, the potential for continued ground-water contamination in the Lake Michigan Region still exists because of the diverse geological nature of the aquifer systems and the intense, varied land-use practices.

Protection and management of the ground-water resource

Major ground-water management and protection activities in Indiana are administered by the IDEM, IDNR, and ISDH. An expanded cooperative effort in the form of the Indiana Inter-Agency Ground-Water Task Force involves representatives of these three agencies as well as the State Chemist, State Fire Marshal, and members of local government, labor, and the business, environmental, and agricultural communities. The Task Force was first formed in 1986 to develop a state ground-water quality protection and management strategy and is mandated by the 1989 Ground Water Protection Act (IC 13-7-26) to coordinate the implementation of this strategy. The strategy is an agenda of state action to prevent, detect, and correct contamination and depletion of ground water in Indiana (Indiana Department of Environmental Management, 1988c). The 1989 act also requires the IDEM to maintain a registry of contamination sites, operate a clearinghouse for complaints and reports of ground-water pollution, and investigate incidents of contamination that affect private supply wells.

Developing a program plan for delineating and managing wellhead protection (WHP) zones for public water supplies is one priority action designated by the State Ground-Water Strategy. The federal Safe Drinking Water Act Amendments of 1986 established the program for protection of wellhead areas for public supply systems from contamination, but requires a state to complete a program plan in order to be eligible for federal financial assistance. As part of the program development plan for wellhead protection, the IDEM identified 218 public water supply systems in Indiana as priority sites for wellhead protection. Nine of the priority sites are located in the Lake Michigan Region. The sites will be used to phase-in delineation and management of WHP Zones during program implementation (Indiana Department of Environmental Management, 1988d).

Determining the relative vulnerability of geographic areas to ground-water contamination is important to developing a management and protection program because of the broad spectrum of potential protection, monitoring, management, and regulatory activities which need to be implemented on a state-wide basis.

Indiana's 92 counties were evaluated by the IDEM to determine the vulnerability of ground-water resources to contamination. Counties which might benefit most from earliest implementation of ground-water management activities were considered as priorities. The priority counties were determined by summing weighted factor scores for 11 criteria. The criteria include numbers of public water wells, private water wells, non-community water wells, ground-water contamination sites, hazardous material spills, underground storage tanks, hazardous waste facilities, sanitary landfills, and abandoned waste sites, as well as county population and geological susceptibility to contamination. Four of the 16 designated priority counties in Indiana lie partly within the Lake Michigan Region and include Lake, Porter, LaPorte, and St. Joseph Counties.

Numerous ground-water protection activities are in-progress in the Lake Michigan Region. The U.S. Geological Survey (USGS) has been contracted by the U.S. Environmental Protection Agency (USEPA) for a 2-phase study within the EPA's Geographic Enforcement Initiative Area in the Region. The USGS study area is bounded on the north by Lake Michigan in Indiana and 80th Street in Illinois, on the south by the Little Calumet River, on the east by Mineral Springs Road in Porter County, and on the west by Crawford Avenue in Illinois.

Phase 1 of the USGS project consists of ground-water level measurement in 500 wells, including over 300 in Indiana; production of regional ground-water flow maps for the unconsolidated and bedrock aquifers; and publication of results. Phase 2 of the project includes ground-water chemistry sampling and characterization of the ground-water chemistry for the area. Water-level maps have been produced and the report of results has been completed. Additional water-level measurements may be repeated in 130 wells. Ground-water sampling for phase 2 of the project was completed in the summer of 1993 and a draft report has been completed (Richard Duwelius, U.S.Geological Survey, personal communication, 1994).

Another USEPA activity within the Area of Concern is the incorporation of relevant information into a Geographic Information System (GIS). Pertinent activities include completing and digitizing topographic map revisions for the area by the USGS in 1991; digitizing historic ground-water level information; mapping man-made fill; and a contract from USEPA and IDEM to computerize water-well logs for Lake and Porter Counties by the Indiana Geological Survey (IGS).

The USEPA and IDEM have also funded a project with the Indiana Geological Survey to define ambient ground-water chemistry in Porter County. The analysis was based on samples from 30 recently-drilled water wells that have well-defined geology developed from gamma-ray log analysis. Chemical analyses of the waters include inorganics, trace metals, methane, and radon. In addition, local entities within Porter County have contracted the IGS to provide aquifer sensitivity analysis for the County.

The LaPorte County Health Department has funded the IGS to define ambient ground-water quality for the county. Similar chemical analyses to that used for Porter County will be used for this county. Twenty wells have been sampled in LaPorte County and another 10 are planned.

WATER RESOURCE DEVELOPMENT

The potential for urban and industrial development depends considerably on the availability of adequate surface-water or ground-water supplies. In northwestern Indiana, abundant fresh water from Lake Michigan has promoted the development of an extensive urban and industrial belt along the southern coast of the Lake. Water supplies in the interior of the Lake Michigan Region come mainly from unconsolidated aquifers, including *glaciofluvial* and *glaciolacustrine* sediments. Bedrock aquifers, however, also provide an important water supply source for the southwestern part of the Region.

Future water demands in the Lake Michigan Region are expected to remain high, especially for both the large population and the manufacturing-based industries in northern Lake and Porter Counties. Therefore, it becomes increasingly important to protect the quantity and quality of existing supplies, and increase the efficiency of water use. Although political and legal constraints limit diversion from Lake Michigan, water supplies in the Region should be adequate to support a variety of water demands in the near future.

WATER USE AND PROJECTIONS

The demand for water in the Lake Michigan Region is dependent on socioeconomic factors, population shifts within, into or out of the Region, and water-use efficiency. The status of the economy can affect water use in the Lake Michigan Region because most of the withdrawals are used for industrial and energy production purposes.

During an economic downturn, water use by manufacturing-based industries may decline because of layoffs, plant closings, and cutbacks in production. Demands for energy may also decline, thus resulting in declines in water use for energy production purposes. Economic growth, on the other hand, may spur an increase in water use for both industrial and energy production purposes.

Population shifts from urban to suburban areas within the Lake Michigan Region, as well as the continued decline in total population may affect water use in the Region. Annual water withdrawals for the major water-use categories were projected through the 1990s to help identify areas of potential conflict between supply and demand. Projections beyond the year 2010 were not included because of data limitations and the variability of socioeconomic factors.

Withdrawal uses

Withdrawal uses involve the physical removal of water from its surface-water or ground-water source. As discussed in the **Socioeconomic Setting** chapter of this report in the section entitled **Water-Use Overview**, the Division of Water maintains a registry of facilities capable of withdrawing at least 100,000 gallons per day of surface water, ground water, or surface water and ground water combined. The Division also maintains annual reports of water used by registered facilities. Reported water use is determined by metering devices, the multiplication of pump capacity and total time of pumpage, or other methods approved by the Division of Water.

It should be emphasized that the term "water use" in this report refers both to total amount of water withdrawn from available sources and to the intended purpose of the withdrawal. The term "use" does not refer to the amount of water which is consumed or made available for reuse within a short period of time.

The portion of the withdrawn water that is consumed varies with the intended purpose of the withdrawal. Water consumption rates for livestock watering and irrigation are highest, ranging from 80 to 100 percent. In contrast, withdrawals for industrial, energy production and public supply uses have much lower consumption rates which range from 3 to 25 percent. Water withdrawn for purposes that have low consumption rates is returned to surface-water or ground-water systems within a short time period, thus creating less potential for significant impacts on water availability.

It should also be noted that the term "withdrawal capability" represents the amount of water which theoretically could be withdrawn by registered facilities if all pumps were operating at their rated capability 24 hours a day. During 1990, total withdrawals by the facilities in the Lake Michigan Region were more than 50 percent of the total withdrawal capability (figure 67).

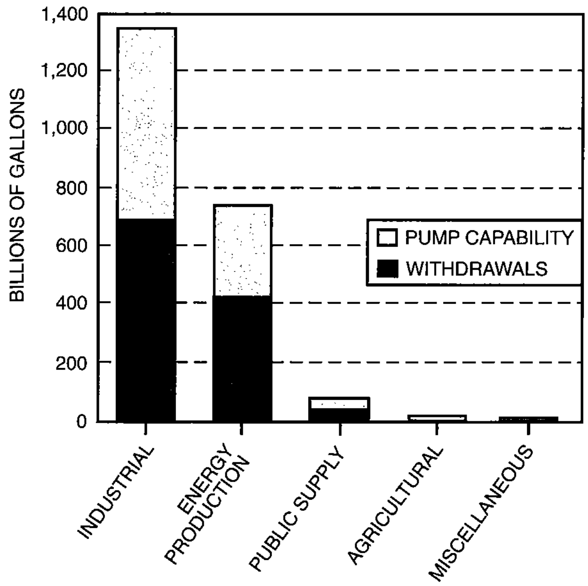


Figure 67. Registered withdrawal capability and reported water use (1990)

Region overview

A total of 80 significant water-withdrawal facilities representing 108 surface-water intakes and 112 wells in the Lake Michigan Region were registered in 1990 (table 23). These facilities had a combined surface-water and ground-water withdrawal capability of about 2185 billion gallons for the year or 5986 million gallons per day (mgd). Most of the registered facilities are located in the vicinity of the industrialized areas along the shores of Lake Michigan and the urban areas in the interior parts of the Region (figure 68). Consequently, these areas also have the highest registered water use in the Lake Michigan Region.

Non-registered facilities include domestic wells, livestock operations, and other facilities capable of withdrawing less than 100,000 gallons of water per day. The total water use for any non-registered facility is fairly low.

In the Lake Michigan Region, surface-water withdrawals accounted for approximately 99 percent of the registered withdrawals during 1990. Water withdrawn for energy production purposes came directly from Lake Michigan, but water withdrawn for industrial, public supply, agricultural and miscellaneous uses came from both surface-water and ground-water sources (table 23).

During 1990, most of the registered withdrawals in the Lake Michigan Region were used for industrial and energy production purposes (figure 67). Withdrawals for both water-use categories constituted about 97 percent of the registered withdrawals in the Region, while the remaining 3 percent of withdrawals were used for public supply, agricultural, and miscellaneous purposes. In 1990, there were no registered facilities grouped under the rural category in the Lake Michigan Region.

Registered facilities

The reported water use by category and county in 1990 is summarized in appendix 13. The number of facilities by category and the amount of water withdrawn, as well as the surface- and ground-water distribution are shown in table 23.

Industrial self-supplied

Industrial self-supplied water use refers to process water, waste assimilation, dewatering, sand and gravel operations, and some cooling and mineral extraction uses. Industrial water use is classified by the Division of Water as withdrawals that a company develops for itself. If an industry also purchases water from a public supply utility, the amount of water that is purchased is included in the public supply water use.

In 1990, industrial self-supplied water use was almost 682 billion gallons, or about 60 percent of the registered water withdrawals in the Lake Michigan Region. About 99.6 percent of the withdrawals for industrial purposes came from surface-water sources (table 23), with Lake Michigan being the primary source.

Many of the registered facilities grouped under the industrial self-supplied category are located in the highly industrialized and urbanized areas along the southwestern coast of Lake Michigan. Facilities are concentrated in northwestern Lake County and in the vicinity of Burns Harbor in Porter County (figure 68).

The various industries in northwestern Lake County accounted for more than 75 percent of the total industrial water use in the Lake Michigan Region. The high water use industries include steel manufacturing plants, oil companies, and both consumer product and building material manufacturers.

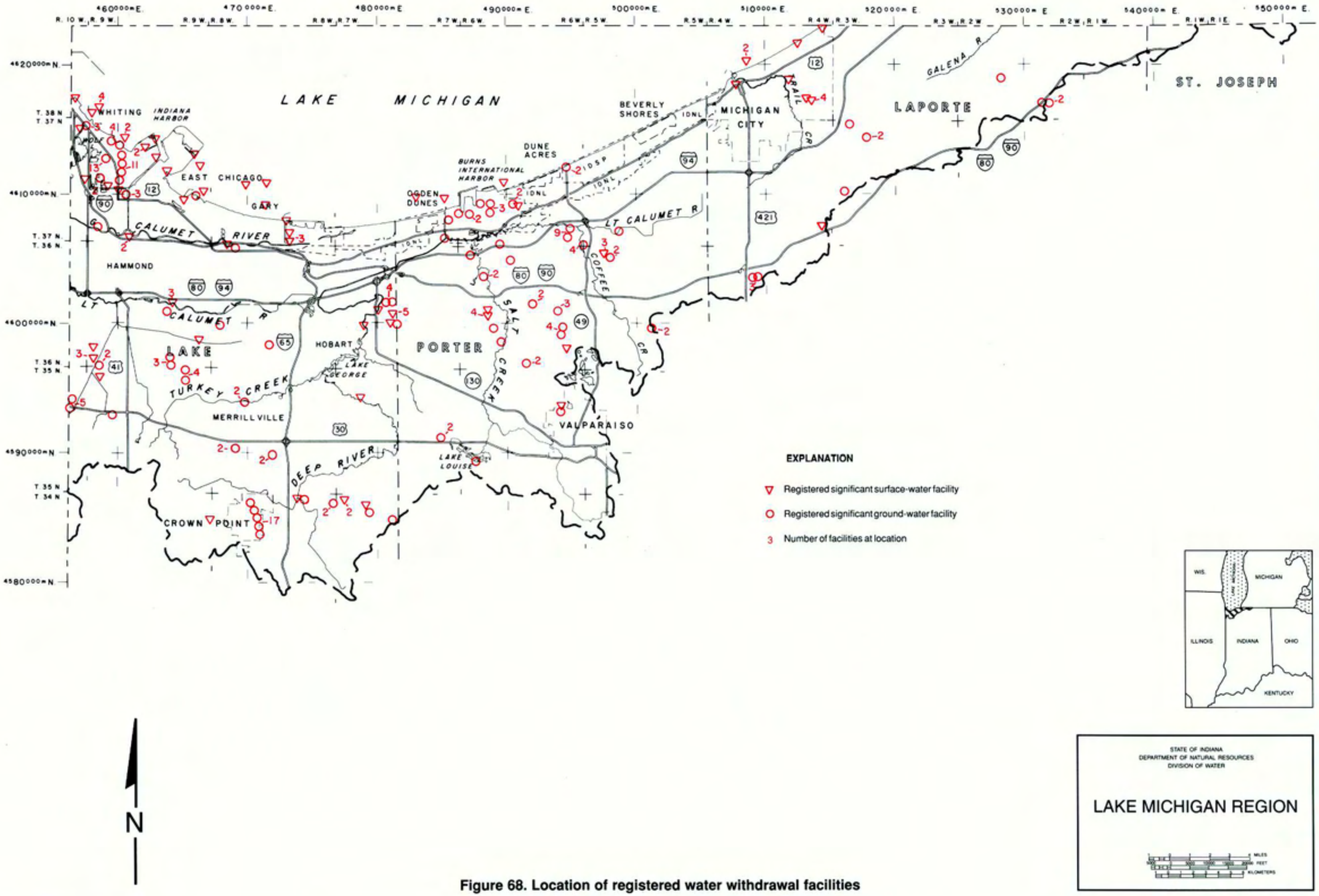


Figure 68. Location of registered water withdrawal facilities

Table 23. Summary of registered water-use during 1990.

Registered Capability (bg): Maximum pump capability of the registered facilities (in billions of gallons).
Withdrawals (bg): Water-use by registered facilities (in billions of gallons).
Capability Development (%): water-use as a percentage of the maximum pump capability of the registered facilities (expressed in percentages).

Water Use Category	Registered Facilities (number)	Withdrawal Source	Withdrawal Points (number)	Registered Capability (bg)	Withdrawals (bg)	Capability Development (%)
Industrial	19	combined	78	1352.3	681.5	50.4
		surface	54	1344.0	678.8	50.5
		ground	24	8.3	2.7	32.5
Energy Production	4	combined	4	731.4	412.0	56.3
		surface	4	731.4	412.0	56.3
		ground	0	0	0	-
Public Supply	25	combined	68	77.3	32.4	42.0
		surface	9	67.9	30.2	44.5
		ground	59	9.4	2.2	23.4
Agricultural	20	combined	53	16.7	0.4	2.4
		surface	36	15.1	0.3	2.0
		ground	17	1.6	0.1	6.3
Miscellaneous	12	combined	17	7.1	1.3	18.3
		surface	5	2.1	0.01	0.5
		ground	12	5.0	1.3	26
Rural	0		-	-	-	-
TOTAL	80	combined	220	2184.8	1127.6	51.6
		surface	108	2160.5	1121.3	51.9
		ground	112	24.3	6.3	25.9

Water use at the industrial complex near Burns Harbor in Porter County constituted about 24 percent of the total industrial water use in the Lake Michigan Region. The large steel manufacturing plants which dominate the complex are the only registered industrial water users in northern Porter County. Overall, the primary metal industry in Lake and Porter Counties accounted for more than 91 percent of the total industrial water use in the Lake Michigan Region.

Industrial water use in the Lake Michigan Region did not vary considerably during 1990 (figure 69). Monthly withdrawals typically ranged from about 50 to 60 billion gallons.

Future industrial water use in the Lake Michigan Region is expected to show a declining trend in the next twenty years (table 24). The projected decline in industrial water use can be attributed to an anticipated decrease in the population of the Region and an increase in water-use efficiency by industries. The methodology used for making the industrial water use projections is explained in a report by the Governor's Water Resource Study Commission (1980).

Energy Production

Energy-production water use includes any self supplied water withdrawals related to the energy produc-

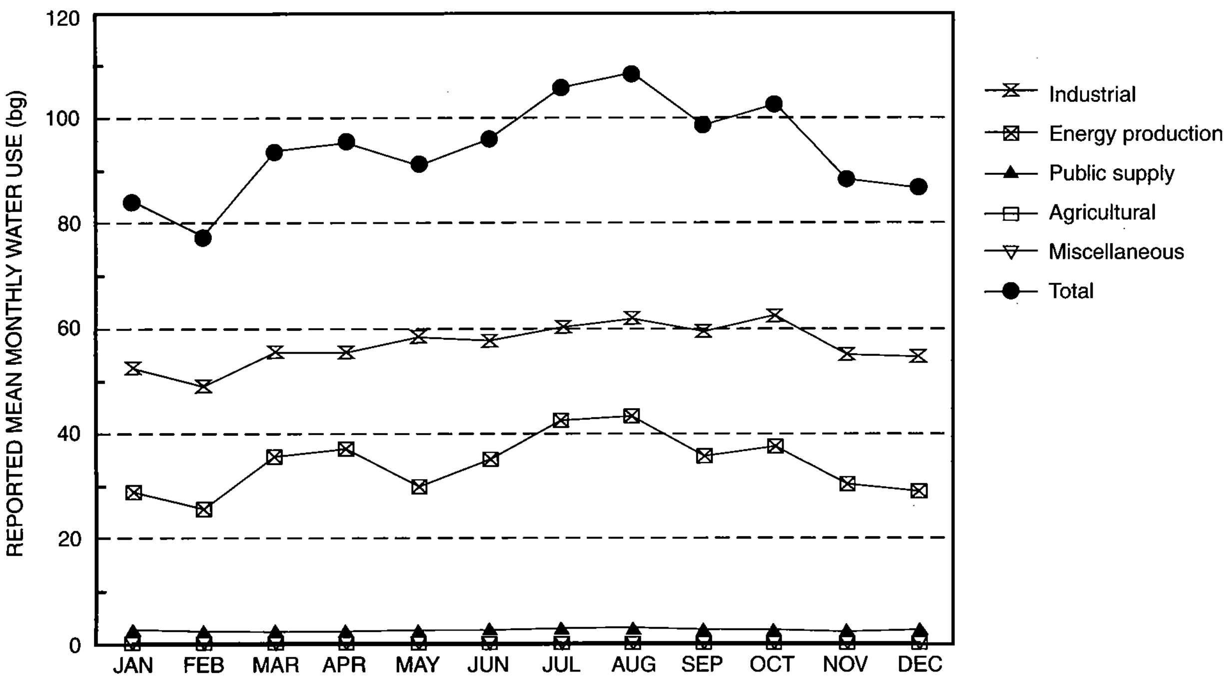


Figure 69. Variation of monthly water use (1990)

tion process. Included are withdrawals for coal preparation, oil recovery, cooling water, mineral extraction, and power generation.

Energy production was the second highest water use in the Lake Michigan Region during 1990 (figure 67). The four facilities registered under the Division of Water's energy production category withdrew almost 412 billion gallons of water from Lake Michigan or more than 36 percent of total withdrawals in the Region. There were no registered ground-water withdrawals in the Lake Michigan Region that were used for energy production purposes in 1990 (table 23).

Of the four facilities registered under the energy production category, three are operated by the Northern Indiana Public Service Company (NIPSCO). These include the D. H. Mitchell Generating Station in northern Lake County, the Bailly Generating Station in northern Porter County, and the Michigan City Plant in LaPorte County. The fourth facility is the Indiana State Line Generating Station in northwestern Lake County and is operated by Commonwealth Edison.

Energy-production water use in the Lake Michigan Region is highest during the summer months (figure 69). The peak energy demands that occur during the months of July and August are for air conditioning and other purposes.

Energy demands in the Lake Michigan Region are expected to decrease as the Region's population continues to decline. Consequently, water use for energy production purposes is also expected to decline barring abnormal conditions.

Public supply

Public supply water use includes withdrawals by both public and private water suppliers that are delivered to users who do not provide their own water. Water suppliers provide water for a variety of uses such as residential, commercial, and industrial use. As presently defined by the Division of Water, public supply also refers to subdivisions, mobile home parks, schools, healthcare facilities, hotels and motels, conservancy districts, and other facilities that have their own water supplies (usually wells) for drinking, washing, cooking and sanitary purposes. However, many of these water use types generally are considered as either domestic self-supplied or commercial uses by some states and organizations.

In 1990, 25 registered water withdrawal facilities in the Lake Michigan Region were classified under the public supply category by the Divison of Water. Of the 25 facilities, thirteen are used by municipal utilities, six are used by schools, three are used by subdivisions, two are used by mobile home parks, and one is used by a state park (table 25).

Public supply water use in the Lake Michigan Region was more than 32 billion gallons or almost 3 percent of total withdrawals in the Region during 1990. The high withdrawal facilities are used primarily for municipal supplies (table 25).

The municipalities of St. John in Lake County and Valparaiso in Porter County are both located partly in the Lake Michigan Region. However, public water supplies for both municipalities are obtained from well fields that are located entirely in the Kankakee River Basin (Indiana Department of Natural Resources, 1990a).

Most of the water withdrawn in the Lake Michigan Region for public supply purposes was derived from Lake Michigan. Many of the large communities in the northern and central parts of the Region are served by public-supply utilities that withdraw water from Lake

Table 24. Projected annual water use for industry and public supply

Category	Water use (million gallons)	
	2000	2010
Industry	605,003	550,674
Public Supply	31,773	31,184

Table 25. Public water supply facilities and type of water use during 1990

County	Facility name	Type	Pump Capability (mg)	Water use (mg)
LAKE	Crown Point	Municipality	2922.3	747.0
	Dyer Water Dept.	Municipality	1232.5	360.0
	East Chicago Water Dept.	Municipality	10219.8	5112.3
	Gary Hobart Water Corp.	Municipality	18980.0	10206.9
	Hammond Water Works	Municipality	18249.9	11172.6
	Independence Hill Water Corp.	Municipality	37.3	11.2
	Lake Station	Municipality	578.2	311.0
	Schererville	Municipality	315.4	3.0
LAPORTE	J.B. Waterworks Inc.	Subdivision	88.3	12.5
	Long Beach Water Dept.	Municipality	657.0	73.3
	Michigan City Dept. Water Works	Municipality	11037.6	2661.9
	New Prairie School Corp.	School	42.0	1.1
	Jean Strachan	Subdivision	63.1	2.0
PORTER	Burns Harbor Estates	Subdivision	131.4	13.9
	Chesterton Utilities	Municipality	1314.0	380.7
	DNR-Dunes	Park	394.2	7.8
	Duneland School Corp.[4]	School	393.1	8.5
	Elmwood Mobile Home Park	Mobile home	72.0	18.4
	Evergreen Mobile Home Park	Mobile home	42.0	1.0
	Gary Hobart Water Corp.	Municipality	8760.2	999.9
	South Haven Water Works	Municipality	1674.0	368.7
	Union Township School Corp	School	126.1	0.4
IN-BASIN			77330.4	32474.1

[4] Four facilities

Michigan. However, the towns of Crown Point, Dyer, Lake Station and Schererville in Lake County and small communities scattered throughout the interior parts of the region use ground-water sources for public water supplies.

Water withdrawals for public supply in the Lake Michigan Region do not vary considerably during the year (figure 69). However, peak water use occurs during the summer months.

According to a Division of Water analysis, total and per capita water use increases with municipal population growth. Per capita use may be higher for municipalities with many industries than for municipalities of comparable size with a small industrial base.

During the 1990s, water withdrawals by public supply facilities are expected to decrease slightly in the Lake Michigan Region, roughly paralleling the anticipated decline in population (figure 5, appendix 1). Water use projections for public supply are presented in table 24.

Agricultural

Agricultural water use, formerly referred to as irrigation water use by the Divison of Water, include withdrawals for agricultural irrigation, golf course irrigation, field drainage and agricultural service purposes. Of the 20 registered facilities in the Lake Michigan Region grouped under the agriculture category, 12 are primarily used for golf irrigation, and eight are mainly used for agricultural irrigation.

In 1990, agricultural water use was about 368 million gallons or 0.03 percent of the total water use in the Region. About 94 percent of the withdrawals for agricultural purposes were used by golf courses, and the remaining 6 percent were used by farms for agricultural irrigation. Withdrawals by the Griffith Golf Center, which constituted about 58 percent of the agricultural water use in the Region, were not only used for golf course irrigation, but also for field drainage, and drinking and sanitary purposes.

Peak withdrawals for agricultural purposes usually occur during the irrigation season of late spring and summer. However, field drainage of severely flooded areas during November and December of 1990 greatly affected total agricultural water use in the Lake Michigan Region.

Withdrawals from surface water sources comprise about 85 percent of agricultural water use in the Lake Michigan Region. Of the twenty facilities that were registered in 1990, eight facilities withdrew surface water only, seven withdrew both surface water and ground water, and five withdrew ground water only.

Agricultural water use demand is not expected to increase significantly within the next decade.

Miscellaneous

Miscellaneous water use refers to withdrawals for fire protection, fish and wildlife areas, pollution abatement, amusement parks, hydrostatic testing, temporary construction dewatering, dust control and recreational field drainage. In 1990, twelve significant water withdrawal facilities in the Lake Michigan Region were grouped under the miscellaneous category.

Withdrawals for miscellaneous purposes constituted only 0.1 percent of total water use in the Region. More than 99 percent of the 1.26 billion gallons of water withdrawn for miscellaneous purposes was used for construction dewatering. There were minor withdrawals for snow making and recreational purposes in the Region. Miscellaneous water use did not vary considerably in the Lake Michigan Region during 1990 (figure 69).

Little or no increase in miscellaneous water use is expected within the next 10 years.

Non-registered use categories

Domestic self-supplied

Domestic self-supplied water use refers to residential water users who obtain water from private wells rather than from public supply systems. An estimated 85,810 residents or 14 percent of the population of the Lake Michigan Region have domestic wells. As stated previously, the Division of Water categorizes withdrawals by commercial or institutional organizations as public supply uses rather than as domestic self-supplied or commercial uses.

Estimated domestic withdrawals in 1990 (2.4 billion gallons) constituted about 0.2 percent of total water use in the Region. Estimates of withdrawals by county were obtained by multiplying the approximated self-supplied population within the portion of each county in the Region by an estimated per capita usage of 76.46 gallons per day (Indiana Department of Natural

Resources, 1982[a]).

Domestic self-supplied water uses for the next 10 years in the Lake Michigan Region are expected to decline, primarily because of projected decreases in population.

Instream uses

Instream uses are defined as non-withdrawal uses taking place within a stream, lake or reservoir. The primary instream uses in the Lake Michigan Region include commercial navigation, commercial fishing, recreation activities, fish and wildlife habitat, and waste assimilation.

Commercial navigation in the Lake Michigan Region plays an integral part in the regional and statewide economy. The harbors along the southern coast of Lake Michigan, which connect northwest Indiana to the St. Lawrence River waterway, are expected to continue handling both midwestern and global cargo.

Water-related recreation needs in the 1990s will depend on user demand, the availability of facilities, and a variety of demographic and socioeconomic factors. Estimates of recreational use demand were made for Lake, Porter, and LaPorte Counties (table 26) based on a survey sample of 278 residents.

The estimates are considered conservative since they were based on the number of respondents who participated in each activity at least once in the past 12 months. The estimates do not imply that all participants use waters in the Lake Michigan Region exclusively as the location of their activity. However, approximately 93 percent of the residents did participate in the activities within their region. In addition, the estimates do not account for visitors from outside the three-county area.

Future recreation needs in the Lake Michigan Region may differ from present needs, but predictions for water-based recreation demand are difficult to make. The change in the age distribution of the Region's population may affect the demand for recreational opportunities; however, although the general population is aging, the trend for older adults is to remain active rather than "slowing down" as was once the norm. In addition, little or no growth in the population is predicted for the Region in the near future. It is unclear how this trend will affect recreation demand.

A number of initiatives which have been taken to stimulate regional economic diversity may influence future water-based recreation demand. A shift toward a tourism and recreation-based economy is seen by locals as an answer to steel-industry downsizing in the Region. Marina development, river-boat gaming casinos, and greater public access could all represent a significant change in Lake Michigan shoreline use. Development of a Coastal Zone Management Program may also enhance recreational opportunities in the coastal zone. In addition, planned improvements to water quality in the lakes, rivers and streams of the Region could also have a positive affect on recreational demand.

Summaries of Region fisheries and wastewater treatment were presented in the **Surface-Water Hydrology** chapter of this report under the subheading **Surface-Water Quality**. The future quality of basin fisheries will depend largely on the water quality and presence of suitable habitat, the availability of sufficient stream flow, stocking activities by the IDNR, and fishing demand. Factors that will help maintain or improve surface-water quality in future years include control of nonpoint-source pollution, upgrading wastewater treatment facilities, improvement in both treatment-plant operations and compliance with discharge limits. Detailed information on wastewater-management plans is available from the Indiana Department of Environmental Management.

Table 26. Estimated recreation participation by local residents of the region

{Data from Indiana Department of Natural Resources}

Activity	Number of participants
Fishing	231,737
Swimming	282,027
Powerboating	78,571
Sailing	20,161
Waterskiing	46,314
Canoeing	26,209
Ice skating	24,193
Rowing	22,177
Jetskiing	20,161
Total	**751,550**
Other activities (enhanced by water)	971,021

The conservation of wetland wildlife habitat was discussed in the **Surface-Water Hydrology** chapter of this report under the subheading **Wetland Protection Programs**. Compliance with existing regulations, implementation of existing programs, and establishment of additional programs will help to ensure the future conservation of wetland and riparian habitats.

SURFACE-WATER DEVELOPMENT

Sources of surface water in the Lake Michigan Region include wetlands and lakes, Lake Michigan, and streams and ditches. Development of the potential sources of surface water depends not only upon the physical availability of water but also upon political and legal constraints.

Lake Michigan

Lake Michigan is by far the major source of surface-water withdrawal use in the Region, accounting for approximately 99 percent of total water withdrawals. In recent years there have been numerous suggestions for using water from Lake Michigan and other Great Lakes as a supply for other regions, especially portions of the western United States. For example, one plan proposed using water from Lake Michigan for the High Plains. Another proposal called for diverting water by pipeline from Lake Superior to the Missouri River, while yet another would have sent water to Wyoming for use in a coal slurry pipeline. Lake Ontario water was also to be diverted for New York City (Bixby, 1986).

Although Lake Michigan and the Great Lakes appear to be a limitless supply of water, the Lakes have a finite capacity. Under present climatic conditions, precipitation accounts for only 1.5 percent of the storage volume of the Great Lakes System (Bixby, 1986). The remaining volume of water accumulated in the past during wetter climatic conditions. Therefore, the long-term supply potential of the Great Lakes System is approximately 1.5 percent of the Great Lakes low-water datum volume, or approximately 90 trillion gallons.

Limitations on use

Various artificial changes such as diversions, consumptive uses, channel modifications, and construction of control structures to manage lake levels have the potential to affect Lake Michigan and the Great Lakes. Changes such as these have occurred in the last century and have become the subject of investigations by the International Joint Commission's (IJC) International Great Lakes Levels Board (1973 and 1993), and the Diversions and Consumptive Uses Study Board (1981).

Diversions

A diversion is a man-made transfer of water outside the basin or from one Great Lake to another. There are presently five major diversions of Great Lakes water. These diversions are regulated by control structures which change the natural water supply to the lakes or bypass a natural outlet. Two of the diversions raise water levels of the Great Lakes by minor amounts by diverting some of the tributary flow of the Hudson Bay southward into Lake Superior. Two interbasinal diversions have no overall effect on the Great Lakes-St. Lawrence River system, except to lower water levels of Lakes Erie and Michigan-Huron due to one of the diversions. The remaining diversion at Chicago, which diverts Great Lakes water through the Sanitary and Ship Canal to the Mississippi River, lowers water levels of the Great Lakes by minor amounts (See box on next page for additional details on the Chicago Diversion).

Both the diversion and control modifications affect the lake levels in terms of inches rather than feet and do not, therefore, constitute major factors in the natural system (International Joint Commission, 1989).

Consumptive use

Consumptive use is water that is withdrawn and not returned to the Great Lakes. It was estimated in the Great Lakes Basin Framework Study in 1975 that total consumptive use for the Great Lakes Basin was 4900 cfs (3.2 billion gpd) (Bixby, 1986). The estimate included water taken directly from the lakes and also from inland sources such as tributary streams and ground water. Approximately 71 percent of the consumptive use was a result of direct withdrawal from the lakes. The three largest consumptive uses in the Great Lakes Basin were manufacturing, municipal supply, and energy production at 50, 17, and 10 percent,

Lake Michigan Diversion at Chicago

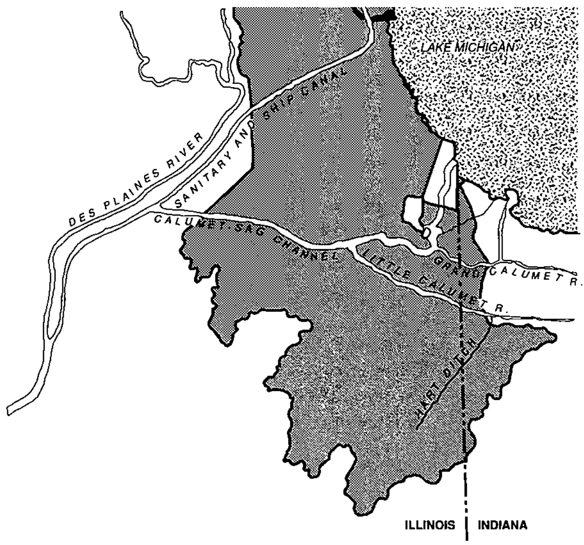
Water supplies for the City of Chicago and other communities in the Metropolitan Sanitary District of Greater Chicago come from Lake Michigan. After the water is used, however, the wastewater treatment plants divert the water to the Illinois River via the Chicago Sanitary and Ship Canal. This process which involves the diversion of water from the Lake Michigan Basin to the Mississippi River Basin is referred to as the Chicago Diversion.

The Chicago Diversion also includes water which is diverted directly into the Illinois waterway system to meet navigation and sanitary requirements and stormwater runoff from the Lake Michigan watershed that was formerly tributary to the Lake. In addition, Lake Michigan water that is used by a number of communities in Indiana is also diverted via wastewater treatment plants into the Little Calumet and Grand Calumet Rivers and eventually ends up in the Mississippi River Basin (see accompanying map).

In the late 1800s, an ambitious program was undertaken to reverse the flow of the Chicago and Calumet Rivers away from Lake Michigan, thus carrying the sewage from the City of Chicago away from its water-supply source. This monumental construction project was necessary to avoid epidemics of waterborne diseases like the outbreak of typhoid and cholera in 1885 which killed 90,000 people. In addition to the sanitary benefit, the project also created a navigation corridor between the Mississippi River system and the Great Lakes.

Water diversion from Lake Michigan into the Mississippi River Basin at Chicago initially began in 1848 upon completion of the Illinois and Michigan Canal. The current diversion by the State of Illinois began in 1900 with the completion of the Sanitary and Ship Canal by the Metropolitan Sanitary District of Greater Chicago.

The reversal of the Chicago River initially took place in 1900 under a permit obtained from the Secretary of War. Litigation resulted and has continued off and on since 1922. The Supreme



Court issued decrees regarding the diversion in 1925, 1930, and in 1967.

Illinois presently operates under the 1967 Supreme Court decree which was amended in 1980. This decree allows Illinois to divert 3200 cfs on an annual basis averaged over a 40-year period. A 5-year accounting period can be allowed to compute this average, but the diversion may not exceed 110 percent of the authorized limit for any one-year period (Great Lakes Basin Commission, 1975c).

respectively (International Great Lakes Diversions and Consumptive Uses Study Board, 1981b).

In the same study, Lake Michigan consumptive use was estimated to be 1530 cfs (approximately 1 billion gpd) or nearly 31 percent of the total use in the Great Lakes Basin. Approximately 67 percent of Lake Michigan consumptive use was attributed to direct withdrawal from the lake. The three largest consumptive uses in the Lake Michigan Basin were also manufacturing, municipal supply, and power production at 51, 12, and 11 percent, respectively.

A more recent estimate of total consumptive use in the basin by Environment Canada (1993) of 4943 cfs shows little change from the 1975 estimate. Because there has been a decline in manufacturing use, percentages of total use by category have probably shifted.

The amount of consumptive use increases progressively through the Great Lakes System. Thus, the effect on water levels is least on Lake Superior, and greatest on Lake Ontario.

In 1985, the International Joint Commission (IJC) predicted that consumptive use by the Great Lakes states and provinces will increase to 8400 cfs by the year 2000. USGS estimates, however, produced a more conservative value of about twice the Chicago Diversion or 6400 cfs (Bixby, 1986).

Impact of diversions and consumptive use on the Great Lakes water

Consumptive use and diversions of water from the Great Lakes Basin have the potential to lower lake levels and produce undesirable effects. Lower lake levels reduce power-generating capacity of hydroelectric plants sited on the lakes; affect vegetation, wetlands, and fish and wildlife populations; and affect recreational boating facilities. Lower water levels of only a few inches can also reduce loading potential of cargo ships and necessitate costly dredging. Disposal of dredge spoil is another potential problem because contamination exists in some nearshore areas. In addi-

Destination of streamflow in the Region

The streams in the Lake Michigan Region may flow from Indiana into Lake Michigan or into the states of Michigan or Illinois. Of the 604 square miles of drainage area within the Region, 81 percent or 489 square miles drain directly into Lake Michigan, and 19 percent or 115 square miles drain into Illinois or Michigan. Most of the stream flow that enters the state of Michigan from the Region eventually flows into Lake Michigan. Little of the stream flow into Illinois, however, is returned to Lake Michigan, but is instead diverted to the Mississippi River. See box on Chicago Diversion for additional details.

Part of the Little Calumet River drains into Lake Michigan and part into Illinois. Stream-flow direction is influenced by a hydraulic divide between Hart Ditch and Deep River and flow conditions in the streams. West of the divide, Little Calumet water generally flows west into Illinois to the Illinois River and eventually to the Mississippi Basin. East of the divide, water in the river flows east into Lake Michigan via Burns Waterway in Porter County.

During flood flows, however, the flow in Hart Ditch and Deep River is split, part flowing east and part west (USACE, 1982). The westward overflow of Deep River floodwater is temporarily stored in a subbasin and returned eastward toward Lake Michigan when flood flows subside.

The Grand Calumet River system also has a hydraulic divide which is located near Columbia Avenue in Hammond. West of Columbia Avenue, the river flows to the west. East of Columbia Avenue, the river flows east or west depending on water level of Lake Michigan, effluent flow, and the influence of wind direction and velocity (Crawford and Wangsness, 1987).

Flow and discharge in the Grand Calumet River are difficult to determine and a regression equation has been developed to estimate flow entering Illinois from Indiana via the Grand Calumet River (Northeastern Illinois Planning Commission, 1985). The equation relates Grand Calumet flow entering Illinois from Indiana to water levels of Lake Michigan and flows from the Hart Ditch gaging station.

Numerous studies have been conducted to determine discharge and flow direction of the western portions of the Little Calumet and Grand Calumet Rivers. Recently, three stream gaging stations were installed by the USGS and IDEM to better define flow and discharge relationships of the Grand Calumet River and Lake Michigan. A description of the gaging stations may be found in the Chapter entitled **Surface-Water Hydrology**.

The contributing drainage area and ultimate destination of water from Wolf Lake are also difficult to determine. Flow direction of water from Wolf Lake is toward Illinois, but the flow direction of the Calumet River near the area of discharge for Wolf Lake appears to be toward the south. Hence, Wolf Lake water would drain to the Mississippi River drainage basin.

Additional details on various aspects of surface-water hydrology may be found by consulting numerous publications listed in the **Selected References** Section of this report.

Drainage destination	Drainage Area (sq mi)
Little Calumet River into Lake Michigan	331
Little Calumet River into state of Illinois[1]	56.6
Drainage into state of Michigan	56.6
Trail Creek and other streams directly into Lake Michigan	93.2
Grand Calumet River and adjoining drainage into Lake Michigan[2]	65
Thorn Creek into Illinois	1.9
Total	604

[1] Indiana portion only- Plum Creek, with a drainage area of 34.1 sq mi, drains from Illinois into Indiana near Dyer

[2] Includes drainage into Wolf Lake which flows to Illinois

tion, existing pollution problems in the lakes are increased by a reduction in dilution potential. However, there can be benefits from lower lake levels such as the reduction of erosion and flood damage.

Legal and political constraints

Present political and legal constraints limit diversion and consumptive use of water from the Great Lakes including Lake Michigan.

Concerns that diversion and consumptive use of Great Lakes water might cause adverse effects on the Great Lakes economy led to the development of a charter calling for management of the Great Lakes basin as one system. The Great Lakes Charter was signed by the governors and premiers of the Great Lakes states and Canadian provinces. It requires that any state or province that is considering approval of a new or increased diversion or consumptive use of Great Lakes water exceeding 5 million gallons per day in any 30-day period notify and consult with the governors and premiers of the other Great Lakes states and provinces.

In addition, a law was passed by the U.S. Congress in 1986. The law requires that any new or increased diversions of Great Lakes water be approved by all of the governors of the Great Lakes states.

Wetlands and lakes

Although some withdrawals occur along wetlands and lakes in the Region, these systems are not considered as probable major water-supply sources because of their limited storage capacity, water-quality considerations and regulatory, economic and environmental constraints (See discussion in **Surface-Water Hydrology, Surface-Water Development Potential** section).

Streams

The largest water withdrawals from streams come from the Grand Calumet and Little Calumet Rivers. Hart Ditch, Deep River and Trail Creek also have a few large-capacity withdrawal facilities. The largest volumes of water withdrawn from streams in the Lake Michigan Region are used for industrial processing and golf-course irrigation.

Stream rights

The impacts of withdrawal uses on stream flows must be considered to determine how the potential for water-use conflicts can be minimized, particularly during a drought. Historically, water users have developed the most readily available source of supply without consideration of the effects of such development on other uses, particularly instream uses. Constraints on water use in a particular location may result from its competing value for various instream and withdrawal uses.

Indiana has long recognized the "riparian rights doctrine". Riparian rights are based on ownership of land abutting a watercourse. Indiana has adopted a modified reasonable-use policy in which each riparian landowner's right to use water from the watercourse is limited to uses that are reasonable under the circumstances. The person who asserts the unreasonableness of the use has the burden of proof.

Withdrawal rights are considered as private rights arising out of land ownership. Instream-use rights, unlike withdrawal rights, may exist both for private individuals and public entities; however, public rights are not held to be paramount to every conflicting private riparian right or public activity. Resolution of conflicting interests as well as statutory expansion of public rights, are influenced by the state's economic interests.

Under Indiana law (I.C. 13-2-4-9), a permit is required for many facilities which withdraw water from a navigable waterway. The navigable river program is administered by the IDNR Division of Water. In the Lake Michigan Region, Lake Michigan and its extensions into Trail Creek (1 mi.), Burns Waterway Harbor (1.3 mi.), and Indiana Harbor have been designated as navigable. The Indiana Harbor Canal, including Calumet River Branch and George Lake Branch, are also considered navigable from the Indiana Harbor to the Grand Calumet River. In addition, the Grand Calumet River has been designated navigable from the Illinois State Line to Marquette Park. The Little Calumet River is also designated navigable from the Indiana-Illinois State Line to Burns Waterway Harbor and navigable for an additional 17.75 river miles to its junction at Kemper Ditch with Interstate 94.

Under the navigable rivers law, permit applications are evaluated for potential impacts on navigability, the environment, and safety of life and property at the withdrawal site. Although the permitting program is directly relevant to water-resource management, it has a number of shortcomings. First, the program is limited in scope because it applies only to navigable rivers and excludes public water-supply utilities. Second, the law is difficult to enforce because no administrative rules have been promulgated. Finally, the program's effectiveness is limited because no defined criteria exist for evaluating the effects of proposed withdrawals.

The existing Indiana stream program does not adequately provide certainty of rights to use, mitigation or resolution of conflicts over withdrawal and conveyance of water from its source, impacts of such withdrawals on other uses and interests, or over competing or conflicting uses. At present, there is no procedure, other than through the courts, by which questions of use may be resolved on a timely basis.

Because of such limitations in existing programs, additional steps may be needed to help protect streams in localized areas. The Natural Resources Commission may establish criteria for determination of minimum streamflow (I.C. 13-2-6.1). If established, the minimum stream-flow criteria may govern the amount of water withdrawn from streams in some areas.

In an ongoing effort to establish a sound framework for administrative and statutory decisions, the Division of Water has contracted researchers to examine technical issues related to surface-water withdrawals. In one study (Delleur and others, 1988), investigators examined the ability of a variety of statistical models to reliably and accurately forecast low flows and assess the severity of a given low flow. The study further explored design flows for waste assimilation.

Another study (Delleur and others, 1990) expanded on the first study by evaluating how much stream flow should be protected from withdrawal in order to provide for instream needs such as fish habitat, waste assimilation, and recreation. This study examined 25 stream gage sites in Indiana, including two sites in the Lake Michigan Region; namely, Trail Creek at Michigan City and Little Calumet River at Porter. The study also suggested a general minimum flow criteria to be applied at a site when a detailed study is not warranted.

Surface-water supply in the Region generally exceeds demand. Although localized or short-term water-quantity conflicts may have occurred among water users, the greatest conflicts in the Lake Michigan Region have been related to water-quality issues. Refer to the chapter on **Surface-Water Hydrology, Supply potential of streams**, for discussion on specific streams.

GROUND-WATER DEVELOPMENT

Ground-water resource availability of the Lake Michigan Region is considered fair to moderate when compared with the rest of the state. Development of ground water in the coastal region has been somewhat limited, due primarily to the proximity of Lake Michigan's vast water resource. Ground-water withdrawals in the interior portion of the Region are used primarily for public and domestic drinking water supplies. Whereas, ground water withdrawals near the coast are used primarily for industrial purposes. The largest ground-water withdrawal in the Lake Michigan Region is used to recover petroleum product.

Ground-water rights

Historically, under Indiana's "common law" approach to water rights issues, a ground-water user was not held liable for damages to surrounding landowners if his use of ground water was reasonable and beneficial, and was not done maliciously or gratuitously. Conflicts involving ground-water supply and demand were handled on a case-by case basis, and often were resolved by court decisions.

In 1982, a new law (I.C. 13-2-2.5) was enacted to provide protection for individuals in Jasper and Newton Counties whose domestic or livestock wells were being adversely affected by declines in ground-water levels caused by nearby high-capacity withdrawals. Under the provisions of this law, the owner of a high-capacity ground-water withdrawal facility (capable of pumping at least 100,000 gallons per day) can be liable for impacts on adjacent domestic wells if high-capacity pumpage has substantially lowered ground-water levels in the area, subsequently causing the domestic wells to fail. In order to have protection under the statute, affected domestic or livestock wells had to meet minimum well-construction standards established by the IDNR. Because ground-water availability conflicts were occurring elsewhere in Indiana, the law was amended on September 1, 1985 to provide protection for small-capacity well owners throughout the state.

Ground-water quantity conflicts have not been a primary issue for the Lake Michigan Region. From September 1, 1985, when the Emergency Regulation statute became effective, to December, 1994, the Water Rights Section of the IDNR, Division of Water has conducted ten investigations in the Lake Michigan Region. Most investigations were made to collect "baseline" ground-water level data as a result of concerns expressed by domestic well owners about nearby high-capacity pumpage for agricultural irrigation, construction dewatering, municipalities, and industry. However, two of the ten investigations resulted in documentation that a dewatering operation for mineral extraction and another for construction purposes had impacted domestic wells, and "timely and reasonable compensation" was provided to the homeowners under the provisions of IC 13-2-2.5.

SUMMARY

In response to legislative directives contained in the 1983 Water Resource Management Act, the Indiana Department of Natural Resources, Division of Water published a report describing the availability, distribution, quality and use of surface water and ground water in the Lake Michigan Region, Indiana. The fourth in a series of 12 regional watershed assessments, this report provides hydrologic data and related information for planners, government officials and others interested in the Region's water resource.

The Lake Michigan Region encompasses a total of 604 square miles (sq.mi.) in northwest Indiana and approximately 241 sq.mi. of Lake Michigan. The Region, as it exists today, forms a portion of two separate major drainage basins. Of the total area in the Region, about 81 percent (489 sq. mi.) is drained by streams that flow directly into the Indiana portion of Lake Michigan. The remaining 115 sq. mi. or 19 percent is drained by streams that flow into the states of Illinois or Michigan.

Most of the streamflow from the Region that enters the state of Michigan eventually enters Lake Michigan. However, little if any, of the streamflow entering the state of Illinois from the Region enters Lake Michigan. Instead, the water travels through the Mississippi River Basin and into the Gulf of Mexico.

Four Indiana counties lie partially within the Lake Michigan Region, but the three counties of Lake, Porter, and LaPorte constitute more than 99.5 percent of the Region's land area in Indiana.

SOCIOECONOMIC SETTING

The Lake Michigan Region is predominantly urban and is one of the state's most heavily populated and industrialized areas. In 1990, approximately 86 percent of the Region's total population of 607,424 resided in urban areas. Fifteen of the 21 urban areas in the Region had population totals of 10,000 persons or greater. Gary and Hammond, the Region's largest cities, had populations of 116,646 and 84,236, respectively.

The total population in the Lake Michigan Region has been declining since the 1970's and is expected to continue to decline for the next two decades. There has been a southward shift of population from highly urbanized areas near Lake Michigan to urban and suburban areas lying near the southern boundary of the Region.

Per capita income in the Region has been variable, and recent unemployment trends have been higher than the state average. Employment and earnings by industy are based to a large extent on manufacturing, trade, services and government. These four economic sectors make up approximetely 81 percent of the total workforce and total earnings in the Region. The service sector has the largest workforce among the economic sectors; and although manufacturing engages only about 22 percent of the workforce, it accounts for the largest payroll (approximately 36 percent). The regional economy is shifting from a manufacturing base to a service and trade base.

Although the Region is highly urbanized in the north, agricultural land constitutes almost one-half of the land. Urban or built-up land accounts for about 29 percent of the Region's land area; forest land for about 17 percent; and water, wetlands and barren land for the remaining 5 percent.

PHYSICAL ENVIRONMENT

The climate of the Lake Michigan Region is classified as temperate continental, which describes areas with warm summers, cool winters, and the absence of a pronounced dry season. Precipitation and temperature throughout the Region vary considerably on a daily, seasonal and yearly basis. Superimposed upon the regional variability are localized weather modifications attributable to the presence of Lake Michigan and the Gary-South Chicago metropolis. Lake-effect processes in northern areas of the Region help to moderate extremes in temperature. The lake effect also causes more cloudiness, on average, and can produce frequent snows. In snow-belt areas of Lake, Porter, LaPorte and St. Joseph County, annual snowfall averages as much as 70 inches, or about twice the normal amount received elsewhere in northern Indiana.

Annual evapotranspiration in the Lake Michigan Region accounts for approximately 25 inches (70 percent) of the 36 inches of normal annual precipitation. The theoretical average annual water surplus of

11 inches is considered adequate for the Region as a whole; however, the variability of rainfall and its uneven geographic distribution can occasionally limit crops and water supplies.

The landscape of the southern part of the Lake Michigan Region is primarily a product of latest Wisconsinan glacial events of the Lake Michigan lobe. Subsequent retreat of the Lake Michigan lobe from the morainal area and development of the ancestral Lake Michigan were responsible for most of the landscape in the northern part of the Region. Major landscape elements include: 1) the Valparaiso Morainal Area which is comprised of the Valparaiso, Tinley, and Lake Border end moraines; and 2) the Calumet Lacustrine Plain. Local relief ranges from a nearly featureless lake plain to more than 100 feet along the crest and northern flank of the Valparaiso Moraine.

The surficial deposits in the southern part of the Region are primarily the result of glacial processes, but the deposits in the northern part of the Region are the result of glacial, lacustrine, coastal, and eolian sedimentation. Tills overlie most outwash sands in the Lake Michigan Region and extend to the surface. However, the thickness and texture of the surficial tills are not uniform across the morainal complex. Thick basal tills cover the surface of the western segment of the Valparaiso morainal complex and a veneer of debris-flow tills is present along the northern slopes and crest of the eastern part of the Valparaiso morainal complex. A relatively impermeable till overlies the sandy core of the Lake Border Moraine and extends to the surface. Fine-grained lacustrine and dunal sands, and medium-grained coastal sands form most of the surficial deposits of the Calumet Lacustrine Plain.

The thickness of unconsolidated deposits generally ranges from 100 to more than 350 feet. Unconsolidated deposits are thinnest in the western portion of the Region and thickest where the Valparaiso Moraine forms a topographic high over a bedrock valley west of LaPorte.

Regional bedrock structure in the Lake Michigan Region is controlled by two principal features: the Kankakee Arch in the southwest and the Michigan Basin in the northeast. Bedrock is not exposed at the surface, but rocks occurring at the bedrock surface range from Silurian to Mississippian age.

Soils associated with the Valparaiso Morainal Area are generally clayey or loamy soils; and sandy soils are found in the Calumet Lacustrine Plain. Soils on the end moraines of the Valparaiso Morainal Area have been developed primarily in clay-rich glacial till. Loamy soils are more common in the eastern part of the morainal area. The soils that are formed on morainal swells and slopes are well-drained, but the soils in plains, ice-block depressions and relict glacial drainageways are poorly-drained. In the Calumet Lacustrine Plain, sandy soils occur on dune and beach complexes and on lacustrine and coastal deposits.

COASTAL ENVIRONMENT

Fluctuations of water levels have occurred on Lake Michigan and the other Great Lakes since they were formed. Changes in lake levels affect extent of flooding, shoreline erosion and shoreline property damage, wetland acreage, depths of navigation channels, and hydroelectric power output. Unusually high lake levels in the 50s, 70s and mid-80s led to numerous investigations concerning causes of lake level fluctuations and potential modifications to the lake system to solve problems related to extreme lake levels.

The amount of erosion or deposition that occurs in any given year at any given location along the shoreline is affected by such natural factors as: physical configuration of the shoreline, direction of sand movement, availability of sand, and seasonal differences in storm intensity. In general, seasonal differences in storm intensity result in a yearly cycle of narrow winter beaches and wide summer beaches. High lake levels and severe storms usually result in the highest erosion rates along the unprotected portions of the Indiana shoreline.

Changes occurring to Indiana's shoreline during historic times are the result of both natural processes and human influence. One of the greatest changes to the shoreline is the existence of peninsulas of man-made land projecting out into Lake Michigan, created primarily for industrial expansion. A total of approximately 4,053 acres of man-made land was created, surveyed and is now patented.

Man-made structures affect sand movement along the shoreline, resulting in erosion of sand in some locations and accumulation of sand in other locations. Numerous examples of both situations exist along the Lake Michigan shoreline.

Although a very limited resource, Indiana's 45-mile shoreline has much to offer to many diverse users; hence, competition and conflicts are inevitable. The shoreline now accomodates a diversity of uses, ranging from heavy industry to environmental preservation.

Management of Indiana's shoreline is now subject to an array of federal, state and local jurisdictions. An inititative is, however, currently underway to build a comprehensive coastal zone management program for Indiana. The state has acquired federal funds to develop a coastal zone management (CZM) program acceptable for inclusion in the federal CZM program. If Indiana is accepted into the federal program, the state will be eligible for approximately $500,000 a year to administer its program.

SURFACE-WATER HYDROLOGY

The surface-water resources of the Lake Michigan Region include Lake Michigan; the Little Calumet, Grand Calumet, and Galena Rivers; Trail Creek; an extensive network of smaller tributary streams and ditches; several natural and man-made lakes; ponds and man-made excavations; and scattered remnants of marshes, swamps, and other wetlands.

The present surface-water hydrology of the Lake Michigan Region is markedly different from the natural drainage conditions that existed prior to permanent settlement of the area. The most extensive changes include modifications of the Lake Michigan nearshore and lakeshore areas and channelization of the Grand Calumet and Little Calumet Rivers.

Of the Region's streams, the Grand Calumet River supports the largest number of high-capacity withdrawals, primarily for industrial purposes. The Grand Calumet River has considerable flow but was not analyzed for supply potential because natural-flow analysis is almost impossible because most of the flow in the river is industrial cooling and processing water and waste treatment plant effluents.

The water-supply potential of the Little Calumet River and its tributaries varies considerably across the Lake Michigan Region because of the geographic variation in flows. The water-supply potential of the Little Calumet River and its major tributaries is greater along the reaches in Porter County than in Lake County. In Lake County, the high variability in flow is mainly due to the low permeability of the soils and the considerable degree of urbanization and development in the northern part of the county. Conversely, greater sustained (low) flows occur in the drainage networks of the Little Calumet River in Porter County because of higher ground-water contributions.

In both the Little Calumet River at Porter and Salt Creek at McCool, base flow comprises about 68 and 64 percent of the respective stream flow during a year of average precipitation. In Hart Ditch at Munster, base flow comprises, on average, only about 43 percent of the total stream flow.

The water-supply potential of Trail Creek is the most favorable of all the streams in the Lake Michigan Region. The surficial sediments in the watershed of Trail Creek are highly permeable compared to other watersheds in the Region. On average, base flow comprises about 76 percent of total stream flow in Trail Creek. At present, registered water withdrawals from Trail Creek are used for irrigation of golf courses.

Flooding in the Lake Michigan Region is primarily due to overbank flow and inadequate storm drainage. Most of the critical flooding occurs along the mainstem and tributaries of the Little Calumet River in Lake County. Extensive development of the area, poor drainage characteristics of the soil, inadequate channel capacity to handle flood flows, and high water table all contribute to prolonged floods. The most disastrous flooding in the watershed is in northern Lake County because of the high concentration of development.

Flooding problems along the mainstem of the Little Calumet River in Lake County are expected to be alleviated to a considerable degree after completion of the Little Calumet River Flood Control and Recreation Project. Work on the project began in 1990 and is scheduled for completion by 1998.

SURFACE-WATER QUALITY

The extensive urban and industrial development that characterizes much of the Lake Michigan Region has had detrimental effects on surface-water resources of the area. Within the Region, only three of 17 selected stream sections evaluated by IDEM were found to fully support designated uses. Consequently, various federal and state agencies have produced strategies to protect and restore the surface-water resources of the area.

Because Lake Michigan is hydrologically connected with other Great Lakes, and because much of the Region's drainage ultimately discharges into Lake Michigan, pollution in the Calumet Area and other areas around the Great Lakes has also been a source of concern for other states and Canadian provinces which surround the Great Lakes.

As a result of such concerns, the first Great Lakes Quality Agreement was signed in 1972 between the United States and Canada. The primary goal of the agreement was to reduce pollutant loads to the Great Lakes and to control cultural eutrophication. Emphasis was placed on municipal and industrial point-source discharge problems.

Early in the 1980s, the Great Lakes Water-Quality Board, a scientific subcommittee of the International Joint Commission (IJC), placed parts of northwest Lake County on a list of areas around the Great Lakes, called Areas of Concern (AOC), where remedial actions were necessary to restore all beneficial uses.

A number of plans and strategies have thus, been developed to improve water-quality conditions in streams in the AOC of Northwest Indiana. Current strategies include: the Northwest Indiana Action Plan, the Remedial Action Plan for the Grand Calumet River/Indiana Harbor Canal-Nearshore Lake Michigan Area Of Concern, the Lakewide Management Plan, and the Great Lakes Initiative. There have also been efforts to improve water-quality in the Trail Creek watershed. The most recent effort is development of a Watershed Management Plan for Trail Creek.

Data from nine of the 22 active IDEM monitoring stations in the Lake Michigan Region are used in this study to analyze selected constituents of streams in the Lake Michigan Region. Data used in the analysis was collected for a 10-year period, primarily spanning the time from the early 1980s to early 1990s. Results are compared to state and federal water-quality standards.

Apparent seasonal trends are noted in median levels of dissolved oxygen within streams in the Lake Michigan Region. The variations in seasonal median DO levels may be inversely related to seasonal changes in median water temperature. Seasonal variations in specific conductance may not be significant for most stations.

Variations in water-quality are observed among samples from different streams and from different locations within the same stream. Lower median concentrations of dissolved oxygen and higher median levels for chloride and specific conductance are observed in samples from the West Branch of the Grand Calumet River than in samples from the East Branch of the Grand Calumet River. Differences in median specific conductance and median DO levels are also observed between the East Branch and West Branch of the Little Calumet River, and between different segments of the Indiana Harbor Canal.

Over the 10-year period from 1982 to 1992, violations of the dissolved-oxygen criteria are observed in a greater percentage of samples from the West Branch of the Grand Calumet River, than in samples from the East Branch. Of the stations in the Indiana Harbor Canal, the highest percentage of DO criteria violations are observed in the Lake George Branch for the same period. DO violations are recorded in fewer samples from the East Branch of the Little Calumet River than in samples from the West Branch. Violations of DO standards are also recorded in samples from Trail Creek, which is a designated salmonid stream.

The levels of certain parameters in some Lake Michigan Region streams have, at times, exceeded applicable water-quality standards. Many samples from the IDEM stream-monitoring stations contain iron levels that exceed the 0.3 mg/L secondary maximum contaminant level (SMCL). Coliform bacteria levels in many of the major streams of the Lake Michigan Region frequently exceed standards established for body-contact recreation. Furthermore, concentrations of cyanide in waters of the Grand Calumet River, the Little Calumet River, and Indiana Harbor Canal have sometimes exceeded the maximum permissible levels for protecting aquatic life.

Various trace metals were detected in both effluent and ambient water samples collected during a 1988 IDEM study to quantify the presence and distribution of toxic substances in the Grand Calumet River and Indiana Harbor Canal. No violations of minimum water-quality criteria for antimony, nickel or zinc were detected in any of the 1988 IDEM samples. Violations of minimum water-quality standards for copper, lead, and arsenic were only detected in samples from the West Branch of the Grand Calumet River. However, minimum-standards may vary within the Grand Calumet River and Indiana Harbor Canal waterway due to variations in hardness. It is therefore, possible that levels of copper, lead or arsenic were present in samples from the East Branch of the Grand Calumet River or the Indiana Harbor Canal at levels above the minimum-standards but below analytical detection limits.

The samples from the 1988 IDEM study of the Grand Calumet River and the Indiana Harbor Canal were also screened for 145 synthetic organic compounds. Thirty-five of the different organic compounds being screened for were detected in ambient stream samples. However, only 11 of the 35 compounds which were found above detectable levels in stream samples were also detected in effluent samples. This difference in number of organic compounds detected was interpreted to indicate that non-point sources may contribute synthetic organic compounds to the Grand Calumet River and Indiana Harbor Canal. Uncontrolled combined sewer overflows and stormwater discharges have also been identified by IDEM as possible sources of potentially toxic substances in the Grand Calumet River and Indiana Harbor Canal.

The IDEM has conducted biological sampling in the Region, including sampling macroinvertebrate communities. Streams in the Region classified as non-supportive of aquatic life include: the Grand Calumet River, Indiana Harbor Canal, Little Calumet River, Burns Ditch, Trail Creek, Deep River, Salt Creek, and Coffee Creek. Streams classified as supportive of aquatic life include Galena River and its tributaries, an unnamed tributary of Little Calumet River near the town of Pines in Porter County, Plum Creek, and Hart Ditch.

Fish population sampling has been chosen by the USEPA and the IDEM as one biological method for assessing Indiana water quality. IDEM and EPA staff, in 1990, sampled a total of 197 headwater and wading stream sites in the Central Corn Belt Plain ecoregion to develop and calibrate an Index of Biotic Integrity for use in Indiana.

Lake Michigan drainageways in northwest Indiana were among three sub-basins sampled for the ecoregion study. In contrast to other subregions sampled, a trend in declining water quality with increasing drainage area was observed in the Lake Michigan drainageways. 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 Basin division of the Lake Michigan drainage includes the Grand Calumet River basin and the West Branch of the 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, because 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 as poor in terms of biotic integrity. Only 10.4 percent 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.

The Indiana State Department of Health (ISDH) is responsible for issuing fish consumption advisories for streams and lakes in the state. Fish consumption advisories are issued for specific lakes and streams, and represent suggested restrictions on the size and species of fish that should be eaten. The Indiana portion of Lake Michigan and tributary streams (Burns Ditch, the Little Calumet River, Trail Creek, and Kintzele Ditch) are all included in a joint fish-consumption advisory due to concerns about PCBs. The advisory applies to the following fish 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 ISDH advises that women of child-bearing age and children should completely avoid eating these fish, and that women past child-bearing age and adult men should limit consumption to one-half pound per week. More stringent consumption advisories, however, have been issued by ISDH for larger fish in Lake Michigan. The following fish from the waters under the advisory should not be consumed by anyone: brown trout and lake trout over 23 inches; chinook salmon over 32 inches, and carp and catfish. The IDEM also advises that no fish species of any size should be eaten from the Grand Calumet River and Indiana Harbor Canal.

Within the Lake Michigan Region, the IDEM had 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 in both streams are cyanide, metals, PCBs, PAHs, and other organic compounds. Contaminated sediments in the Indiana Harbor Canal may represent a threat to Lake Michigan. Some sediments from another stream in the Region, Trail Creek, have pesticide and metal concentrations above background levels. Contaminated sediments are thought to present one of the most serious threats to water quality in the Region.

Navigational waterways, such as the Indiana Harbor and Canal and Trail Creek, require periodic dredging to remove and dispose of accumulated bottom sediment. Although the Indiana Harbor and Canal needs to be dredged, the Corps of Engineers has had great difficulty locating a site to dispose of the contaminated sediments which have accumulated on the bottom.

The 240 square miles of Lake Michigan subject to Indiana jurisdiction is one of the most important natural resources in the state. Thus, maintaining and protecting water-quality in Lake Michigan will be necessary for continued use and development of this valuable resource.

During 1980 and 1981, the Indiana State Board of Health (ISBH)/now the Department of Health (ISDH), examined the relationship between climate and water chemistry in Indiana's Lake Michigan. Water samples were collected from nearshore, offshore, near-surface, and near-bottom of the lake in an attempt to establish spatial and seasonal trends in water chemistry.

Seasonal thermal layering, both vertical and parallel to the shoreline, were identified in the lake during the course of the ISBH study. Differences in concentrations of certain ions were also detected between near-shore and off-shore samples and between shallow and deep samples. Thermal layering was thought to explain the differences in chemistry because it might prohibit mixing. Thermal layering in Lake Michigan does not appear to be permanent or seasonally stable.

In the mid 1970s, two important investigations took place which provided important insights about chemical dispersion and current flow of southern Lake Michigan. One, by IIT Research Institute, examined chemical dispersion of materials from Indiana Harbor Canal into Lake Michigan and as a result, provided evidence that pollution from Indiana Harbor Canal could enter Lake Michigan. The other, by Argonne National Laboratory, examined current movement and pollution transport in southern Lake Michigan. The researchers were able to trace the movement of water from Indiana Harbor Canal to the City of Chicago's South Water Filtration Plant. The Canal water descended as a plume below the surface of Lake Michigan and was carried toward the offshore intake of the Chicago plant by the prevailing current.

Selected data from five water-quality monitoring stations in Lake Michigan are analyzed in this report and compared to legal standards and suggested concentration limits. Analysis indicates that median levels of sulfate, chloride, and specific conductance are similar among the stations. In general, few violations of applicable water-quality standards are observed in Lake Michigan data set. Graphs of median monthly values at three Lake Michigan monitoring stations may indicate that DO levels in Lake Michigan are inversely proportional to ambient temperatures.

Although the data set examined contains few violations of E. coli bacteria, there are times when beaches along the Lake Michigan coastline in Indiana are closed because E. coli counts have exceeded values for full-body contact recreation.

The only other lake besides Lake Michigan which is part of the IDEM fixed-station water-quality monitoring network is Wolf Lake. Data collected from 1982 to 1992 from this station were used in this report to estimate median levels and variability in concentrations of selected water-quality parameters in the lake. None of the Wolf Lake samples contained DO levels below minimum DO criteria for aquatic-life use. However, slightly more than three percent of samples analyzed exceed the upper limit of pH for aquatic-life use. Approximately 81 percent of monthly measurements from Wolf Lake (1988 to 1992) contain E. coli levels below or equal to 10 organisms per 100 ml. The highest single-sample level in the data does not exceed recreational-use criteria, but is above the permissible 30-day average E. coli level. Concentrations of phosphorous and nitrate+nitrite are observed in some water samples from Wolf Lake at levels which may promote algae growth. Nine samples, collected from December, 1988 to October 1991, were analyzed for metals. Concentrations of lead and copper in excess of the detection limit were found in some samples. Mercury was not detected in eight of the nine samples, but was detected at a level of almost twice the established MCL in the remaining sample.

GROUND-WATER HYDROLOGY

Ground-water availability in much of the Lake Michigan Region is considered poor to moderate. Six unconsolidated aquifer systems are defined according to hydrologic characteristics of the deposits and environments of deposition. Three bedrock aquifer systems are defined on the basis of hydrologic and lithologic characteristics.

Only three of the six unconsolidated aquifer systems are laterally extensive in the Lake Michigan Region: the Valparaiso Moraine Aquifer system, the Lacustrine Plain Aquifer system, and the Calumet Aquifer system. The southernmost system, the Valparaiso Moraine Aquifer system is a till-capped deposit cored with fine-to medium-grained sand which contains some gravel lenses. Common thicknesses of this aquifer system generally range from about 10 to more than 100 feet in Lake and Porter Counties, but are greater in LaPorte County. Expected high-capacity yields are 100 to 600 gpm, although yields of up to 800 gpm are reported in some areas.

The Lacustrine Plain Aquifer system consists of a series of aquifers present beneath the Calumet Lacustrine Plain. The individual aquifers consist of fine- to medium-grained glaciolacustrine and coastal sands capped by either lacustrine clays or till. Thickness of individual aquifers frequently ranges from 7 to 90 feet, and averages about 24 feet. Expected high-capacity yields range from 50 to 150 gpm, but yields up to 500 gpm are reported in some areas.

The Calumet Aquifer system consists of fine- to medium-grained sand with dispersed lenses of beach gravel. Beds of interlaminated silt and clay, and deposits of peat and muck confine the aquifer in small areas across the Region. The Calumet Aquifer has not been developed significantly because of its proximity to Lake Michigan, an abundant surface-water source. Expected high-capacity yields for the Calumet Aquifer range from 20 to 100 gpm, but up to 150 gpm are obtained in some areas.

The Valparaiso Outwash Apron, the Kankakee, and the St. Joseph aquifer systems have small areal extent in the Lake Michigan Region but consist of highly-productive glacial outwash sand and gravel with yields ranging from 100 to 1200 gpm.

Silurian and Devonian carbonate rocks form the most utilized bedrock aquifer system in the Lake Michigan Region. However, water-yielding capabilities of the aquifer system are not uniform throughout its extent. It is composed of limestone, dolomite, and dolomitic limestone and is the only bedrock aquifer capable of supporting high-capacity pumpage. Many large-diameter irrigation wells produce 100 to 500 gpm, but small-diameter wells produce 10 to 30 gpm.

GROUND-WATER QUALITY

Ground water in the Lake Michigan Region is generally hard to very hard, neutral to slightly alkaline, and generally dominated by calcium, magnesium, and bicarbonate. Although ground water in the Region is predominantly calcium and bicarbonate dominated, numerous samples are chemically dominated by other anions and cations. The domination of ground water by anions and cations other than calcium and bicarbonate indicates that, locally, there can be considerable variation in the nature of water chemistry in the Lake Michigan Region. A large degree of variation in ground-water chemistry is exhibited in the Calumet Aquifer system; whereas, little variation is exhibited in the Valparaiso Moraine Aquifer system.

In some areas of the Lake Michigan Region, human-induced aquifer pollution has locally diminished the quality and utility of ground-water resources. In most of the Region, however, ground water meets drinking-water standards, although iron commonly exceeds the Secondary Maximum Contaminant Level (SMCL). Other constituents that commonly exceed SMCLs include manganese and total dissolved solids (TDS). Chloride and sulfate concentrations can be variable and are sometimes high; and nearly all aquifer systems in the Region have some samples that exceed the SMCLs. Fluoride also exceeds the SMCL in a few samples in the Calumet Aquifer and in the Silurian and Devonian Bedrock Aquifer systems and even exceeds the MCL in one sample from the Region. Nitrate concentrations are below the MCL for all ground-water samples in the data set.

The Valparaiso Moraine Aquifer system, the most highly mineralized of the Region's unconsolidated systems, has ground water containing the highest median alkalinity and hardness, and the highest median concentrations of calcium, magnesium, iron, sulfate and TDS. Ground water of the Lacustrine Plain Aquifer system underlying the Calumet contains the lowest median concentrations of these constituents except for alkalinity and magnesium.

Alkalinity, TDS, and fluoride concentrations are generally higher in bedrock aquifer water than the unconsolidated aquifers. In addition, hydrogen sulfide gas is most commonly detected in bedrock wells, where reducing conditions are most likely to occur.

Over the past 100 years, the intensive settlement and the industrial and agricultural practices that accompany development have created ample opportunity for ground-water contamination in the Lake Michigan Region. Some cases of actual or potential ground-water contamination have already been identified in the Region. For example, in four of five National Priority List (NPL) sites in the northwest portion of the Region, ground-water contamination was considered severe enough to justify treatment of the contaminated aquifers.

Numerous ground-water sampling studies have been done in the past decade to determine the extent of ground-water contamination in the Region. Since 1981, the USEPA found detectable levels of at least one Volatile Organic Compounds (VOCs) in raw water of four public supplies within the Region. Numerous cases of ground-water contamination within the Region have also been documented by the Indiana Department of Environmental Management. A registry of case histories is maintained by the IDEM and provides additional details on chemical contamination in the Region.

Unconsolidated aquifer systems that are highly susceptible to contamination from surface sources include the Kankakee, Valparaiso Outwash Apron, St. Joseph, and the Calumet. The Valparaiso Moraine Aquifer System can be susceptible where surficial clay layers are absent or discontinuous.

Numerous ground-water protection initiatives have been undertaken in the state in recent years, including development of a Ground-Water Protection Strategy and Implementation Plan and a Wellhead Protection Plan. Special emphasis is currently being placed on northwest Indiana with numerous studies being performed in the Region by Indiana Department of Environmental Management (IDEM), U.S. Environmental Protection Agency (USEPA), U.S. Geological Survey (USGS), and the Indiana Geological Survey (IGS).

WATER USE AND PROJECTIONS

In northwestern Indiana, abundant fresh water from Lake Michigan has promoted the development of an extensive urban and industrial belt along the southern coast of the lake. Water supplies in the interior of the Lake Michigan Region come primarily from unconsolidated aquifers.

In the Lake Michigan Region, surface-water withdrawals accounted for approximately 99 percent of the registered facilities during 1990. Registered water withdrawals in the Lake Michigan Region averaged 1127.6 billion gallons or approximately 3 billion gallons per day in 1990. About 60 percent of the withdrawals were for industrial purposes, and nearly 37 percent were for energy production purposes. The remaining 3 percent of withdrawals were for public supply, agricultural or miscellaneous facilities.

A general declining trend in demand is projected for most water withdrawal uses in the Region, but an increase in demand is projected for instream uses.

WATER RESOURCE DEVELOPMENT

Although there is a general declining trend in demand for water, future water demands in the Lake Michigan Region are expected to remain high, especially for both the large population and the manufacturing-based industry. It is anticipated that most of the demands will be on Lake Michigan because it is by far the major source of water withdrawal use in the Region, accounting for approximately 99 percent of total water withdrawals. There are, however, constraints on development of Lake Michigan and the other Great Lakes. Present political and legal constraints limit diversion and consumptive use of water from the Great Lakes including Lake Michigan. The Great Lakes Charter was signed by the governors and premiers of the Great Lakes states and provinces which requires that any state or province that is considering approval of a new or increased diversion or consumptive use of Great Lakes water exceeding 5 million gallons per day in any 30-day period notify and consult with the governors and premiers of the other Great Lakes states and provinces. In addition, a law passed by the U.S. Congress requires that any new or increased diverions of Great Lakes water be approved by all of the governors of the Great Lakes states.

Lakes and wetlands will continue to provide a wide range of recreational opportunities, fish and wildlife habitat, various hydrologic benefits, and, in a few cases, minor water supply sources. However, these systems are not considered as significant sources of supply because of their limited storage capacity, water-quality considerations, and regulatory, economic and environmental constraints.

The largest withdrawals from streams come from the Grand Calumet and Little Calumet Rivers. The largest volumes of water withdrawn are used for industrial processing and golf-course irrigation. Despite the constraints discussed above, surface-water supply in the Region generally exceeds demand. Although localized or short-term water-quantity conflicts may have occurred among water users, the greatest conflicts in the Lake Michigan Region have been related to water-quality issues.

Ground-water resources availability of the Lake Michigan Region is considered fair to moderate when compared with the rest of the state. Development of ground water in the coastal region has been somewhat limited, due primarily to the proximity of Lake Michigan's vast water resource. Ground-water withdrawals in the interior portion of the Region are used primarily for public and domestic drinking water supplies. Whereas, ground water withdrawals near the coast are used primarily for industrial purposes.

Ground-water quantity conflicts have not been a primary issue for the Lake Michigan Region. Since the Emergency Regulation statute became effective, the Water Rights Section of the IDNR, Division of Water has conducted ten investigations in the Lake Michigan Region. Two of the ten investigations resulted in documentation that a dewatering operation for mineral extraction and another for construction purposes had impacted domestic wells, and "timely and reasonable compensation" was provided to the homeowners under the provisions of IC 13-2-2.5.

GLOSSARY

ablation - describes processes that remove snow or ice from a glacier, including melting, evaporation, wind erosion, and sublimation

accretion - an increase by natural growth or by gradual external addition

action level - the Food and Drug Administration's recommended limit for a toxic substance in the edible portion of a fish, above which fish are not safe to consume and interstate sales are not allowed

acute aquatic criterion - "AAC", the highest concentration of chemical that, if met instream will protect the aquatic life present from mortality or other irreversible effects due to short-term exposure.

adiabatically - occurring without loss or gain of heat

air mass - a large portion of the atmosphere that is fairly uniform in temperature and humidity

alluvium - a general term describing deposits of clay, silt, sand, gravel, or other particulate rock material in a streambed, on a floodplain, or on a delta

anion - An atom or molecule that has gained one or more electrons and posseses a negative electrical charge.

anthropogenic - relating to the impact or influence of humans or human activities on nature.

aquifer - a saturated geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients

aquifer system - a heterogeneous body of permeable and poorly permeable materials that functions regionally as a water-yielding unit; it consists of two or more aquifers separated at least locally by confining units that impede ground-water movement, but do not affect the overall hydraulic continuity of the system

aquitard - a confining layer that retards but does not prevent the flow of water to or from an adjacent aquifer

argillaceous - pertaining to, largely composed of, or containing clay-sized particles or clay minerals

aromatic compound - any of a class of organic compounds containing an unsaturated ring of carbon atoms, as benzene or naphthalene and their derivatives, and usually having an agreeable odor

artesian - see confined

back-barrier - refers to an environment which lies landward of an elongate sand ridge extending generally parallel with the shore

backwater - water held or forced back, as by a dam, flood, tide, etc.

bank storage - the water absorbed into the banks of a stream channel when the stage rises above the water table, then returns to the channel as effluent seepage when the stage falls below the water table

basal contact - the bottom interface of a rock unit

basal tills - refers to tills originating from the zone of the glacier near the bed

base flow - the portion of stream flow derived largely or entirely from ground-water discharge

benthic - describes organisms, sediment, and other material at the bottom of an aquatic system

bioaccumulative - in this usage, referring to or relating to substances capable of undergoing bioconcentration in organisms

biochemical oxygen demand (BOD) - the amount of dissolved oxygen needed for the decomposition of organic matter in water

bioconcentration - the increase in concentration of the chemical of concern and its metabolites in or on the target organisms (or specified tissue) relative to the concentration of the chemical of concern in the ambient water

bioturbation - biotic processes, such as direct uptake and disturbance, which separate materials, including contaminants, from bottom sediments in an aquatic ecosystem and make such materials bioavailable to accumulate in the food chain

bog - a poorly drained wetland, usually found in a glacial depression, which is characterized by the presence of saturated organic soil (peat) and acidic ground water; plant decomposition is very slow in this environment

calcareous - describes a rock or sediment that contains calcium carbonate

carcinogenic - capable of producing a cancer

cation - an atom or molecule that has lost one or more electrons and possesses a positive charge.

centrarchid - an individual that is a member of the sunfish family. The sunfish family includes the black basses, rock bass, sunfish, and bluegill

channel slope - the difference in elevation between points 10 percent and 85 percent of the distance along the channel from a gaging station (or discharge point) upstream to the watershed boundary, divided by the distance between the two points; expressed in feet per mile

channelization - in this usage, any excavation and construction activities intended to widen, deepen, straighten or relocate a natural river channel; the term does not include maintenance activities on existing channels, such as the clearing of debris or dredging of accumulated sediments

chlorinated - introduction of a halogen (chlorine) into an organic compound

chronic aquatic criterion - "CAC", the highest concentration of chemical that, if met instream will protect the aquatic life present from toxic effects due to long-term exposure, e.g., adverse effects on growth and reproduction

colluvium - loose rock debris at the foot of a slope or cliff deposited by rock falls, landslides and slumpage

combined sewer overflow - a discharge composed of untreated or partially treated sewage mixed with stormwater

confined - describes an aquifer which lies between impermeable formations; confined ground-water is generally under pressure greater than atmospheric; also referred to as artesian

conformable - describes strata or groups of strata lying one above another in parallel order

contaminant (drinking water) - as defined by the U.S. Environmental Protection Agency, any physical, chemical, biological, or radiological substance in water, including constituents which may not be harmful

continuous-record station - a site on a stream or lake where continuous, systematic observations of stage and/or discharge are obtained by recording or nonrecording instruments and periodic measurements of flow

crest-stage station - a site on a stream or lake where peak stage and/or discharge data are collected systematically over a period of years

debris-flow tills - a high-density flow of water-laden sediment which results from the direct action of gravity on a body of sediment, with properties indicating a degree of internal strength

deltaic sequences - a succession of deltaic deposits arranged in chronologic order to show relative position and age with respect to geologic history as a whole

detection limit - is the amount of constituent that produces a signal sufficiently large that 99 percent of the trials with the amount will produce a detectable signal 5 X the instrumental detection limit

diatom - any of numerous microscopic, marine or fresh-water algae having siliceous cell walls

direct runoff - see runoff, direct

dissecting - the process of being cut by erosion into hills and valleys or into flat upland areas separated by valleys

drainage basin - the land area drained by a river and its tributaries; also called watershed or drainage area

drawdown (ground water) - the difference between the water level in a well before and during pumping

dune - a sand hill or sand ridge formed by the wind

ecoregion - an area or region of relative homogeneity in ecological systems. It is defined by map overlays of soil, geology, geomorphology, potential natural vegetation, and land use. Six ecoregions are recognized in Indiana: Interior River Lowland, Interior Plateau, Eastern Corn Belt Plain, Central Corn Belt Plain, Southern Michigan-Northern Indiana Till Plain, and Huron-Erie Lake Plain

ecosystem - the community of plants and animals interacting together and with their physical and chemical environment

effluent streams - a stream or reach of a stream that receives water from the zone of saturation and provides base flow; its channel lies below the water table

end moraine - see moraine, end

englacial channels - refers to channels occurring within the glacier but above any debris-rich basal zones

eolian - describes sediments deposited after transport by wind

ephemeral gully erosion - see erosion, ephemeral gully

epilimnion - the uppermost layer of water in a lake, characterized by an essentially uniform temperature that is generally warmer than elsewhere in the lake and by a relatively uniform mixing caused by wind and wave action

erosion, ephemeral gully - uneven removal of soil on tilled land caused by runoff waters converging and flowing along a concentrated flow path, causing scouring of land; a short-term feature, obscured by tillage, which normally occurs more than once per year

erosion, gully - uneven removal of soil by running water that forms distinct, narrow channels that are larger and deeper than rills and that cannot be obscured by normal tillage operations

erosion, rill - uneven removal of soil by running water that forms many small, closely-spaced channels, typically a few inches deep, that can be obscured by normal tillage operations

erosion, sheet - removal of a thin, fairly uniform layer of soil from an extensive area of gently sloping land by broad, continuous sheets of running water or by wind

eutrophic - in this usage, streams or lakes characterized by an abundant accumulation of nutrients that support a dense growth of plant and animal life, the decay of which depletes the shallow waters of oxygen in summer

eutrophication - in this usage, a general term describing the process by which lakes and streams become enriched by high concentrations of nutrients such as nitrogen and phosphorus

eutrophy - the state of being eutrophic; see above

evapotranspiration - a collective term that includes water discharged to the atmosphere as a result of evaporation from the soil and surface-water bodies and by plant transpiration

facies - features, such as bedding characteristics or fossil content, which characterize a sediment as having been deposited in a unique environment

fecal coliform - bacteria that occur naturally in the intestines of humans and animals; bacterial counts in waterways are used as indicators of pollution from human and animal waste

fen - a saturated wetland characterized by the presence of basic or calcareous ground water (as contrasted to a bog); often found as seepage areas on gentle slopes comprised of glacial deposits

finished water - water that has been treated and is ready for distribution

flood, 100-year - a statistically-derived flood discharge having an average frequency of occurrence of once in 100 years, or a one percent chance of being equaled or exceeded in any given year

flowing well - a well completed in a confined aquifer in which the hydrostatic pressure is greater than atmospheric pressure, and the water rises naturally to an elevation above land surface

fluvial - of or pertaining to rivers

foreshore - the ground between high-water mark and low-water mark

fossiliferous - containing fossils, which are preserved plant or animal imprints or remains

gamma-ray logs - the radioactivity log curve of the intensity of natural gamma radiation emitted from rocks in a cased or uncased borehole. It is used for correlation, and for distinguishing shales and till (which are usually richer in naturally radioactive elements) from sand, gravel, sandstone, carbonates, and evaporites

geomorphic - describes physical characteristics of the land surface that are the result of geologic processes

glacial lobe - one of the lobate protrusions of the margin of a slowly moving ice mass (glacier) originating from the compaction of snow

glaciofluvial - of or pertaining to rivers associated with glaciers

glaciolacustrine - pertaining to, produced by, or formed in a lake or lakes associated with glaciers

grab sample - water collected at a single location and at a single time as opposed to a sample composited over space or time

granitic - a term loosely applied to any light-colored, coarse-grained plutonic rock containing quartz as an essential component, along with feldspar and mafic minerals

ground-water discharge - in this usage, the part of total runoff which has passed into the ground and has subsequently been discharged into a stream channel

gully erosion - see erosion, gully

gypsiferous - containing gypsum, a mineral consisting of hydrous calcium sulfate

Health Advisories (HAs) - provide the level of a contaminant in drinking water at which adverse non-carcinogenic health effect would not be anticipated with a margin of safety

herbaceous - with the characteristics of a herb; a plant with no persistent woody stem above ground

highly erodible (cropland) - as defined by the U.S. Department of Agriculture, Soil Conservation Service, land on which the potential erosion is at least eight times the rate at which the soil can maintain continued productivity

Holocene - geologically recent times, from approximately 10,000 years ago to present

horizon (soils) - a layer of soil, approximately parallel to the land surface, having distinct characteristics produced by soil-forming processes

hummocky - describes glacial deposits arranged in mounds with intervening depressions

hydraulic conductivity - a parameter that describes the conductive properties of a porous medium; often expressed in gallons per day per square foot

hydraulic head - the height of the free surface of a body of water above a given subsurface point

hydric soil - soil that in its undrained condition is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation

hydrophyte - plants typically found in wet habitats; any plant growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content

hydrostatic pressure - the pressure exerted by the water at any given point in a body of water at rest. The hydrostatic pressure of ground water is generally due to the weight of water at higher levels in the zone of saturation.

hypolimnion - the lowermost layer of water in a lake, characterized by an essentially uniform temperature (except during a turnover) that is generally colder than elsewhere in the lake, and often by relatively stagnant or oxygen-poor water

Hypsithermal - a term proposed as a substitute for climatic optimum and thermal maximum. It represents the Holocene interval when "most of the world entered a period when mean annual temperatures exceeded those of the present"

ice karst - a type of topography in a glacial terrain that is characterized by closed depressions, caves, and underground drainage

igneous - describes rocks that solidified from molten or partly molten material

immunoassay - is a quantitative or qualitative method of analysis for a substance which relies on an antibody or mixture of antibodies as the analytical reagent. Antibodies are produced in animals in response to a foreign substance called an antigen. The highly sensitive and specific reaction between antigens and antibodies is the basis for immunoassay technology

incised - describes the result of the process whereby a downward-eroding stream deepens its channel or produces a narrow, steep-walled valley

industry - in this usage, a general term encompassing all major employment categories

infiltration - the process (rate) by which water enters the soil surface and which is controlled by surface conditions

interflow - the part of precipitation which infiltrates the surface soil, and moves laterally toward streams as perched ground water

International Great Lakes Datum (IGLD) - the reference system by which Great Lakes-St. Lawrence River Basin water levels are measured. It consists of benchmarks at various locations on the lakes and St. Lawrence River, which are referenced to a point in the St. Lawrence River that roughly coincides with sea level. All water levels are measured in feet or meters above this point. Movements in the earth's crust necessitate updating this datum every 25-30 years. The first IGLD was based upon measurements and benchmarks that centered on the year 1955, and it was called IGLD (1955). The most recently updated datum uses calculations that center on 1985, and it is called IGLD (1985).

interpolate - to estimate intermediate values of a function between two known points

ion exchange - the process of reciprocal transfer of ions

isostatic - pertaining to the equilibrium of the earth's crust, a condition in which the forces tending to elevate balance those tending to depress

karst - topography characterized by closed depressions or sinkholes, caves, and underground drainage formed by dissolution of limestone, dolomite or gypsum

kettle hole - a steep-sided, usually basin- or bowl-shaped hole or depression, commonly without surface drainage, in glacial drift deposits, often containing a lake or swamp; formed by the melting of a large, detached block of stagnant ice (left behind by a retreating glacier) that had been wholly or partly buried in the glacial drift

lacustrine - pertaining to, produced by, or formed in a lake or lakes

lakeshore - lake front or land along the edge of a lake

leeward - pertaining to, situated in, or moving toward the quarter toward which the wind blows

lenticular - resembling in shape the cross section of a lens, especially of a double-convex lens

lithofacies - a lateral, mappable subdivision of a designated stratigraphic unit, distinguished from adjacent subdivisions on the basis of lithology

lithologic - describes the physical character of a rock; includes features such as composition, grain size, color and type of bedding

lithostratigraphic unit - a defined body of strata that is distinguished and delimited on the basis of lithic characteristics and stratigraphic position

loam - describes a soil composed of a mixture of clay, silt, sand, and organic matter

macrophyte - a plant large enough either as an individual or in communities to be readily visible without the aid of optical magnification

major land resource area - as defined by the U.S. Department of Agriculture, Soil Conservation Service, a geographic area characterized by a particular pattern of soils, climate, water resources, and land uses

marsh - a wet, level, treeless area covered mostly with grasses, sedges or cattails and usually underlain by a mucky or mineral soil; sometimes referred to as a wet meadow

mass movement - a unit movement of a portion of the land surface; gravitative transfer of material down a slope

maximum contaminant level - the maximum permissible level of a contaminant in water which is delivered to the free-flowing outlet of the user of a public water system

mean - arithmetic average of a set of observations

median - middle value of a set of observations arranged in order of magnitude

meltwater - water resulting from the melting of snow or glacial ice

mesoscale - medium or intermediate in scale

metabolite - a product of metabolic action

methemoglobinemia - a disease, primarily in infants, caused by the conversion of nitrate to nitrite in the intestines, and which limits the blood's ability to transport oxygen.

moraine - unsorted, unstratified glacial drift deposited chiefly by the direct action of glacial ice

moraine, end - a ridgelike accumulation of drift built along any part of the outer margin of an active glacier

moraine, ground - material (primarily till) deposited from a glacier on the ground surface over which the glacier moved, and generally forming a region of low relief

morphometric - in this usage, of or pertaining to the structure and form of a lake

morphometry - in this usage, the structure and form of a lake

moving average - a consecutive chronological sequence of arithmetic averages

muck - a highly organic dark or black soil less than 50 percent combustible

mutagenic - capable of inducing a mutation or alteration

nearshore - extending lakeward an indefinite but generally short distance from the shoreline

nearshore sediments - sediments deposited in an environment which extends seaward or lakeward an indefinite but generally short distance from the shoreline

nektonic - describes the aggregate of actively swimming aquatic organisms in a body of water, able to move independently of water currents

non-halogenated volatile organic compound - a volatile organic compound which has not been combined with a halogen such as fluorine, chlorine, bromine, etc (see volatile organic compound)

normal (climate) - the average (or mean) value for a particular parameter over a designated period, usually the most recent 30-year period ending every decade

Ordinary High Water Mark (OHWM) - the line on the shore of a waterway established by the fluctuations of water and indicated by physical characteristics. Examples of such physical characteristics include the following: a) a clear and natural line impressed on the bank; b) shelving; c) changes in the character of the soil; d) destruction of terrestrial vegetation; e) presence of litter or debris

organic (soils) - containing partially decomposed plant remains; formal designation depends on relative percentage of organic material and clay

orographic lifting - the rising and adiabatic cooling of air as it passes upward over mountains or rough terrain

outwash - sand and gravel deposited by meltwater streams in front of or beyond the margin of active glacial ice

outwash apron - a broad slope formed by coalescing outwash fans deposited by meltwater streams

outwash cone - a steeply-sloping, cone-shaped accumulation of outwash deposited by meltwater streams flowing in front of or beyond a glacier

outwash fan - a fan-shaped accumulation of primarily sand and gravel deposited by meltwater streams flowing in front of or beyond a glacier

overbank - describes water or sediment carried out of a stream channel onto the surrounding land surface during a flood

overland flow - the part of runoff which passes over the land surface to the nearest stream channel

oxbow - a sharp bend in a river forming a distinct crescent or U-shape

paleoshoreline - an ancient shoreline

palustrine - includes wetlands dominated by vegetation such as trees, shrubs and persistent emergents; or an area less than 20 acres lacking such vegetation and having a water depth less than 6.6 feet at low water

parabolic - having the form or outline of a parabola

paraconformably - not really or not quite conformable

parent material (soils) - the horizon of weathered rock or partly weathered soil material from which soil is formed

partial-record station - a site where limited stream-flow and/or water quality data are collected systematically over a period of years

pathogen - any disease-producing organism

peat - a highly organic soil more than 50 percent combustible, composed of partially decayed vegetable matter found in marshs or damp regions, which is cut and then dried for use as fuel

per capita income - the total money income of the residents of a given area divided by the resident population of that area; as defined by the U.S. Bureau of the Census, total money income is the sum of all sources of cash income, excluding transfer payments, the imputed value of non-monetary income, and other income included under the Bureau of Economic Analysis' definition of personal income

percolate (geology) - to seep downward from an unsaturated zone to a saturated zone

permeability - the capacity of a porous medium to transmit a fluid; highly dependent upon the size and shape of the pores and their interconnections

photosynthesis - the synthesis of complex organic materials, esp. carbohydrates, from carbon dioxide, water, and inorganic salts, using sunlight as the source of energy and with the aid of a catalyst, as chlorophyll

physiographic region - an area of characteristic soils, landforms and drainage that have been developed on geologically similar materials

phytoplankton - an assemblage of suspended or floating microscopic plants that drift passively with water currents

piezometric surface - an imaginary surface representing the level to which water from a given aquifer will rise under the hydrostatic pressure of the aquifer

plankton - an assemblage of suspended or floating microscopic plants and animals that drift passively with water currents

Pleistocene - geologic epoch corresponding to the most recent ice age; beginning about 2 million years ago and ending approximately 10,000 years ago

polychlorinated biphenyls (PCBs) - a family of chlorinated hydrocarbons potentially toxic to animals and humans and that persists in the environment for as long as 30 years

porosity - the amount of pore space; specifically, the ratio of the total volume of voids to the total volume of a porous medium

Precambrian basement - the crust of the Earth below sedimentary deposits, extending down to the boundary of the mantle; in this case, of Precambrian age

probable maximum precipitation - the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage basin at a certain time of year

proglacial - describes deposits formed just beyond the outer limits of a glacier

progradation - a seaward advance of the shoreline resulting from the nearshore deposition of sediments brought to the sea by rivers

projected - describes a number based on trends and patterns of the past

pumping test - a test conducted by pumping a well at a constant rate for a period of time, and monitoring the change in hydraulic head in the aquifer

raw water - water direct from the source, prior to any treatment

recurrence interval - the average number of years within which a stream-flow event is expected to occur once

recharge (ground water) - the process by which water is absorbed and added to the zone of saturation

reducing - describes the process of removing oxygen from a compound

relict - said of a topographic feature that remains after other parts of the feature have been removed or have disappeared

rill erosion - see erosion, rill

runoff, direct - water entering a stream channel promptly after a precipitation event; it is presumed to consist of surface runoff and a substantial portion of the interflow

runoff, surface - water which passes over the land surface to the nearest stream channel (overland flow) plus precipitation falling directly onto the stream

runoff, (total) - the part of precipitation that appears in surface-water bodies; it is the same as stream flow unaffected by artificial manipulation

saline - describes water that contains a high concentration of dissolved solids, typically greater than 10,000 milligrams per liter

salmonid - belonging or pertaining to the family Salmonidae, including the salmons, trouts, chars, whitefishes, etc.

savanna - grassland region with scattered trees (average tree canopy cover less than 50 percent), grading into either open plain or woodland

sedimentary rock - formed by the deposition of sediment

seismic - pertaining to an earthquake or earth vibration, including those that are artificially induced

senescence (lakes) - approaching the end stages of eutrophication when the lake is being filled in by organic sediments and aquatic weeds

sheet erosion - see erosion, sheet

skewed - describes the state of asymmetry of a statistical frequency distribution, which results from a lack of coincidence of the mode, median, and arithmetic mean of the distribution

slough - a backwater area or remnant of a former river channel which contains standing water and serves as the main river channel only during high water

solvent extraction - a process which involves use of a solvent to treat and extract organic contaminants from sediments

specific conductance - the ability of a body of unit length and unit cross-sectional area to conduct an electrical current at a specific temperature. In general, the specific conductance of water is proportional to the total amount of dissolved solids.

standard industrial classification code - a four-digit code established by the Office of Management and Budget, and used in the classification of establishments by type of activity

static water level - the level of water in a well that is not being affected by withdrawal of ground water

stratigraphy - the geologic study of the formation, composition, sequence and correlation of unconsolidated or rock layers

surface runoff - see runoff, surface

swamp - a forested wetland that usually is seasonally flooded and that is dominated by either trees or shrubs; the interior of swamps may contain open-water areas such as ponds

swale - a slight depression, sometimes swampy, in the midst of generally level land

teratogenic - capable of producing monstrous or abnormal growths and/or birth defects

thermocline - the horizontal plane in a thermally stratified lake located at the depth where temperature decreases most rapidly with depth

till - sediment transported by and deposited from glacier ice with little or no sorting by water, and consisting of a heterogeneous mixture of clay, sand, and gravel varying widely in size and shape

till plain - an extensive area with a flat to undulating surface, underlain by till and commonly covered by ground moraines and subordinate end moraines

time of concentration - time it takes for the first raindrop fallen at the most distant point of the drainage area to reach the outlet of the watershed

topography - the relief and contour of a surface, especially land surface

total runoff - see runoff, total

toxic - describes materials which are or may become harmful to plants or animals when present in sufficient concentrations

transgression - the spread or extension of the sea over the land areas

transmissivity - the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient

transmission (soils) - process by which water moves through the soil and which is controlled by the soil horizons

transpiration - process by which water is evaporated from plants, primarily through microscopic air spaces in their leaves

trophic - concerned with nutritive processes

tunnel valley - wide, linear channel oriented perpendicular to an ice margin and eroded into the substrate below the ice sheet. A tunnel valley typically represents a major route for meltwater draining part of an ice sheet, and exiting the front of that ice sheet

unconfined - describes an aquifer whose upper surface is the water table which is free to fluctuate under atmospheric pressure

unconformably - not succeeding the underlying rocks in immediate order of age or not fitting together with them as parts of a continuous whole

unit (discharge) - a general term describing a stream-flow parameter calculated on a unit-area basis, usually per square mile, during a specified period of time

upper shoreface - wave-washed zone extending lakeward or seaward from the mean low water level to 1 meter in depth; characteristic deposits are parallel-laminated sand

volatile organic compounds - a chemical compound composed mostly of carbon and hydrogen, that easily evaporates (for example, trichloroethylene, or TCE)

waterspout - a funnel-shaped or tubular portion of a cloud over the ocean or other body of water which, laden with mist and spray, resembles a solid column of water reaching upward to the cloud from which it hangs

water table - the upper surface of the zone of saturation below which all voids in rock and soil are saturated with water

water-table control structure - a structure placed in a ditch or tile line to alter the water-table elevation for subsurface irrigation and/or drainage purposes

watershed - see drainage basin

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APPENDICES

Appendix 1. Historic and projected population in northwest Indiana.

Upper county figures: Division of Water estimates, in-basin portion only.
Lower county figures: U.S. Census Bureau, total county (1910-1990); Indiana State Board of Health (1988), total county (2000-2010).
City figures: U.S. Census Bureau (1960-1990); Division of Water projections (2000-2010) (tabulation includes only cities and towns having at least 2,500 residents in 1980).

Location	1910	1920	1930	1940	1950	1960	1970	1980	1990	2000	2010
Lake County	75873	152242	252822	282762	353509	491339	518511	486695	435283	422394	410710
	82864	159957	261310	293195	368152	513269	546253	522965	475594	*459124	*446424
Crown Point						8443	10931	16455	17728	17114	16641
Dyer						3993	4906	9555	10923	10545	10253
East Chicago						57669	46982	39786	33892	32718	31813
Gary						178320	175415	151953	116646	112606	109492
Griffith						9483	18168	17026	17916	17296	16817
Hammond						111698	107983	93714	84236	81319	79070
Highland						16284	24947	25935	23696	22875	22243
Hobart						18680	21485	22987	21822	21066	20484
Lake Station[1]						9309	9858	14294	13899	13418	13046
Merrillville[2]						-	-	27677	27257	26313	25585
Munster						10313	16514	20671	19949	19258	18726
New Chicago						2312	2231	3284	2066	1994	1939
St. John[3]						1128	1757	3974	4921	4751	4619
Schererville						2875	3663	13209	19926	19236	18704
Whiting						8137	7054	5630	5155	4976	4839
LaPorte County	29448	32249	41731	43628	51340	63359	71363	70257	67861	62616	61097
	45797	50443	60490	63660	76808	95111	105342	108632	107066	99390	96980
Michigan City						36653	39369	36850	33822	31397	30636
Trail Creek						1552	2697	2581	2463	2286	2231
Porter County	14873	14441	17332	21545	32985	51273	75879	99267	104148	108305	111359
	20540	20256	22821	27836	40076	60279	87114	119816	128932	133710	137480
Chesterton						4335	6177	8531	9124	9462	9729
Portage						11822	19127	27409	29060	30137	30987
Porter						2189	3058	2988	3118	3234	3325
Valparaiso						15227	20020	22247	24414	25319	26033
St Joseph County	78	79	91	107	121	130	125	133	132	121	123
	84312	103304	160033	161823	205058	238614	244827	241617	247052	242530	246450
Total (In-Basin)	120272	199011	311976	348042	437955	606101	665878	656352	607424	593436	583289

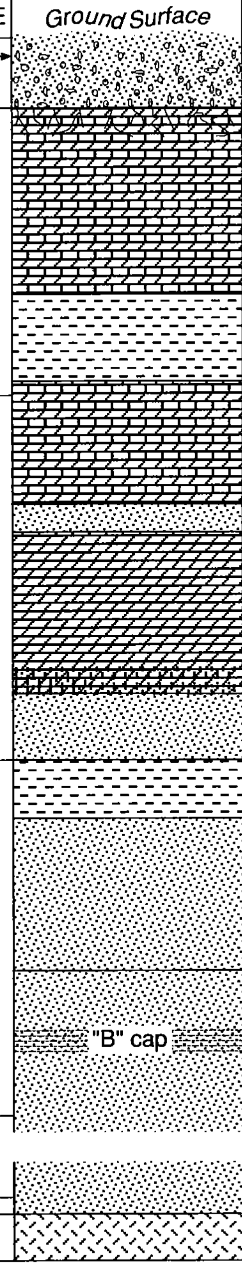
* Lake County projections have been adjusted to reflect 1990 Census
1 Lake Station - East Gary town was renamed Lake Station city
2 Merrillville - town was incorporated (1970 population 24,075)
3 St. John - Corporate limit lies partially outside basin boundary.

Appendix 2. Land Use for the Lake Michigan Region

{U.S. Geological Survey digital files Land-use and land-cover. Values are approximate}

Land Use	Acreage	Sq. miles	Percent
URBAN OR BUILT-UP LAND	113627	177.53	29.39
Residential	56860	88.84	14.71
Commercial	18466	28.85	4.78
Industrial	22284	34.82	5.76
Trans., Comm. & Util.	9705	15.16	2.51
Mixed Urban/Built-up	184	0.29	0.05
Other Urban/Built-up	6128	9.57	1.58
AGRICULTURAL LAND	189107	295.48	48.91
Cropland and Pasture	188203	294.07	48.69
Orchards, etc.	768	1.20	0.19
Confined feeding	96	0.15	0.02
Other Agricultural land	40	0.06	0.01
FOREST LAND	66016	103.15	17.08
Deciduous Forest	65456	102.27	16.93
Evergreen Forest	409	0.64	0.11
Mixed Forest	151	0.24	0.04
LAKES AND WETLANDS	11768	18.38	3.05
Lakes	1135	1.77	0.29
Reservoir	3198	5.00	0.83
Bays	955	1.49	0.25
Forested Wetland	3815	5.96	0.99
Nonforested Wetland	2665	4.16	0.69
BARREN LAND	6042	9.44	1.57
Sandy areas other than beaches	933	1.46	0.24
Str. Mines, Quarries, Gr. pits	1656	2.59	0.43
Transitional areas	3151	4.92	0.82
Mixed Barren land	302	0.47	0.08
TOTAL	386560	603.98	100.00

Appendix 3. Geologic column from surface of Valparaiso Moraine to Precambrian basement



AQUIFER SYSTEM	ROCK SYSTEM	STRATIGRAPHIC UNIT	APPROX. DEPTH IN FEET BELOW SURFACE	HYDROLOGIC PROPERTIES	MATERIAL DESCRIPTION
Unconsolidated	QUATERNARY	Pleistocene Series	Water table	Aquifer Aquitard	Sand and gravel Till
Shallow bedrock	DEVONIAN AND SILURIAN		150	Aquifer	Limestone and dolomite
	ORDOVICIAN	Maquoketa Gr.		Aquitard	Shale
		Trenton Ls.	1,000		
Deep bedrock		St. Peter Ss.		Aquifer	Sandstone
		Knox Dol.			
	CAMBRIAN	Galesville Ss.		Aquifer	Sandstone
		Eau Clair Fm.	2,000	Aquitard	Shale
				Aquifer	Sandstone
		Mount Simon Ss.		Aquitard	Shale
			3,000	Aquifer	Sandstone
			4,000		
	PRECAMBRIAN			Aquitard	Granite

* Aquifers having 10,000 parts per million (ppm) are generally not considered a source for drinking water.

** The Mount Simon sandstone below the "B" cap shale is considered the most suitable of the aquifers for waste injection.

*** Chloride values may approach or exceed 10,000 ppm, especially in the eastern portion of the Region.

The following paragraphs give a brief description of the erosion and accretion conditions that exist in the 5 littoral cells along Indiana's 45 mile coastline starting at the Michigan state line to the east, and ending with the Illinois state line to the west. The figure below identifies the locations of the 5 littoral cells.

Michigan City to Michigan state line (CZM Reach)

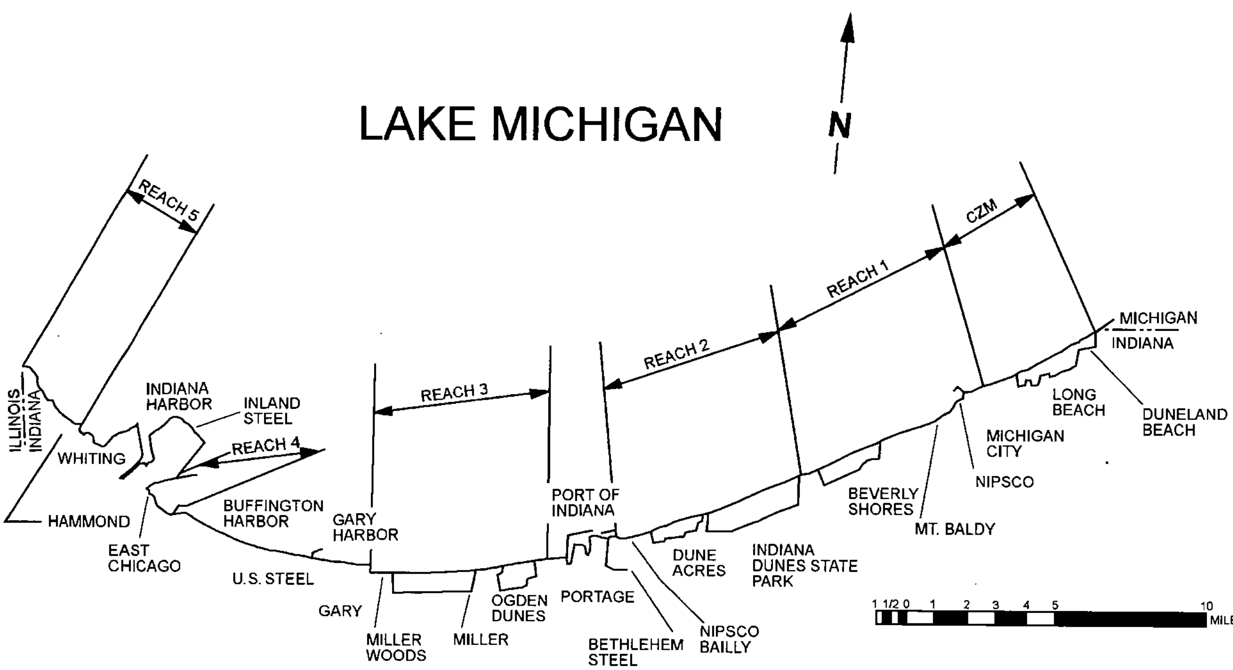
The shoreline east of Michigan City has a northeast by southwest orientation, causing "net" longshore sand movement to be from the east toward the west.

The lighthouse pier at Trail Creek in Michigan City extends 1000 feet out into Lake Michigan from the present day shoreline (see aerial photo on next page). This shoreline immediately east of Michigan City is approximately 0.3 miles (1500 feet) lakeward of the 'natural' 1834 shoreline. Construction in 1836 of the first east and west piers at Trail Creek created a "total littoral barrier", completely blocking the westward movement of sand. The beach toward the east grew lakeward at a rate of 10 feet per year, requiring new pier extensions be built to maintain an open navigation channel. At the same time, the "sand-starved" shoreline west of Trail Creek began to erode.

By 1910 the pier complex was in the configuration seen today, with an east and west pier at Trail Creek, a detached breakwater west of the lighthouse, and NIPSCO's sheet-steel and rock wall extending one mile west of Trail Creek. Continuous accumulation of sand against the east pier wall built the east shoreline lakeward, until sand eventually began to leak westward around the end of the lighthouse pier during storms of sufficient intensity.

This movement of sand around the east pier resulted in a "balance" between the volume of sand coming in from the east and the volume of sand moving west into the Trail Creek channel. The position of the shoreline immediately east of the pier stabilized in 1934, requiring beach nourishment materials be brought in to artificially create a beach on the north side of the Michigan City marina.

Sand leaking around the lighthouse means the pier is now a "partial littoral barrier". However, the detached breakwater west of the lighthouse continues to capture the sand by detaining it in the low energy "shadow zone" between the detached wall and the shoreline.



Therefore, the Michigan City breakwater complex remains a "total littoral barrier".

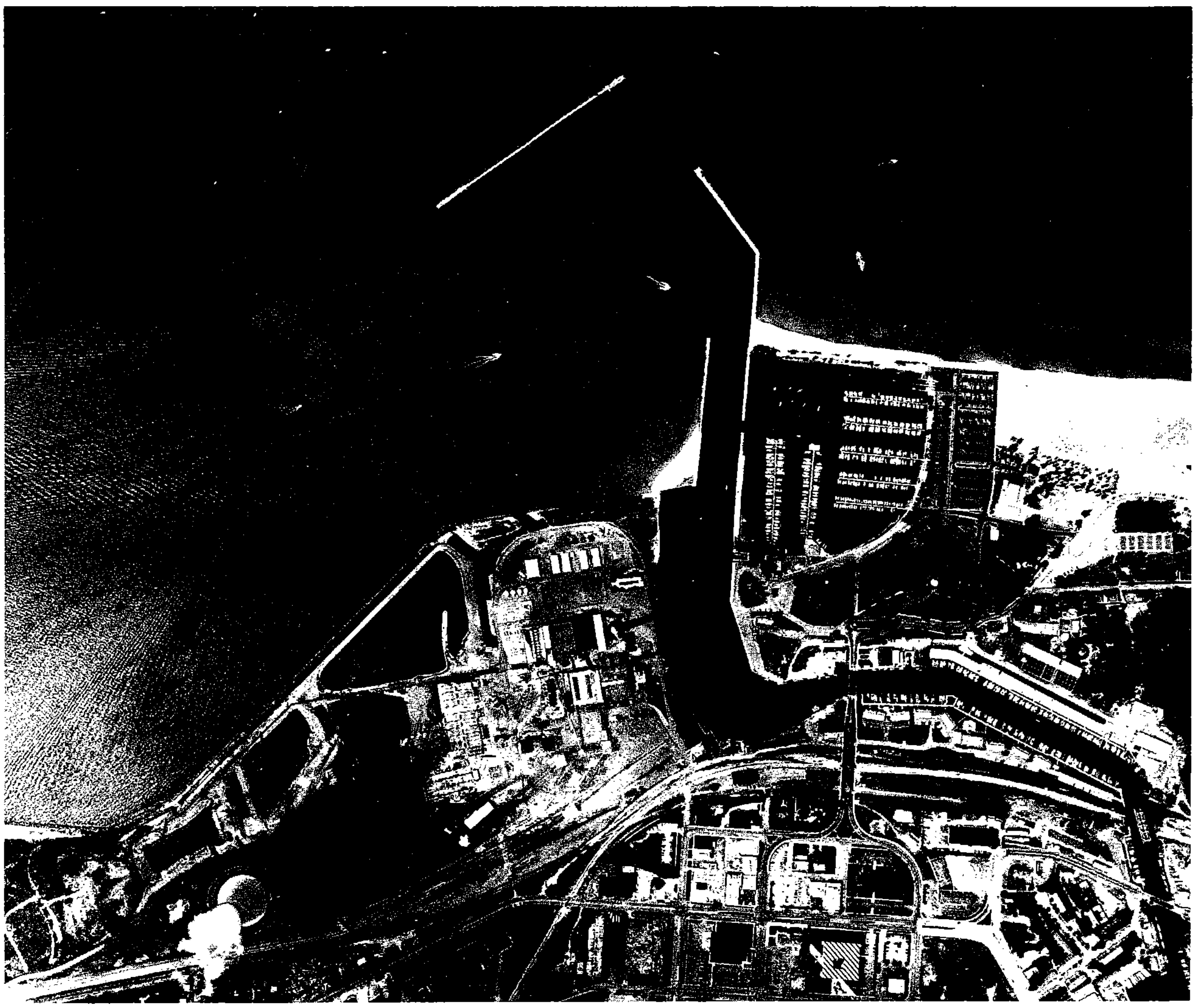
Frequent dredging is necessary to keep the Trail Creek channel open for deeper draft vessels. Dredging records from 1920 to 1978 show a total of 1.6 million cubic yards of sand have been removed from the area west of the lighthouse. Most of this sand was barged offshore and dumped in deep water.

During high lake levels and years with high energy storms, the "fillet" beach east of the lighthouse pier can disappear, resulting in approximately 2 to 5 feet of water depth along the north breakwall of the Michigan City marina. The beach returns again during lower lake levels and years with lower energy storms.

The effect of the "accretional fillet" of trapped sand extends approximately one mile toward the east from Trail Creek, creating an area of wide beaches and expanding "back beach" sand dunes. However, the periodic loss of the beach at the marina indicates there can still be episodes of erosion within the sand accretion area.

East of the one mile extent of the "accretional fillet" effect, the coast is fairly well armored by breakwalls along approximately two miles (10,400 feet) of the central portion of this CZM Reach. This corresponds to the community of Long Beach.

The Indiana-Michigan state line lies 0.7 miles (3,600 feet) east of the armored Long Beach section. The



shoreline is more natural and is recessional (suffers erosion). During the 1980s high lake level period, one section of this shoreline had to be protected by an emergency sheet-steel wall to prevent a road from being undercut. Later, a low profile rock revetment was placed along the toe of the dune-bluff from the wall to the Michigan state line to protect the rest of the road. Post-1986 low lake levels have allowed sand to bury most of this rock revetment. But, it is there as insurance to protect the natural dune-bluff and roadway from any more loss if lake levels rise to 1986 conditions again.

The erosion experienced along the eastern-most portion of Indiana's CZM Reach is influenced by the construction of a harbor entrance at New Buffalo, Michigan. The harbor is located 4.8 miles northeast of the Indiana-Michigan state line. Shortly after its construction, erosion rates toward the southwest increased, indicating sand was being trapped on the north side of the harbor. The trapped sand would normally have supplied sand to maintain Indiana's beaches.

Port of Indiana (Burns International Harbor complex) to Michigan City (Reach 1 and Reach 2)

The Corps of Engineers has divided the single "littoral cell" between the Port of Indiana and Michigan City into two reaches. The western Reach 2 extends from the Port of Indiana to Beverly Shores. The eastern Reach 1 includes Beverly Shores and extends to the Michigan City harbor. The shoreline has a northeast by southwest orientation, resulting in a "net" direction of sediment movement from the east toward the west. Both Reach 1 and 2 are generally recessional (suffer erosion).

In western Reach 2, the eastern most wall of the Port of Indiana "breakwater complex" extends north approximately 0.4 miles (2000 feet) into the waters of Lake Michigan, creating a "total littoral barrier" to sand movement toward the west. The "accretional fillet" forming east of the breakwater is creating wide beaches and expanding low sand dunes in the "back beach" area.

The Northern Indiana Public Service Company (NIPSCO) Bailly power plant's water intake is located only 2000 feet east of the Port complex in Lake Michigan. It is continuously threatened of being buried by the continual accumulation of sand. NIPSCO has established a dredging program to keep the water intake from being clogged with sand. NIPSCO by-passes 75% of the dredged Lake Michigan sand downdrift to Ogden Dunes, west of the Port. This "nourishment sand" helps mitigate shoreline erosion. NIPSCO back-passes 25% of the sand toward the east to Beverly Shores. The State of Indiana encourages the use of clean and suitable dredge material as beach nourishment.

The sand-trapping effect of the Port of Indiana extends approximately 1 mile toward the east. The expanding wide beaches and sand dune growth is similar to the "accretional fillet" processes observed immediately east of the Michigan City breakwater and the U.S. Steel breakwater in Gary. Just like the shoreline east of Michigan City, periods of high lake level and severe storms can still threaten coastal structures with erosion in the eastern portion of this accretion zone.

East of this accretion zone, and west of Beverly Shores, the "long term" dune-bluff erosion rates in Reach 2 are variable, with some areas of the coast having high recession rates and some low. The Indiana Dunes State Park lies along 3.3 miles of the shoreline immediately west of Beverly Shores within this variable erosion rate zone. The park is operated by the Indiana Department of Natural Resources. In contrast, dune-bluff erosion rates in eastern Reach 1 (Beverly Shores to Michigan City) have been consistently high historically.

Construction of the 1836 Michigan City breakwater at Trail Creek was the beginning of severe "sand starved" conditions in Reach 1. The 'highest' erosion rates originally occurred immediately west of Trail Creek until these rates were 'transferred' 1 mile to the west to the Crescent Dune and Mt. Baldy shoreline by the construction of NIPSCO's sheet-steel shore protection.

The Crescent Dune area continues to experience 'long term' background erosion rates of approximately 10 feet per year, which are among the highest erosion rates in Indiana. The very existence of Indiana's largest migrating sand dune, Mt. Baldy, located within the boundaries of the Indiana Dunes National Lakeshore was and is still threatened by erosion. Fortunately, as expected, erosion rates progressively decrease toward the west, over the 2 mile length of shoreline from Crescent Dune to the east end of Beverly Shores.

However, a nearly continuous six (6) foot rise in Lake Michigan's lake level, between 1964 and 1974, combined with severe storms to exacerbate long term erosion conditions to a point where "rock revetment" had to be constructed along the eastern 2.5 miles (13,000 foot) of Beverly Shores coast in 1974. Multiple houses were lost to erosion and the roadway along the shoreline was threatened.

"Beach nourishment" projects were conducted in 1974 and again in 1981 to mitigate some of the man-induced erosion on the shoreline at Mt. Baldy. The beach nourishment projects halted the erosion of the "natural" dune-bluff while the nourishment material lasted. Some of this beach nourishment material is probably responsible for a portion of the wide beaches that formed in the central portion of Beverly Shores following the lake level decline after 1986.

Gary works (U.S. Steel lakefill) to Port of Indiana (Burns Int'l Harbor) (Reach 3)

Indiana's shoreline from the U.S. Steel lakefill breakwater in Gary, to the Portage/Burns Waterway in Portage, is identified as Reach 3. The shoreline at Gary is located at the southern-most tip of Lake Michigan, with the shoreline east of Gary having a northeast by southwest orientation. This causes the "net" movement of sand to be from the east toward the west. In general, Reach 3 is accretional in the western third and recessional in the eastern third.

The U.S. Steel lakefill breakwater, constructed in 1967, creates a "littoral barrier" to the westward movement of sand. For approximately 2 miles east, the beach has continued to widen lakeward and new 'back beach' sand dunes have expanded lakeward along with the widening beach. Native dune grasses capture wind blown sand, increasing the height of these new dunes.

One mile east of the lakefill wall, a hundred foot wide beach now lies between the boat launch ramps at Lake Street and the waters of Lake Michigan. Bulldozers try to maintain a small non-structural open water channel across the beach as access to Lake Michigan during the boating season. The central portion of this "littoral cell" (Reach 3) consists of the Indiana Dunes National Lakeshore "West Beach Unit". It has been relatively stable, even during the high lake level period between 1978 to 1987. But, erosion still reaches the "natural" dune-bluffs when storms are intense.

Man-induced erosion on the downdrift (west) side of the Port of Indiana began after construction started in 1967. The eastern 1.2 miles of Reach 3 includes the Portage/Burns Waterway and the community of Ogden Dunes. The shoreline immediately west of the waterway suffers extreme high erosion rates similar to the Crescent Dune area west of Michigan City.

Rising and sustained high lake levels from 1964 to 1986 exacerbated erosion conditions. The average rates of bluff-top recession range from -17.7 feet per year east of Ogden Dunes at the Portage/Burns Waterway (between 1969 and 1978), to -4.7 feet per year at the west end of Ogden Dunes, 1.2 miles toward the west (between 1969 and 1978). This shows erosion rates decrease toward the west with increasing distance from the last shore protection structure, as expected. But, private seawall construction and other methods of erosion control are necessary to protect the lakefront homes in Ogden Dunes.

Sand nourishment from the NIPSCO Bailly power plant dredge program contributes sand to the offshore sand bars in approximately 12 feet of water. Dredging of the Portage/Burns Waterway provided "beach nourishment" sand to help mitigate the "sand starved" conditions in 1985. This nourishment sand and lower lake levels since the "1986 high" have allowed beaches to return to the shoreline of Ogden Dunes. A return to high 1986 lake levels could mean a return of the erosion conditions that forced the construction of the seawalls.

Between Reach 3 and Reach 4

The portion of Gary's shoreline from the eastern wall of the U.S. Steel lakefill breakwater in the east, to the western breakwater at Buffington Harbor in the west is approximately 6.8 miles of non-eroding industrial property. Structures protect and stabilize this man-made land. This shoreline has a northwest by southeast orientation which would normally move sand from the west toward the east. But, because there is no shoreline to erode, there is essentially no sediment to move in the "net" longshore water currents created by storm waves.

Buffington Harbor to Indiana Harbor complex (Reach 4)

Reach 4 covers 1.3 miles of shoreline between Buffington Harbor in Gary to the east, and the Indiana Harbor complex in East Chicago to the west. The shoreline has a northwest by southeast orientation which would normally cause the "net" sediment transport to be from the west toward the east.

However, the Indiana Harbor complex is the largest man-made lakefill structure on the Indiana coast, located at the mouth of the Grand Calumet river. The harbor extends 2.6 miles (14,000 feet) out into Lake Michigan, perpendicular to the shoreline, in a northeast by southwest orientation. Its size and orientation creates a low energy "shadow zone" which shelters the western portion of Reach 4 from direct wave attack by north storm waves. This causes some sand to move westward into this low energy zone, which is opposite to the expected direction if the Indiana Harbor was not there. The eastern portion of Reach 4 is not sheltered and sediment moves from west toward the east as expected.

There does not appear to be large quantities of sand trapped by this "total littoral barrier" primarily because the only sand source is one mile of open coast, part of which has erosion protection. With the Indiana Harbor to the west and Buffington Harbor extending 0.6 miles out into Lake Michigan on the east, Reach 4 is a "closed littoral cell". The main way sand is lost from this "littoral transport system" is to move it far offshore into deep water during severe storm events.

Indiana Harbor complex to Illinois state line (Reach 5)

Reach 5 covers 3.9 miles of Indiana's shoreline from the west edge of the Indiana Harbor complex to the Indiana-Illinois state line. The shoreline has a northwest by southeast orientation which would normally cause the "net" sediment transport to be from the west toward the east. However, 2.3 miles north of the Indiana-Illinois state line, the Calumet Harbor breakwater extends 0.8 miles (4,262 feet) due east from the Illinois shoreline out into Lake Michigan, and then another 1.5 miles (8,075 feet) southeast. This breakwater lies partly in Illinois but mostly in Indiana's waters.

The large size and orientation of the Calumet Harbor creates a large low energy "shadow zone" which shelters the western portion of Reach 5 from direct wave attack by north storm waves. This causes sand to move both eastward and westward within this low energy zone, dependent on the amount of sheltering created by smaller man-made lakefills along Indiana's shore. The highly armored nature of Reach 5 makes contemporary erosion rates and direction of sediment movement difficult to determine because they have been severely modified by shore protection and the massive lakefill structures built out into the waters of Lake Michigan.

The eastern-most portion of Reach 5 is not sheltered by the Calumet Harbor breakwater and sediment moves from west toward the east as expected. No large "accumulation fillets" are found because of the small amount of erodible shoreline that exists between the structures. Erosion is still a concern at the Whihala Beach bathhouse and boat launch facilities.

On the positive side, the Calumet Harbor provides a protected entrance to the Calumet River in Illinois. It also provides some protection to Indiana's Hammond and Whiting shorelines from direct attack by north storm waves. On the negative side, the size of the Calumet Harbor creates a "total littoral barrier" to sand movement, preventing any Illinois sand from reaching Indiana's coast.

Historic erosion data from as far back as 1938 shows isolated areas experienced substantial shoreline erosion. But, recent industrial shoreline protection has made this area relatively stable on the whole.

Appendix 5. Description of wetland protection programs [1]

Administrative agency: IDNR, Indiana Department of Natural Resources - Divisions of Water (DOW), Nature Preserves (DNP), Fish and Wildlife (DFW) and Soil Conservation (DSC); IDEM, Indiana Department of Environmental Management; USACE, U.S. Army Corps of Engineers; USEPA, U.S. Environmental Protection Agency; USDA, U.S. Department of Agriculture, TNC, The Nature Conservancy. Slash denotes cooperative program.

		Program	Administrative Agency	Relevance or Benefit to Wetlands
REGULATORY	STATE	Flood Control Act (IC 13-2-22)	IDNR-DOW	Requires permit from Natural Resources Commission for construction, excavation or filling within a stream's floodway and its encompassed wetlands
REGULATORY	STATE	Lake Preservation Act (IC 13-2-11.1)	IDNR-DOW	Requires permit from Natural Resources Commission to alter the bed or shoreline of a public freshwater lake of natural origin
REGULATORY	STATE	Nature Preserves Act (IC 14-4-5)	IDNR-DNP	Protects wetlands contained within a dedicated Nature Preserve[2]
REGULATORY	STATE	Water quality regulations	IDEM	Authority to protect most wetland types is inherent in the Indiana Stream Pollution Control Law (IC 1971, 13-1-13) and portions of 330 IAC 1-1, which establishes water quality standards for designated water use categories. Anti-degradation provisions typically are applied to wetlands
REGULATORY	FEDERAL	Section 404/401 permit program	USACE/IDEM/USEPA	Regulates discharge of dredge or fill into wetlands and waterways; Section 401 of Federal Clean Water Act requires a water quality certification or waiver by IDEM prior to issuance of a Section 404 dredge-and-fill permit from USACE; USEPA may evaluate suitability of sites for fill placement
REGULATORY	FEDERAL	1986 Emergency Wetlands Resources Act		Requires that statewide outdoor recreation plans include wetland priority conservation plan

Appendix 5. Description of wetland protection programs – Continued

		Program	Administrative Agency	Relevance or Benefit to Wetlands
NON REGULATORY	STATE	Wetland conservation program	IDNR-DFW	Funds land acquisition for wetland protection and waterfowl management
	STATE	Natural areas registry	IDNR-DNP/TNC	Encourages voluntary conservation efforts on private land containing significant natural communities or rare plant or animal species
	STATE	Natural heritage protection campaign (IC 14-4-5.1)	IDNR-DNP/TNC	Identifies and ranks significant natural areas according to the need for protection; funds acquisition and protection of these areas
	STATE	Non-game and endangered wildlife program	IDNR-DFW	Protects wetland habitat if it supports endangered, threatened or special concern wildlife species; program includes monitoring surveys of wetland wildlife
	STATE	Wildlife habitat cost-share project	IDNR-DFW	Reimburses landowners for developing or improving wildlife habitat, including wetlands
	STATE	Classified wildlife habitat and riparian lands program	IDNR-DFW	Provides technical assistance and reduced property tax assessment for land and wetlands placed in the program
	FEDERAL	Food Security Act (1985 Farm Bill)	USDA	"Swampbuster" provision revokes certain federal farm program benefits if wetlands are converted into farmland Conservation Reserve Program promotes financial incentives for removing wetlands from production for at least 10 years Conservation Easements Program grants easements on wetlands to aid in farm debt reduction

[1] Portions of this table were summarized from the appendix to "Indiana Outdoor Recreation 1989: An Assessment and Policy Plan" (Indiana Department of Natural Resources, 1988c).

[2] Nature Preserves, which may be publicly or privately owned, possess significant natural communities, geologic features, or rare plant and animal species.

Appendix 6. Standards and suggested limits for selected inorganic constituents

(All values except pH and are in milligrams per liter. If multiple uses have been designated, the most protective standard applies. Dash indicates no available criterion).

Aquatic life: Values for all constituents except iron, pH, selenium, and silver are 4-day average concentrations; selenium value is the 24-hour average; silver criterion is not to be exceeded at any time. All values are chronic aquatic criteria which apply outside the mixing zone, except for silver which is the acute aquatic criterion. Where applicable, trace metal standards were calculated using a hardness value of 325 milligrams per liter.

Public supply: Unless otherwise noted, values represent maximum permissible level of contaminant in water at the tap. National secondary regulations (denoted sec) are not enforceable; both national primary regulations and state regulations are enforceable (references b, c, f and m).

Irrigation and livestock: All values from the National Academy of Sciences, 1974.

Constituent	Aquatic life		Public supply		Irrigation	Livestock
	Value	Reference	Value	Reference		
Arsenic (trivalent)	0.190	a	0.05	b,c	0.10	0.2
Barium	-	-	2.0	l	-	-
Cadmium	0.003	a	0.005	l	0.01	0.05
Chloride	230	i	250 sec	d,e	-	-
Chlorine	0.011	a	-	-	-	-
Chromium (total)	0.011	a	0.1	l	0.1	1.0
Copper	0.032	a	1.0 sec	l	0.20	0.5
Cyanide	0.005	a	0.2	l	-	-
Fluoride	-	-	4.0	f	1.0	2.0
	-	-	2.0 sec	f		
Iron	1.00	j	0.3 sec	e	5.0	-
Lead	0.014	a	-	l	5.0	0.1
Manganese	-	-	0.05 sec	e	0.20	-
Mercury (inorganic)	0.012	a	0.002	b,c	-	0.01
Nickel	0.427	k	0.1	l	0.20	-
Nitrate (as nitrogen)	-	-	10.0	b,c	-	-
pH (standard unit)	6.0-9.0	d	6.5-8.5 sec	l	4.5-9.0	-
Selenium	0.035	g	0.05	l	0.02	0.05
Silver	0.015	g	0.1 sec	l	-	-
Sulfate	-	-	250 sec	d,e	-	-
Total dissolved solids	-	-	500 sec	l	500-1000	3000
Zinc	0.288	h	5.0 sec	e	2.0	25.0

a U.S. Environmental Protection Agency, 1985a.
b Indiana Environmental Management Board, 1979.
c U.S. Environmental Protection Agency, 1986c.
d Indiana Stream Pollution Control Board, 1985.
e U.S. Environmental Protection Agency, 1979.
f ______1986a.
g ______1980.
h ______1987a.
i ______1988a.
j ______1976b.
k ______1986b.
l ______1993a.

Appendix 7. Statistics of selected constituents for surface waters in the Lake Michigan Region

Statistics of constituents sampled at selected IDEM stream monitoring stations. (Locations of individual monitoring stations displayed in figure 41 and table 17)

Monitoring Station	No. of samples	Median	Mean	Percentiles 10th	Percentiles 90th	Maximum value	Minimum value
			Dissolved oxygen (mg/L)				
GCR 34	102	4.4	4.3	0.6	7.3	11.5	0.0
GCR 37	102	7.3	7.2	4.8	10.2	11.6	3.2
LCR 13	93	6.4	6.5	2.3	10.7	12.8	0.0
LCR 39	103	8.9	9.1	6.6	12.4	16.2	4.8
IHC 3S	105	6.6	6.6	3.8	9.5	11.7	2.0
IHC 3W	98	5.9	6.0	3.5	8.8	10.1	1.9
IHC 0	96	7.8	7.9	6.0	10.1	12.7	3.9
BD 1	106	8.1	8.5	6.2	11.3	14.4	5.1
TC 0.5	96	8.5	8.3	4.2	12.2	14.0	1.3
			Specific conductance (μmhos/cm)				
GCR 34	105	1091	1120	756	1508	1960	241
GCR 37	105	440	519	332	764	5000	243
LCR 13	99	942	973	521	1460	1820	155
LCR 39	102	602	570	403	700	998	290
IHC 3S	107	467	493	354	680	1049	155
IHC 3W	103	490	504	350	672	988	273
IHC 0	97	380	391	276	510	777	203
BD 1	104	520	555	401	665	3300	7
TC 0.5	95	454	460	278	617	772	184
			Chloride (mg/L)				
GCR 34	73	165	166	110	235	300	19
GCR 37	72	41	41	32	50	67	26
LCR 13	NA	NA	NA	NA	NA	NA	NA
LCR 39	NA	NA	NA	NA	NA	NA	NA
IHC 3S	75	45	47	34	62	80	21
IHC 3W	73	47	50	37	64	98	29
IHC 0	103	33	35	23	49	62	14
BD 1	114	43	44	34	54	99	6
TC 0.5	102	32	32	16	46	60	9
			Hardness (mg/L as $CaCO_3$)				
GCR 34	106	300	337	233	442	2260	112
GCR 37	108	176	177	160	196	242	126
LCR 13	104	380	372	249	486	592	88
LCR 39	77	322	308	242	354	384	89
IHC 3S	110	181	184	164	208	246	152
IHC 3W	106	186	188	165	210	266	146
IHC 0	103	162	165	146	184	358	16
BD 1	114	252	251	217	286	322	113
TC 0.5	102	220	219	167	266	280	97
			Total iron (mg/L)				
GCR 34	111	0.9	1.3	0.5	2.3	16.0	0.3
GCR 37	108	1.2	1.5	0.6	2.4	6.3	0.3
LCR 13	NA	NA	NA	NA	NA	NA	NA
LCR 39	NA	NA	NA	NA	NA	NA	NA
IHC 3S	110	1.2	1.3	0.7	2.2	4.4	0.3
IHC 3W	106	0.7	0.8	0.4	1.0	3.6	0.1
IHC 0	98	0.5	0.6	0.2	1.2	3.5	<0.02
BD 1	115	1.0	1.6	0.6	2.6	17.0	0.4
TC 0.5	102	0.8	1.2	0.3	1.9	11.0	0.1

NA = Insufficient data available over the period of study.

Appendix 7. Statistics of selected constituents for surface waters in the Lake Michigan Region – Continued

Statistics of constituents from IDEM monitoring stations along Lake Michigan and Wolf Lake (Locations of individual monitoring stations displayed in figure 41 and table 17)

Monitoring Station	No. of samples	Median	Mean	Percentiles 10th	Percentiles 90th	Maximum value	Minimum value
			Specific conductance (μmhos/cm)				
LM EC	96	280	271	200	323	383	23
LM G	96	270	258	183	311	359	135
LM H	96	279	265	179	320	670	23
LM M	92	271	259	180	310	450	132
LM W	96	270	266	193	324	400	116
WL SL	104	364	377	235	501	1340	163
			Chloride (mg/L)				
LM EC	112	11	12	10	13	119	9
LM G	121	10	11	9	13	23	9
LM H	124	11	11	10	13	19	9
LM M	115	10	11	9	13	44	8
LM W	123	11	12	10	15	95	<5
WL SL	NA	NA	NA	NA	NA	NA	NA
			Sulfate (mg/L)				
LM EC	120	25	25	22	27	39	19
LM G	119	23	24	21	26	49	<5
LM H	121	25	25	22	27	38	19
LM M	114	24	25	22	28	80	18
LM W	120	25	25	22	28	32	19
WL SL	NA	NA	NA	NA	NA	NA	NA
			Hardness (mg/L as $CaCO_3$)				
LM EC	123	142	146	134	160	318	110
LM G	121	141	145	134	156	250	122
LM H	124	144	145	132	162	240	124
LM M	115	142	147	136	158	303	122
LM W	123	142	144	134	156	176	124
WL SL	76	143	141	102	179	246	96
			Total Phosphorous (mg/L as P)				
LM EC	123	<0.03	0.05	<0.03	0.06	1.37	<0.03
LM G	122	<0.03	0.08	<0.03	0.05	3.70	<0.03
LM H	122	<0.03	0.07	<0.03	0.08	1.34	<0.03
LM M	116	<0.03	0.07	<0.03	0.05	1.40	<0.03
LM W	122	<0.03	0.05	<0.03	0.04	2.25	<0.03
WL SL	109	0.04	0.12	<0.03	0.10	2.75	<0.03
			Nitrate+nitrite (mg/L as N)				
LM EC	123	0.3	0.4	0.2	0.4	8.9	<0.1
LM G	121	0.3	0.4	0.2	0.4	4.6	0.2
LM H	123	0.3	0.4	0.2	0.4	4.3	<0.1
LM M	116	0.3	0.4	0.2	0.4	4.9	<0.1
LM W	122	0.3	0.4	0.2	0.5	4.0	<0.1
WL SL	108	<0.1	0.2	<0.1	0.4	0.5	<0.1

NA = Insufficient data available over the period of study.

Appendix 8. Summary of fishery surveys on selected streams and lakes {Indiana Department of Natural Resources, Fish and Wildlife Division}

Fisheries sampling studies done by the Indiana Department of Natural Resources, Division of Fish and Wildlife may provide additional information about fish populations and water quality of streams. The multiple-year surveys, conducted for fisheries management purposes, can provide insights concerning changes in fish populations and water quality in streams through time. Fish are collected at numerous stations and classified by species, size and weight and water-quality samples are taken. In the Lake Michigan Region, IDNR fish sampling studies have been done on the **Little Calumet River** and on **Deep River**.

Within recent years, the East Branch (1974 and 1977) and the West Branch (1980) of the Little Calumet River have each been sampled by the IDNR.

Stocked annually with juvenile salmon and steelhead trout, the **East Branch of the Little Calumet River** plays an important role in Indiana as one of two watersheds managed for salmonids. Fifty-one stations were sampled throughout the watershed in 1977, and the dominant species were found to be nearly identical to those found in the 1974 survey. Generally, the water quality was found to be capable of supporting a coldwater fishery, especially at the upper stations. Some of the tributaries, however, exhibited poor fish habitat and marginal water quality. **Salt Creek** was found to have the poorest water quality in the watershed.

The **West Branch of the Little Calumet River**, sampled in 1980 at five fish collection stations by IDNR, was found to support a very limited and undesirable fish population.

An initial fishery survey of **Deep River** and **Burns Ditch** was conducted by the IDNR in 1978 to identify fish species, document fish habitat and water quality, and evaluate potential of the stream as a salmonid stocking site. As a result of the study, it was concluded that water quality was only marginal for salmonids and even warm-water fish.

An additional fishery investigation was conducted in 1991-92 of **Deep River** and **Burns Ditch** to see if any substantial changes had occurred since 1978. Sampling was conducted at 6 stations in July and August of 1991 to identify the resident population, and in February of 1992 at 2 stations to determine if salmonids were utilizing the stream.

Steelhead trout were found in significant numbers in Deep River below Lake George, even in the summer. A surprising number of bluegill and bass were also found in Deep River between the dams at Lake Station and Lake George at Hobart. However, carp continued to be the dominate species in the 1991-92 collection as it had in the 1978 survey. Water quality in both **Burns Ditch** and **Deep River** was found to still be only marginal for healthy, warm-water fish production.

Wolf Lake–1987–Previous Indiana fisheries surveys were conducted in 1969, 1974, and 1977. The 1987 Wolf Lake fish population was dominated by nongame fish. Alewife, gizzard shad, carp, and golden shiner made up 66 percent and 58 percent of the fish collected by number and weight, respectively. Desirable game species were present but are not abundant because of severe competition with alewife, shad, carp and golden shiners.

In 1977, the same four species accounted for 71 percent of the survey catch by number and 74 percent by weight. Surveys conducted in 1969 and 1974 also revealed the presence of large numbers of nongame fish, although bluegill were the most abundant fish by number in both surveys.

Despite the abundance of nongame fish, Wolf Lake continues to support a fair fishery for bluegill, channel catfish, and largemouth bass. Harvestable-size black crappie, white bass, and northern pike have reportedly been caught. Tiger muskellunge and walleye stocked by Illinois are also occasionally caught in Indiana.

Lake George at Hammond–A small fish survey was conducted of the north basin in 1976, and a brief survey of the south basin was made in 1977. Because the lake is very shallow, there have been massive winterkills in both the north and south basins. The potential for winterkill makes the prospect of sport fishing in the lake doubtful in the near future. In addition, because the lake has a history of use as a fill site for industrial waste, the 1977 survey recommended that a careful evaluation of the entire ecosystem be made before an investment of time or money be made to re-establish sport fishing in the lake. If sport fishing is to be a part of any future recreational use of Lake George, the survey identified renovation and restocking as essential.

Hog Lake was surveyed by the IDNR in 1965, 1969, 1980, and 1985. Although aquatic weed problems have been identified in the lake through the years, the 1985 report described Hog Lake as one of the prettiest places to fish in northwestern Indiana. Described as having an out-of-balance fish population in 1965, Hog Lake was described in 1985 as having good sport fishing. Average alkalinity has increased in the lake through time which may cause an improvement of the carrying-capacity of the lake, but may also cause an increase of aquatic weed problems.

Marquette Park Lagoon–fish surveys were conducted in 1972, 73, and 78. Undesirable species (golden shiner, carp, lake chubsucker and goldfish) made up approximately 21 percent of the population by number in 1978. However, in 1973, undesirable species comprised approximately 59 percent of the fish population. So, although nearly half of lake's biomass consists of undesirable fish, their number has dropped considerably in the 5-year interval. Fish population in 1978 appeared to be capable of furnishing good recreational fishing opportunities. It is believed that the lagoon receives heavy fishing pressure. Consequently, despite good growth rates, few large game fish were found in 1973 or 1978.

Kennedy Park Oxbow–(1982) Fish management is very difficult on this oxbow lake because there is occasional flooding of the lake from the Little Calumet River, and the lake is connected to the river even at normal levels. However, the lake is providing recreational fishing opportunities in spite of an abundance of gizzard shad and carp. Many people fish the lake, probably because it is located near an apartment complex.

Hobart Township Lake (Rosser Park)–1981 The lake does not have an outlet structure and appears to drain westward toward a small marsh near the Little Calumet River. Game fish accounted for 59.9% of the sample; however, game fish comprised only 15.8% of the sample by weight. Despite the overall poor quality of the fishery, no renovation was recommended for the lake at the time of the survey because there was no suitable outlet structure to prevent ingress of fish from below the lake.

Grand Boulevard Park Lake–1982 The lake's water quality appeared adequate for warmwater fish only. At the time of the survey, aquatic weeds were abundant throughout most of this relatively shallow lake. Because the lake is so shallow, it may occasionally have winterkill. The lake was supporting a moderate amount of fishing despite the presence of a large carp population. It is possible that, barring another severe winter, fishing in this lake could improve. There are sufficient numbers and sizes of bluegill and largemouth bass to provide satisfactory fishing. To improve the quality of sport fishing, the survey recommended that the lake be deepened to reduce the chances of winterkill and reduce the areas in which submersed aquatic weeds will grow.

Appendix 9. Results of chemical analysis from selected water wells

{All values in milligrams per liter except as indicated.}

Location: Locations are shown on Plate 3

Well owner: USGS, United States Geological Survey

Township: N, North

Range: E, East; W, West

Aquifer systems: CAL, Calumet; LAC, Lacustrine Plain; LPC, Lacustrine Plain underlying the Calumet; VM, Valparaiso Moraine; KK, Kankakee; SD, Silurian and Devonian bedrock

Date sampled: month and year

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
										LAKE COUNTY											
1.	CRN PT NEW	34N	8W	9	100	VM	4/84	7.4	782	196.0	71.0	13.0	3.4	4.80	0.23	434.0	13.0	350.0	< 0.1	< 0.10	912
2.	CRN PT NEW	34N	8W	9	96	VM	4/84	7.9	756	198.0	63.0	16.0	3.4	5.50	0.25	438.0	21.0	330.0	< 0.1	< 0.10	900
3.	BUFFENBARGR	34N	9W	12	52	VM	10/87	7.6	672	132.0	83.5	53.8	2.6	1.90	0.10	509.3	< 0.1	378.0	0.4	< 0.02	958
4.	CRN PT NEW	34N	8W	9	97	VM	4/84	7.2	758	191.0	68.0	16.0	3.4	6.20	0.25	436.0	20.0	330.0	0.1	< 0.10	897
5.	CRN PT NEW	34N	8W	9	98	VM	4/84	7.6	566	142.0	52.0	14.0	2.5	3.80	0.14	432.0	14.0	140.0	0.1	< 0.10	628
6.	G MISHIVICH	34N	8W	12	73	VM	10/87	7.7	377	93.5	34.9	8.4	0.5	2.10	0.10	304.4	5.8	107.0	0.3	< 0.02	435
7.	CRN PT NEW	34N	8W	9	105	VM	4/84	7.3	604	150.0	55.0	14.0	2.6	3.10	0.12	470.0	13.0	170.0	0.2	< 0.10	690
8.	CRN PT NEW	34N	8W	9	92	VM	4/84	7.5	606	161.0	50.0	11.0	2.2	5.10	0.17	388.0	14.0	230.0	0.1	< 0.10	707
9.	CRN PT NEW	34N	8W	9	90	VM	4/84	7.4	474	127.0	38.0	10.0	1.8	2.70	0.11	314.0	14.0	140.0	0.2	< 0.10	522
10.	CRN PT NEW	34N	8W	9	97	VM	4/84	7.6	740	182.0	69.0	17.0	2.6	3.50	0.14	436.0	22.0	310.0	0.1	< 0.10	868
11.	CRN PT NEW	34N	8W	9	96	VM	4/84	7.7	476	126.0	39.0	11.0	1.9	2.40	0.12	314.0	15.0	160.0	0.2	< 0.10	544
12.	CRN PT	34N	8W	9	275	SD	7/73	7.8	40	10.0	4.0	410.0	7.0	4.60	0.08	740.0	110.0	26.0	6.0	< 0.10	1022
13.	M FEDER	34N	8W	4	100	VM	5/55	7.2	404	99.0	38.0	7.1	1.7	2.30	0.07	311.0	7.0	87.0	0.2	0.07	429
14.	A PICARD	35N	7W	33	61	VM	10/87	7.4	375	92.6	35.0	5.7	0.4	3.00	0.10	314.6	5.7	107.0	0.2	< 0.02	438
15.	W KOONCE	35N	9W	26	94	VM	10/87	7.9	370	81.7	40.4	22.1	1.0	1.80	< 0.10	409.3	< 0.1	49.1	0.4	< 0.02	442
16.	INDEP HILL	35N	8W	20	95	VM	4/79	7.4	294	63.0	33.0	16.0	2.0	2.40	0.02	328.0	< 1.0	< 5.0	0.4	< 0.10	314
17.	F RUBERY	35N	8W	20	192	SD	8/60	7.4	310	64.0	37.0	15.0	2.0	1.20	0.00	342.0	3.0	3.0	0.9	.	331
18.	LINCOLN GAR	35N	8W	19	85	VM	12/77	7.1	672	126.0	86.0	31.0	5.0	3.00	0.04	432.0	19.0	240.0	0.5	0.40	770
19.	G MRAK	35N	7W	21	98	VM	10/87	6.9	522	120.0	54.5	13.2	1.0	2.30	0.10	479.0	1.5	165.0	0.2	< 0.02	645
20.	R WADE	35N	8W	24	58	VM	10/87	7.9	341	62.7	45.0	24.4	1.2	1.50	< 0.10	451.6	< 0.1	< 0.1	0.5	< 0.02	406
21.	SCHERERVILL	35N	9W	17	400	SD	3/87	8.1	216	56.0	18.0	110.0	7.1	0.11	0.00	356.0	5.0	140.0	1.0	0.40	551

Appendix 9. Results of chemical analysis from selected water wells – Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
LAKE COUNTY - continued																					
22.	HOWARD LONG	35N	9W	14	50	VM	10/81	7.3	628	122.0	79.0	26.0	3.1	3.20	0.03	464.0	< 5.0	210.0	.	.	722
23.	DYER	35N	10W	13	250	SD	5/86	7.6	644	193.0	39.0	39.0	5.3	9.50	0.19	406.0	18.0	343.0	0.5	0.00	891
24.	SCHERERVILL	35N	9W	16	324	SD	6/60	7.6	588	107.0	78.0	53.0	7.0	0.80	0.01	422.0	2.0	275.0	0.4	0.05	776
25.	SCHERERVILL	35N	9W	15	326	SD	3/87	7.5	460	93.0	55.0	29.0	4.1	0.35	0.06	322.0	10.0	190.0	0.5	0.30	575
26.	DYER	35N	10W	13	274	SD	11/75	7.4	608	120.0	75.0	45.0	6.0	2.10	0.04	404.0	17.0	290.0	0.5	0.10	798
27.	DYER	35N	10W	13	215	SD	1/76	7.3	608	120.0	75.0	43.0	6.0	2.00	0.03	402.0	14.0	280.0	0.5	< 0.10	782
28.	SEVEN UP	35N	8W	10	72	LAC	6/54	7.6	299	68.0	31.0	12.0	1.5	0.82	0.11	271.0	3.8	40.0	0.1	.	320
29.	KITT EVANS	35N	9W	11	51	LAC	10/81	7.3	474	96.0	57.0	22.0	2.9	2.60	0.02	388.0	< 5.0	130.0	.	.	543
30.	FRANK ROZIC	35N	9W	11	60	LAC	10/81	7.6	240	53.0	26.0	7.0	1.4	1.10	0.02	168.0	7.0	77.0	.	.	273
31.	PLANT FOODS	35N	9W	9	252	SD	5/55	7.4	196	38.0	25.0	148.0	6.7	0.74	0.00	443.0	13.0	71.0	0.2	0.02	570
32.	ANTON GOSE	35N	9W	11	62	LAC	10/81	7.3	668	123.0	87.0	37.0	3.9	4.80	0.03	460.0	< 5.0	280.0	.	.	812
33.	R COLWELL	35N	10W	12	60	LAC	10/87	7.2	490	131.0	39.7	17.6	1.2	5.60	0.20	293.6	12.5	272.0	0.4	< 0.02	656
34.	JOHN PRICE	35N	9W	11	57	LAC	10/81	7.7	236	54.0	24.0	12.0	0.9	0.84	0.08	120.0	17.0	120.0	.	.	301
35.	ART HEGEDUS	35N	9W	11	53	LAC	10/81	7.4	500	96.0	63.0	26.0	3.5	3.50	0.03	392.0	< 5.0	200.0	.	.	627
36.	SYLV REDER	35N	9W	1	56	LAC	10/81	7.3	398	94.0	40.0	16.0	1.8	3.70	0.09	312.0	21.0	100.0	.	.	464
37.	USGS	35N	9W	2	82	LAC	5/54	7.8	360	73.0	43.0	23.0	2.0	2.40	0.00	368.0	6.0	18.0	0.2	.	388
38.	AMER CHEMCL	35N	9W	2	74	LAC	10/81	7.6	312	59.0	40.0	63.0	5.7	0.14	< 0.02	396.0	5.0	60.0	.	.	470
39.	SALESBURY E	35N	9W	1	82	LAC	10/81	7.6	322	74.0	34.0	19.0	2.3	1.40	0.02	334.0	< 5.0	34.0	.	.	365
40.	MAPES MFG	36N	9W	35	60	LAC	5/55	7.4	319	80.0	29.0	19.0	1.9	1.60	0.00	231.0	12.0	101.0	0.4	0.25	384
41.	5031 CLEVEL	36N	8W	32	26	LAC	2/81	7.1	132	33.0	12.0	5.6	1.4	< 0.05	< 0.02	96.0	12.0	27.0	.	0.20	149
42.	E VAN BYSSU	36N	9W	36	50	LAC	10/81	7.6	228	62.0	18.0	11.0	1.0	2.90	0.04	244.0	< 5.0	< 5.0	.	.	242
43.	RDG JEWELL	36N	9W	35	50	LAC	10/81	7.8	200	50.0	18.0	7.0	0.7	0.77	0.03	200.0	< 5.0	18.0	.	.	215
44.	HAYWORTH	36N	8W	31	59	LAC	10/81	7.4	300	75.0	27.0	13.0	1.4	2.10	0.02	328.0	< 5.0	12.0	.	.	328
45.	MONARCH OIL	36N	7W	33	31	LAC	11/81	7.6	244	59.0	23.0	6.5	0.5	0.10	0.08	162.0	9.0	77.0	.	.	272
46.	D WALDRON	36N	9W	34	36	LAC	10/81	7.7	204	51.0	18.0	12.0	1.2	1.10	< 0.02	224.0	< 5.0	< 5.0	.	.	218
47.	LOVIN	36N	9W	35	38	LAC	8/81	7.8	156	38.0	15.0	6.0	0.9	0.64	0.02	168.0	< 5.0	5.0	.	.	166
48.	CITIZENS TV	36N	9W	34	87	LAC	10/81	7.8	228	49.0	26.0	37.0	2.5	1.00	< 0.02	316.0	< 5.0	< 5.0	.	.	305
49.	4380 HAYES	36N	8W	29	36	LAC	2/81	8.3	268	66.0	25.0	38.0	2.7	1.90	< 0.02	363.0	< 5.0	< 5.0	.	< 0.10	351
50.	P SANTELIK	36N	8W	29	60	LAC	2/81	8.3	300	70.0	30.0	47.0	2.0	0.32	0.12	216.0	50.0	110.0	.	< 0.10	439
51.	J DICKERSON	36N	8W	29	60	LAC	2/81	8.1	304	74.0	29.0	36.0	1.7	0.42	0.14	220.0	38.0	110.0	.	< 0.10	421
52.	G HARTHOORN	36N	8W	30	40	LAC	2/81	7.8	246	69.0	18.0	71.0	7.0	< 0.05	0.06	176.0	81.0	90.0	.	5.90	448
53.	F JARAS	36N	9W	29	185	SD	10/87	7.4	216	46.7	24.2	71.1	2.1	< 0.01	< 0.10	361.9	6.8	44.0	0.8	0.00	413
54.	D B AUTO	36N	9W	11	30	CAL	2/81	7.8	396	112.0	28.0	19.0	1.5	3.70	0.38	148.0	66.0	200.0	0.1	.	519
55.	J R WAGNER	36N	8W	30	80	LAC	2/81	7.6	70	20.0	5.0	4.2	0.6	0.08	0.03	73.0	< 5.0	8.0	.	< 0.10	82

Appendix 9. Results of chemical analysis from selected water wells – Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
LAKE COUNTY - continued																					
56.	B LEEP	36N	9W	21	100	LAC	10/87	8.1	62	16.8	4.9	62.8	0.8	0.15	< 0.10	197.5	3.5	< 0.1	0.9	< 0.02	208
57.	NEW CHICAGO	36N	7W	21	64	LAC	7/60	8.0	200	48.0	20.0	3.0	< 1.0	0.08	0.00	146.0	7.0	48.0	0.0	0.29	214
58.	NEW CHICAGO	36N	7W	21	59	LAC	7/60	8.2	229	55.0	22.0	5.0	1.0	0.20	0.00	175.0	7.0	56.0	0.0	0.31	251
59.	NEW CHICAGO	36N	7W	21	61	LAC	7/60	7.9	212	52.0	20.0	4.0	< 1.0	0.10	0.01	154.0	8.0	50.0	0.0	0.36	227
60.	NEW CHICAGO	36N	7W	21	64	LAC	7/60	8.0	217	51.0	22.0	4.0	1.0	0.01	0.00	166.0	5.0	45.0	0.0	0.41	228
61.	LAKESTATION	36N	7W	16	85	LAC	2/83	7.5	354	88.0	33.0	11.0	1.6	0.16	0.06	250.0	22.0	79.0	0.0	2.30	387
62.	LAKESTATION	36N	7W	16	64	LAC	2/83	7.5	360	91.0	32.0	15.0	2.2	0.15	0.08	248.0	28.0	93.0	0.2	1.80	412
63.	LAKESTATION	36N	7W	16	52	LAC	11/80	7.7	310	77.0	28.0	27.0	2.6	1.70	0.19	240.0	45.0	56.0	0.2	< 0.10	382
64.	LAKESTATION	36N	7W	16	86	LAC	2/83	7.6	382	98.0	33.0	19.0	2.4	0.31	0.10	256.0	35.0	110.0	0.2	2.30	454
65.	LAKE STATIO	36N	7W	16	65	LAC	2/83	7.8	322	82.0	28.0	19.0	3.1	0.21	0.08	214.0	34.0	92.0	0.2	2.20	389
66.	2600 CO LI	36N	7W	16	46	LAC	2/81	8.2	344	87.0	31.0	28.0	3.4	2.70	0.21	260.0	43.0	85.0	.	< 0.10	436
67.	USGS A20	36N	8W	10	24	CAL	7/87	7.2	380	110.0	26.0	150.0	4.2	0.01	0.03	246.0	250.0	76.0	1.3	.	765
68.	HOMER CLARK	36N	9W	11	282	SD	5/62	7.5	52	12.0	5.4	98.0	2.6	0.10	0.07	198.0	44.0	5.2	1.0	0.18	287
69.	USGS B10	36N	8W	6	21	CAL	7/87	7.7	220	57.0	19.0	9.3	1.5	< 3.00	< 1.00	150.0	40.0	31.0	0.7	.	248
70.	USGS 237 B	36N	7W	6	45	CAL	4/81	7.0	930	240.0	80.0	390.0	6.7	5.00	0.94	261.0	990.0	140.0	0.1	.	2009
71.	USGS 233 B	36N	7W	4	47	CAL	10/80	8.0	180	41.0	18.0	72.0	3.8	0.02	0.04	117.0	130.0	71.0	0.0	1.70	410
72.	USGS C20	36N	9W	5	6	CAL	7/87	6.9	180	59.0	8.0	21.0	1.6	0.01	0.43	148.0	11.0	71.0	0.4	.	261
73.	USGS LAKE	36N	9W	3	23	CAL	7/86	7.3	372	110.0	21.0	4.3	1.1	8.20	.	229.0	11.0	150.0	.	.	443
74.	SHELL OIL	36N	9W	3	310	SD	6/54	7.6	54	13.0	5.2	136.0	2.9	0.65	0.00	257.0	55.0	4.5	3.2	0.80	375
75.	USGS C18	36N	9W	2	25	CAL	7/87	7.1	390	120.0	22.0	190.0	5.9	.	0.43	490.0	240.0	93.0	0.3	.	966
76.	USGS B7	36N	8W	6	10	CAL	7/87	7.4	210	63.0	13.0	6.8	1.8	< 3.00	< 1.00	180.0	11.0	34.0	1.1	.	239
77.	USGS B8	36N	8W	6	40	CAL	7/87	7.0	.	150.0	29.0	230.0	4.2	16.00	0.41	344.0	420.0	95.0	0.1	.	1151
78.	USGS 236 B	36N	7W	6	45	CAL	10/80	7.3	450	120.0	36.0	240.0	11.0	6.20	0.27	227.0	540.0	80.0	0.1	0.01	1154
79.	USGS E20	36N	10W	1	8	CAL	7/87	7.1	450	150.0	18.0	26.0	4.2	5.70	2.10	430.0	56.0	13.0	1.3	.	534
80.	USGS A4	37N	8W	35	25	CAL	7/87	7.2	240	66.0	18.0	3.1	1.7	1.60	0.38	168.0	4.6	52.0	0.7	.	249
81.	USGS 239 B	37N	8W	36	65	CAL	4/81	7.0	290	85.0	19.0	7.7	1.6	0.25	0.02	279.0	13.0	8.3	0.1	.	302
82.	USGS 235 B	37N	7W	33	45	CAL	4/81	7.2	230	73.0	12.0	5.2	0.8	4.10	0.18	157.0	9.9	76.0	0.2	.	276
83.	GARY AIRPOR	37N	9W	35	41	CAL	2/81	7.8	520	162.0	28.0	3.0	1.8	10.00	0.61	352.0	13.0	160.0	0.3	.	590
84.	USGS D68	37N	9W	32	26	CAL	7/87	7.6	280	94.0	11.0	16.0	3.5	2.70	0.16	182.0	27.0	93.0	0.8	.	357
85.	USGS C12	37N	9W	34	20	CAL	7/87	6.8	710	240.0	27.0	91.0	5.3	.	.	251.0	130.0	490.0	3.2	.	1137
86.	USGS 275	37N	7W	31	24	CAL	4/81	7.7	410	120.0	27.0	220.0	4.0	0.91	0.59	310.0	380.0	64.0	0.3	.	1003
87.	MID CON COK	37N	9W	36	50	CAL	2/81	7.3	1020	288.0	73.0	28.0	9.9	36.00	0.29	396.0	27.0	640.0	0.2	.	1340
88.	USGS 238 B	37N	8W	36	65	CAL	4/81	7.3	1600	430.0	120.0	620.0	7.8	13.00	0.24	472.0	820.0	1200.0	< 0.1	.	3494
89.	USGS A6	37N	8W	36	7	CAL	7/87	7.3	430	92.0	48.0	58.0	48.0	0.08	0.11	321.0	52.0	190.0	1.8	.	683

Appendix 9. Results of chemical analysis from selected water wells – Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
LAKE COUNTY - continued																					
90.	USGS 251	37N	7W	33	27	CAL	4/81	7.3	350	98.0	26.0	85.0	2.9	0.13	0.25	238.0	200.0	53.0	< 0.1	0.17	608
91.	USGS E10	37N	10W	36	9	CAL	7/87	7.0	460	150.0	21.0	62.0	6.5	9.10	0.91	335.0	190.0	24.0	0.8	.	665
92.	NIPSCO	37N	9W	25	42	CAL	2/81	8.0	324	109.0	13.0	65.0	8.8	< 0.05	0.39	152.0	95.0	190.0	1.1	.	573
93.	USGS D60	37N	9W	33	8	CAL	7/87	7.0	390	120.0	23.0	8.4	4.3	.	.	348.0	15.0	35.0	2.3	.	417
94.	USGS C3	37N	9W	23	30	CAL	7/87	7.3	440	130.0	27.0	54.0	5.7	6.70	0.11	291.0	110.0	120.0	0.7	.	629
95.	USGS C4	37N	9W	23	15	CAL	7/87	7.2	450	150.0	18.0	99.0	7.6	0.09	0.06	288.0	150.0	170.0	0.9	.	768
96.	USGS C1	37N	9W	22	7	CAL	7/87	7.3	620	220.0	16.0	130.0	34.0	0.01	0.10	232.0	140.0	540.0	0.5	.	1220
97.	USGS D21	37N	9W	18	20	CAL	7/87	7.4	580	160.0	43.0	54.0	15.0	1.60	0.25	390.0	78.0	210.0	1.6	.	797
98.	WHIHALA BCH	37N	9W	8	34	CAL	2/84	6.4	642	170.0	53.0	20.0	7.3	4.50	0.28	282.0	60.0	330.0	0.3	< 0.10	815
99.	USGS E2	37N	9W	6	6	CAL	7/87	7.6	190	52.0	15.0	6.3	2.3	0.01	< 0.01	142.0	9.8	35.0	0.5	.	206
PORTER COUNTY																					
100.	ROZHON	35N	6W	36	85	VM	10/87	7.2	538	145.0	42.6	3.5	0.4	4.10	0.20	380.5	23.7	175.0	0.3	< 0.02	623
101.	VALPARAISO	35N	5W	29	126	VM	9/87	7.4	314	90.0	22.0	2.8	1.6	3.60	0.22	200.0	< 5.0	100.0	< 0.1	< 0.10	340
102.	VALPARAISO	35N	5W	29	138	VM	9/87	7.4	332	90.0	26.0	3.4	1.7	1.70	0.14	246.0	5.0	79.0	0.0	< 0.10	355
103.	VALPARAISO	35N	5W	29	129	VM	9/87	7.4	319	85.0	26.0	3.0	1.5	1.40	0.14	224.0	6.0	82.0	0.1	< 0.10	340
104.	SHOREWOOD	35N	6W	19	119	VM	8/77	7.1	517	119.0	53.0	12.0	2.0	1.70	0.06	426.0	10.0	87.0	0.3	< 0.10	541
105.	SCHUBERT E	35N	6W	23	65	VM	9/87	7.5	280	76.1	21.9	36.4	0.8	1.80	0.10	257.0	26.0	79.6	0.1	< 0.02	397
106.	WHEELER H S	35N	7W	13	55	VM	10/87	7.8	234	66.3	16.6	4.5	0.3	0.50	< 0.10	151.6	19.2	33.3	< 0.1	< 0.02	232
107.	KRAISINGER	35N	6W	11	125	VM	9/87	7.6	418	111.0	34.6	4.3	0.4	3.00	0.10	308.4	0.9	143.0	0.1	< 0.02	482
108.	G HOWARD	35N	7W	12	72	LAC	11/81	7.7	208	48.0	21.0	11.0	1.2	0.77	0.02	228.0	< 5.0	8.0	.	.	227
109.	BURL HUCKAB	35N	7W	1	72	LAC	11/81	7.7	268	46.0	37.0	41.0	2.8	1.40	< 0.02	358.0	< 5.0	< 5.0	.	.	343
110.	WARN MCAFEE	35N	7W	2	145	LAC	11/81	7.6	184	40.0	20.0	56.0	5.2	1.50	0.03	294.0	5.0	< 5.0	.	.	304
111.	WORTHINGTON	35N	7W	3	137	LAC	11/81	7.7	292	62.0	34.0	79.0	5.1	1.30	0.02	322.0	110.0	< 5.0	.	.	485
112.	ED CARNEY	35N	7W	2	161	LAC	11/81	7.6	208	43.0	24.0	96.0	5.9	0.91	0.00	312.0	85.0	< 5.0	.	.	442
113.	PAUL HOHRUN	35N	7W	3	141	LAC	11/81	7.8	172	37.0	19.0	73.0	4.0	0.79	< 0.02	292.0	32.0	5.0	.	.	346
114.	JASN GALLER	35N	7W	3	80	LAC	11/81	7.2	524	130.0	49.0	32.0	11.0	< 5.00	< 0.02	378.0	23.0	190.0	.	.	662
115.	WILLM KASLO	35N	7W	3	100	LAC	11/81	7.7	222	47.0	25.0	68.0	5.7	0.57	< 0.02	304.0	52.0	< 5.0	.	.	381
116.	E WARD	36N	7W	35	90	LAC	11/81	7.8	178	38.0	20.0	59.0	2.5	0.77	< 0.02	308.0	< 5.0	< 5.0	.	.	305
117.	ELLINGHAUSE	36N	7W	34	102	LAC	11/81	7.8	220	46.0	25.0	91.0	4.4	0.86	< 0.02	302.0	86.0	< 5.0	.	.	434
118.	ELMER KUHRT	36N	7W	36	96	LAC	11/81	7.7	260	42.0	37.0	44.0	3.8	0.22	< 0.02	352.0	< 5.0	< 5.0	.	.	338
119.	GRG SHAFFER	36N	7W	34	105	LAC	11/81	7.4	180	40.0	19.0	76.0	5.4	1.30	0.00	296.0	35.0	< 5.0	.	.	354
120.	SOUTH HAVEN	36N	6W	34	93	VM	5/79	7.4	418	102.0	40.0	6.0	1.5	1.90	0.09	332.0	5.0	100.0	0.2	< 0.10	456

Appendix 9. Results of chemical analysis from selected water wells - Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
PORTER COUNTY - Countinued																					
121.	S HAVEN SUB	36N	6W	34	101	VM	10/75	8.0	400	95.0	39.0	6.0	2.0	1.70	0.08	318.0	4.0	74.0	0.2	0.10	413
122.	RICH RAFFIN	36N	5W	32	165	VM	9/81	6.7	668	158.0	66.0	6.0	1.5	13.00	0.22	380.0	68.0	200.0	.	.	741
123.	JOANIE FOLL	36N	6W	36	68	VM	9/81	7.0	414	102.0	38.0	5.0	2.0	1.90	0.15	310.0	11.0	91.0	0.1	< 0.10	437
124.	CP LOWRENCE	36N	6W	36	181	VM	9/81	7.5	542	137.0	49.0	5.0	1.8	< 0.05	< 0.02	404.0	< 5.0	130.0	0.2	0.60	566
125.	R D MARKINS	36N	5W	30	142	VM	9/81	7.5	474	122.0	41.0	3.0	1.0	0.26	0.13	376.0	< 5.0	97.0	.	.	490
126.	S HAVEN SUB	36N	6W	29	131	LAC	10/75	7.4	460	78.0	65.0	80.0	5.0	1.30	0.02	448.0	120.0	4.0	0.4	0.60	623
127.	LUTH CHURCH	36N	5W	30	140	VM	9/81	7.6	472	120.0	42.0	3.0	1.3	1.70	0.08	326.0	< 5.0	140.0	.	.	504
128.	S HAVEN SUB	36N	6W	29	170	LAC	3/69	8.1	196	38.0	24.0	135.0	6.0	1.00	0.00	338.0	100.0	< 1.0	0.6	< 0.10	507
129.	ED PILLMAN	36N	6W	26	69	VM	9/81	6.9	614	145.0	61.0	19.0	1.9	5.80	0.20	440.0	56.0	130.0	0.2	< 0.10	683
130.	PAT MULLEN	36N	5W	30	150	VM	9/81	6.8	724	171.0	72.0	5.0	1.3	4.20	0.16	420.0	10.0	290.0	.	.	806
131.	SUNST HL FM	36N	6W	25	46	VM	9/81	7.6	304	78.0	27.0	9.0	1.9	1.40	0.04	198.0	17.0	110.0	0.1	< 0.10	363
132.	RBT BROWNER	36N	6W	27	75	LAC	9/81	7.2	348	83.0	34.0	7.0	1.2	1.90	0.04	298.0	< 5.0	56.0	0.2	< 0.10	362
133.	W MCCLELLAN	36N	5W	30	168	VM	9/81	7.0	506	125.0	47.0	3.0	1.0	3.60	0.10	388.0	< 5.0	130.0	.	.	543
134.	LIBERTY FRM	36N	6W	25	149	VM	9/81	7.0	444	111.0	40.0	7.0	1.4	6.40	0.11	380.0	< 5.0	90.0	.	.	487
135.	STAN OIL CO	36N	5W	30	87	VM	9/81	6.9	608	154.0	54.0	26.0	2.2	2.80	0.08	284.0	200.0	88.0	.	.	697
136.	G MATAVICH	36N	5W	19	80	VM	9/81	7.4	630	155.0	59.0	53.0	3.5	2.30	0.11	312.0	230.0	100.0	.	.	790
137.	STAN OIL CO	36N	5W	19	105	VM	9/81	7.5	464	115.0	43.0	38.0	2.7	2.70	0.09	320.0	107.0	66.0	.	.	567
138.	ELMWOOD PRK	36N	6W	23	62	VM	9/81	6.9	430	101.0	43.0	5.0	1.4	2.40	0.10	330.0	9.0	99.0	0.2	< 0.10	459
139.	LIBERTY M S	36N	6W	23	70	LAC	3/73	7.5	434	107.0	40.0	10.0	2.0	2.20	0.07	384.0	4.0	66.0	0.2	< 0.10	462
140.	2924 GLENRO	36N	7W	14	35	LAC	2/81	8.1	164	34.0	19.0	6.5	0.7	< 0.05	0.06	132.0	< 5.0	40.0	.	1.60	181
141.	TOLL ROAD	36N	5W	18	90	LAC	5/56	7.6	388	96.0	36.0	7.7	1.8	3.20	0.02	352.0	2.0	40.0	0.1	0.05	398
142.	LEIMBACHER	36N	5W	10	108	VM	10/87	7.5	316	84.0	25.7	3.5	0.3	3.10	0.10	290.3	1.5	51.8	0.2	< 0.02	344
143.	PORTAGE N U	36N	6W	8	75	LAC	10/75	8.1	266	69.0	23.0	8.0	1.0	0.30	0.06	190.0	18.0	56.0	0.2	1.80	291
144.	PORTAGE N U	36N	6W	8	74	LAC	10/83	7.6	312	82.0	26.0	11.0	1.2	0.22	0.07	220.0	26.0	55.0	0.1	3.00	337
145.	SEAS HEATIN	36N	7W	11	34	CAL	2/81	8.0	194	48.0	18.0	8.0	1.9	0.85	0.06	120.0	13.0	81.0	.	< 0.10	243
146.	USGS 229 B	36N	7W	2	62	CAL	4/80	7.7	140	38.0	12.0	11.0	0.7	0.51	0.04	130.0	11.0	15.0	0.2	0.05	166
147.	USGS 240 B	36N	6W	6	55	LAC	4/81	7.4	350	90.0	30.0	62.0	2.9	< 0.01	0.00	183.0	150.0	99.0	< 0.1	.	544
148.	USGS 227 B	37N	6W	34	52	LAC	4/80	7.1	220	60.0	18.0	6.0	1.7	2.60	0.19	170.0	19.0	43.0	0.1	0.00	253
149.	USGS 227 C	37N	6W	34	24	LAC	4/81	6.1	300	75.0	28.0	190.0	7.0	0.01	0.09	112.0	430.0	88.0	0.0	0.28	886
150.	CHESTERTON	37N	6W	36	81	LAC	12/82	7.5	372	90.0	35.0	11.0	2.4	1.20	0.09	282.0	20.0	79.0	0.2	< 0.10	408
151.	USGS 225 B	37N	6W	34	55	LAC	4/80	8.3	210	50.0	20.0	5.5	1.0	0.50	0.13	150.0	6.6	58.0	0.2	0.02	232
152.	USGS 228 B	37N	6W	32	52	LAC	5/80	6.7	320	89.0	24.0	13.0	2.1	0.05	0.04	250.0	24.0	55.0	0.2	0.09	357
153.	OGDEN DUNES	37N	7W	35	28	CAL	4/57	7.4	213	54.0	19.0	3.8	0.8	0.13	0.15	167.0	3.0	38.0	0.1	0.93	228
154.	USGS 231 B	37N	7W	34	45	CAL	10/80	7.0	240	59.0	22.0	1.9	0.7	7.60	0.37	219.0	4.9	48.0	0.1	0.07	276

Appendix 9. Results of chemical analysis from selected water wells – Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
PORTER COUNTY - Countinued																					
155.	MOORE-USGS	37N	7W	35	22	CAL	4/74	6.9	280	70.0	25.0	8.6	2.0	.	.	258.0	7.6	29.0	.	.	297
156.	TITTLE-USGS	37N	7W	35	30	CAL	10/73	8.0	260	66.0	24.0	50.0	1.2	.	.	176.0	78.0	82.0	.	.	407
157.	CHESTERTON	37N	6W	36	73	LAC	12/82	7.4	370	90.0	35.0	12.0	2.1	0.62	0.07	260.0	32.0	77.0	0.2	< 0.10	405
158.	USGS 206 A	37N	5W	35	182	LAC	10/80	7.6	230	57.0	22.0	8.1	2.6	0.67	0.14	254.0	3.1	0.0	0.2	0.01	246
159.	USGS 206 B	37N	5W	35	72	LAC	10/80	7.4	250	61.0	24.0	4.4	0.9	1.20	0.11	260.0	2.7	28.0	0.2	0.01	278
160.	USGS 206 C	37N	5W	35	24	LAC	4/81	8.1	300	72.0	28.0	8.1	0.9	0.29	0.10	132.0	15.0	140.0	< 0.1	.	344
161.	USGS 230 S	37N	7W	35	55	CAL	5/80	6.7	440	120.0	33.0	70.0	2.0	0.05	0.27	290.0	120.0	120.0	0.1	0.00	639
162.	USGS 230 D	37N	7W	35	126	LPC	5/80	7.2	290	72.0	26.0	280.0	2.9	0.06	0.28	130.0	500.0	17.0	0.8	0.01	977
163.	USGS 230 D	37N	7W	35	24	CAL	4/81	5.9	42	13.0	2.3	3.8	0.7	0.49	0.03	12.0	5.4	27.0	< 0.1	2.00	62
164.	USGS 242 B	37N	6W	31	83	CAL	4/81	7.7	160	41.0	14.0	22.0	0.9	0.67	0.04	171.0	33.0	1.4	0.3	.	216
165.	USGS 226 R	37N	6W	35	64	LAC	4/81	7.3	530	140.0	44.0	73.0	4.1	3.80	0.29	311.0	210.0	94.0	0.2	.	756
166.	USGS 226G	37N	6W	35	30	LAC	4/81	7.4	380	85.0	40.0	16.0	1.0	< 0.01	0.00	274.0	44.0	66.0	0.2	2.30	419
167.	USGS 207 A	37N	5W	27	170	LAC	10/80	7.6	240	56.0	24.0	23.0	2.6	1.50	0.04	272.0	32.0	0.0	0.2	0.01	301
168.	USGS 207 B	37N	5W	27	85	LAC	10/80	7.6	240	58.0	22.0	9.1	2.1	1.40	0.03	267.0	7.2	0.0	0.2	0.01	260
169.	USGS 244 A	37N	7W	25	125	LPC	10/80	7.8	73	19.0	6.2	78.0	1.3	0.03	0.05	249.0	19.0	2.0	1.2	0.07	276
170.	USGS 244 B	37N	7W	25	65	CAL	10/80	7.3	310	86.0	24.0	8.1	1.3	3.10	0.18	294.0	24.0	43.0	0.0	0.03	366
171.	USGS 232 B	37N	7W	27	45	CAL	4/81	7.3	320	92.0	22.0	6.2	1.9	7.00	0.12	315.0	15.0	14.0	0.0	.	347
172.	USGS 224 B	37N	6W	27	52	LAC	10/80	7.1	340	81.0	33.0	4.2	1.4	0.01	< 0.01	308.0	8.5	45.0	0.1	1.50	359
173.	USGS 223 B	37N	6W	26	113	LAC	10/80	7.5	250	56.0	27.0	45.0	2.4	0.01	0.06	354.0	62.0	0.0	0.4	0.03	405
174.	USGS 105 DP	37N	6W	28	77	LPC	5/78	7.7	250	57.0	25.0	75.0	2.0	0.05	0.36	200.0	160.0	8.3	0.5	.	448
175.	USGS 106 SH	37N	6W	28	25	CAL	5/78	7.0	300	75.0	28.0	30.0	1.7	< 0.01	< 0.01	210.0	58.0	77.0	< 0.1	.	396
176.	USGS 219 B	37N	5W	30	69	LAC	10/80	7.2	430	81.0	55.0	12.0	2.3	1.20	0.09	409.0	4.9	84.0	0.2	0.02	486
177.	KRATZ-USGS	37N	7W	26	27	CAL	4/74	7.0	310	90.0	21.0	86.0	10.0	.	.	263.0	120.0	53.0	.	.	538
178.	US ARMY	37N	6W	27	125	LAC	9/64	7.9	428	81.0	55.0	9.9	1.5	0.29	0.16	331.0	12.0	103.0	0.1	0.20	462
179.	USGS 103	37N	6W	27	77	LPC	5/78	8.2	110	29.0	10.0	37.0	1.9	0.16	0.04	170.0	19.0	1.5	0.6	.	201
180.	USGS 104	37N	6W	27	24	CAL	5/78	7.7	370	84.0	39.0	17.0	2.3	2.60	0.09	280.0	14.0	100.0	< 0.1	.	427
181.	USGS 205 B	37N	5W	26	65	LAC	10/80	7.5	220	55.0	20.0	5.9	1.3	0.65	0.05	216.0	3.8	17.0	0.2	0.01	233
182.	USGS 208 B	37N	5W	28	71	LAC	10/80	7.3	370	67.0	50.0	30.0	3.2	0.23	0.03	471.0	9.3	30.0	0.4	0.24	473
183.	NIPSCO USGS	37N	6W	27	24	CAL	9/76	7.1	300	63.0	35.0	15.0	3.4	2.90	0.13	291.0	16.0	28.0	0.1	.	338
184.	USGS 243 B	37N	5W	19	85	LAC	4/80	7.3	310	64.0	37.0	21.0	2.3	0.02	0.01	320.0	7.1	15.0	0.4	0.19	339
185.	USGS 243 C	37N	5W	19	165	LAC	5/80	7.5	290	60.0	35.0	19.0	2.4	0.02	0.02	310.0	7.3	8.4	0.7	0.14	318
186.	NIPSCO USGS	37N	6W	22	23	CAL	10/77	7.2	340	72.0	39.0	14.0	2.1	0.08	0.08	290.0	15.0	56.0	0.1	.	372
187.	USGS GRT MS	37N	6W	22	8	CAL	4/81	7.6	360	81.0	38.0	11.0	1.3	1.60	0.08	304.0	18.0	71.0	0.2	.	405
188.	USGS 102	37N	6W	21	86	LPC	1/78	8.3	190	20.0	33.0	21.0	2.5	0.07	0.06	210.0	7.9	1.9	0.1	.	213

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
PORTER COUNTY - Countinued																					
189.	NIPSCO USGS	37N	6W	22	23	CAL	10/77	6.7	160	46.0	12.0	7.0	3.2	17.00	0.34	217.0	11.0	14.0	0.1	.	241
190.	USGS GRT MS	37N	6W	22	8	CAL	5/81	6.9	420	86.0	50.0	13.0	2.1	1.50	0.05	391.0	9.8	55.0	0.2	.	452
191.	NIPSCO USGS	37N	6W	22	22	CAL	9/76	7.1	230	58.0	20.0	5.4	1.7	3.60	0.11	196.0	5.8	25.0	0.2	.	237
192.	NIPSCO USGS	37N	6W	21	29	CAL	3/77	6.4	660	240.0	15.0	21.0	34.0	0.22	0.61	0.0	12.0	730.0	0.1	.	1053
193.	NIPSCO USGS	37N	6W	21	49	CAL	5/78	7.8	280	110.0	1.9	16.0	17.0	0.20	0.06	38.0	11.0	270.0	1.7	.	451
194.	NIPSCO USGS	37N	6W	21	29	CAL	5/78	6.5	630	250.0	0.7	12.0	25.0	0.36	0.04	55.0	34.0	590.0	0.0	.	945
195.	NIPSCO D	37N	6W	22	13	CAL	10/77	.	47	14.0	2.9	2.6	1.1	0.09	0.00	8.0	3.6	47.0	0.0	.	76
196.	USGS 222 A	37N	6W	24	180	LAC	4/81	7.8	200	47.0	20.0	190.0	3.9	0.42	0.05	224.0	290.0	0.6	0.9	0.01	687
197.	USGS 222 B	37N	6W	24	62	LAC	4/81	7.7	320	62.0	41.0	34.0	2.9	0.85	0.03	349.0	13.0	40.0	0.5	.	404
198.	USGS 222 C	37N	6W	24	28	LAC	4/81	6.1	130	32.0	12.0	21.0	4.1	1.20	0.02	31.0	59.0	71.0	< 0.1	0.10	219
199.	USGS GRT MS	37N	6W	22	16	CAL	4/81	7.1	340	68.0	42.0	20.0	1.1	1.30	0.05	401.0	12.0	0.2	0.4	.	386
200.	USGS GRT MS	37N	6W	22	13	CAL	4/81	6.7	430	98.0	44.0	9.2	2.1	5.00	0.14	491.0	4.5	1.2	0.2	.	459
201.	USGS GRT MS	37N	6W	23	7	CAL	4/81	6.3	170	37.0	18.0	58.0	3.8	0.89	0.17	68.0	110.0	67.0	< 0.1	.	336
202.	USGS 101 DP	37N	6W	21	75	CAL	10/77	7.5	230	46.0	27.0	35.0	3.6	1.30	0.08	230.0	26.0	38.0	0.4	.	315
203.	USGS GRT MS	37N	6W	22	9	CAL	4/81	6.6	270	60.0	29.0	15.0	0.8	9.00	0.21	327.0	14.0	7.4	0.2	.	332
204.	NIPSCO D	37N	6W	21	17	CAL	4/78	.	290	87.0	18.0	14.0	15.0	0.12	0.21	69.0	10.0	250.0	< 0.1	.	436
205.	USGS GRT MS	37N	6W	22	8	CAL	4/81	6.9	400	74.0	52.0	17.0	2.0	0.01	0.05	393.0	10.0	59.0	0.3	.	450
206.	USGS GRT MS	37N	6W	22	20	CAL	4/81	7.1	470	96.0	55.0	14.0	2.3	1.90	0.10	396.0	8.4	94.0	0.2	.	509
207.	USGS GRT MS	37N	6W	22	18	CAL	4/81	7.0	440	93.0	51.0	12.0	2.1	1.90	0.09	400.0	9.1	98.0	0.2	.	507
208.	USGS GRT MS	37N	6W	22	18	CAL	4/81	7.0	400	78.0	51.0	13.0	1.9	2.00	0.05	371.0	13.0	85.0	0.3	.	467
209.	USGS GRT MS	37N	6W	22	12	CAL	4/81	7.0	400	77.0	51.0	16.0	2.1	1.40	0.04	363.0	12.0	81.0	0.3	.	459
210.	NIPSCO D	37N	6W	21	21	CAL	4/78	.	380	110.0	26.0	14.0	9.8	< 0.10	3.90	45.0	12.0	400.0	0.1	.	603
211.	LUTZ-USGS	37N	6W	24	60	LAC	4/74	6.8	160	38.0	16.0	25.0	3.0	.	.	52.0	80.0	54.0	.	.	247
212.	NIPSCO D	37N	6W	21	17	CAL	4/78	.	320	88.0	25.0	13.0	7.6	0.43	1.50	64.0	10.0	290.0	< 0.1	.	474
213.	USGS GRT MS	37N	6W	23	8	CAL	4/81	7.3	140	36.0	12.0	4.2	0.5	0.81	0.04	149.0	3.8	14.0	0.1	.	161
214.	DUNE ACRES	37N	6W	23	16	CAL	5/88	7.3	218	55.0	19.0	10.0	1.1	6.80	0.13	188.0	16.0	21.0	0.1	< 0.10	242
215.	NIPSCO D	37N	6W	21	12	CAL	4/78	.	60	15.0	5.4	3.2	0.5	1.80	0.07	33.0	4.9	41.0	.	.	92
216.	USGS 107 DP	37N	6W	23	64	CAL	10/77	8.4	180	46.0	16.0	14.0	1.6	0.31	0.18	160.0	20.0	21.0	0.2	.	215
217.	USGS 108 SH	37N	6W	23	16	CAL	10/77	7.3	140	34.0	13.0	13.0	1.1	5.50	0.35	200.0	4.9	2.1	0.2	.	194
218.	KAISER-USGS	37N	6W	24	13	CAL	4/74	7.6	290	57.0	36.0	26.0	4.0	.	.	328.0	11.0	4.6	.	.	335
219.	USGS GRT MS	37N	6W	22	8	CAL	10/80	5.4	96	30.0	5.2	1.5	0.5	11.00	0.12	72.0	8.0	30.0	0.1	0.00	131
220.	NIPSCO D	37N	6W	22	12	CAL	10/77	.	39	8.0	4.7	3.2	1.7	6.30	0.12	5.0	6.0	54.0	0.1	.	87
221.	USGS GRT MS	37N	6W	22	8	CAL	4/81	6.1	150	40.0	12.0	2.5	0.2	18.00	0.09	114.0	7.7	70.0	< 0.1	.	219
222.	USGS GRT MS	37N	6W	23	5	CAL	4/81	6.6	220	53.0	22.0	7.1	0.2	5.70	0.17	248.0	6.5	5.0	0.1	.	249

Appendix 9. Results of chemical analysis from selected water wells – Continued

Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
PORTER COUNTY - Countinued																					
223.	USGS 220 R	37N	6W	24	63	LAC	10/80	7.6	290	48.0	41.0	30.0	2.9	1.30	0.03	427.0	17.0	1.0	0.5	0.01	398
224.	USGS 220 C	37N	6W	24	16	CAL	4/81	8.0	230	56.0	22.0	10.0	4.6	0.25	0.03	138.0	32.0	72.0	< 0.1	0.00	280
225.	USGS 218 A	37N	5W	19	141	LAC	4/80	6.9	460	79.0	64.0	25.0	2.8	1.90	0.04	468.0	7.3	28.0	0.4	0.00	489
226.	USGS 218 B	37N	5W	19	25	LAC	4/80	5.8	140	34.0	13.0	3.9	0.3	0.71	0.04	80.0	9.4	50.0	0.1	0.00	159
227.	USGS 209	37N	5W	16	75	LAC	10/80	7.2	430	80.0	55.0	18.0	3.0	0.99	0.07	497.0	6.3	13.0	0.3	0.01	475
228.	USGS 210 A	37N	5W	15	106	LAC	5/80	7.3	470	73.0	69.0	70.0	4.7	0.59	0.16	430.0	7.5	190.0	0.8	0.05	674
229.	USGS 210 B	37N	5W	15	28	LAC	4/80	6.7	350	64.0	46.0	70.0	55.0	9.90	1.10	520.0	77.0	42.0	0.1	0.01	676
230.	DUNESP-USGS	37N	6W	13	120	CAL	4/74	7.8	310	56.0	41.0	130.0	11.0	.	.	325.0	210.0	1.2	.	.	644
231.	DUNESP-USGS	37N	6W	13	92	CAL	10/73	7.6	390	69.0	53.0	59.0	8.2	.	.	481.0	29.0	2.5	.	.	509
232.	USGS 221A	37N	6W	13	24	CAL	4/81	7.5	240	69.0	16.0	1.4	1.0	0.02	0.02	235.0	1.4	23.0	< 0.1	0.82	254
233.	USGS GRT MS	37N	5W	17	6	CAL	10/80	6.5	130	32.0	13.0	15.0	0.6	2.80	0.15	61.0	29.0	48.0	0.0	0.00	177
234.	USGS GRT MS	37N	5W	18	5	CAL	4/81	6.7	170	41.0	17.0	11.0	0.8	4.30	0.18	108.0	36.0	51.0	0.1	.	226
235.	USGS 211 A	37N	5W	16	176	LAC	4/81	7.5	290	46.0	43.0	89.0	9.3	1.20	0.01	486.0	13.0	1.8	0.5	.	495
236.	USGS 211 B	37N	5W	16	22	LAC	4/81	6.0	310	55.0	42.0	15.0	2.1	0.74	0.07	298.0	12.0	26.0	0.4	.	332
237.	USGS 204 B	37N	5W	13	125	LAC	4/81	7.4	270	60.0	28.0	12.0	1.8	0.24	0.03	277.0	4.9	15.0	0.3	.	288
238.	USGS 204 C	37N	5W	13	57	LAC	4/81	6.9	1600	200.0	270.0	82.0	7.4	4.20	0.04	664.0	11.0	1200.0	0.5	.	1093
239.	USGS 211 9	37N	5W	16	6	LAC	5/86	6.0	.	13.0	3.3	37.0	1.2	.	.	58.0	51.0	16.0	.	.	156
240.	USGS 241 A	37N	5W	10	137	LAC	5/80	7.1	280	58.0	33.0	46.0	4.0	0.75	0.08	310.0	51.0	1.0	0.4	0.12	380
241.	USGS 241 B	37N	5W	10	85	LAC	5/80	7.4	300	55.0	39.0	47.0	2.8	1.10	0.09	370.0	14.0	0.3	0.5	0.02	382
242.	USGS 241 C	37N	5W	10	24	LAC	4/81	7.5	320	53.0	45.0	24.0	3.3	2.10	0.04	350.0	18.0	8.1	0.2	.	364
243.	D VENANDER	37N	5W	12	76	LAC	12/81	7.5	120	19.0	17.0	120.0	2.7	0.09	< 0.02	268.0	99.0	< 5.0	.	.	419
244.	USGS GRT MS	37N	5W	9	5	CAL	4/81	6.7	180	41.0	20.0	23.0	3.4	1.50	0.05	167.0	29.0	35.0	< 0.1	.	253
245.	GEORGE HERO	37N	5W	12	33	LAC	12/81	7.2	178	45.0	16.0	4.2	1.2	4.10	0.19	124.0	11.0	55.0	.	.	211
246.	USGS 321 9	37N	5W	9	6	CAL	5/86	7.0	.	54.0	33.0	53.0	0.7	.	.	334.0	19.0	41.0	.	.	401
247.	CHESTER LEW	37N	5W	12	48	LAC	12/81	7.3	64	18.0	5.0	90.0	1.6	0.46	< 0.02	210.0	29.0	< 5.0	.	.	270
248.	ROY JOHNSON	37N	5W	12	75	LAC	12/81	7.6	138	29.0	16.0	97.0	4.4	0.54	< 0.02	272.0	68.0	< 5.0	.	.	378
249.	USGS 305 7	37N	5W	9	6	CAL	5/86	6.3	.	50.0	14.0	13.0	2.9	.	.	158.0	7.5	61.0	.	.	243
250.	USGS 305-156	37N	5W	9	156	LPC	11/84	7.7	0	26.0	15.0	160.0	4.3	.	.	359.0	110.0	0.2	.	.	531
251.	USGS 305-11B	37N	5W	9	11	CAL	5/86	6.4	.	55.0	9.6	3.5	1.8	.	.	130.0	2.5	55.0	.	.	205
252.	USGS 305B 7	37N	5W	9	7	CAL	5/86	6.2	.	24.0	4.9	7.2	1.4	.	.	67.0	2.7	26.0	.	.	106
253.	USGS GRT MS	37N	5W	9	5	CAL	4/81	7.1	510	160.0	27.0	32.0	0.9	8.00	0.68	406.0	32.0	180.0	0.2	.	684
254.	USGS305 11A	37N	5W	9	9	CAL	5/86	6.1	.	14.0	4.7	7.9	1.4	.	.	32.0	7.4	31.0	.	.	86
255.	USGS 305D 8	37N	5W	9	8	CAL	5/86	6.5	.	65.0	7.9	41.0	2.5	.	.	164.0	57.0	37.0	.	.	309
256.	USGS GRT MS	37N	5W	10	6	CAL	4/81	6.6	81	20.0	7.6	19.0	1.1	2.10	0.09	47.0	39.0	39.0	0.1	.	156

Appendix 9. Results of chemical analysis from selected water wells – Continued

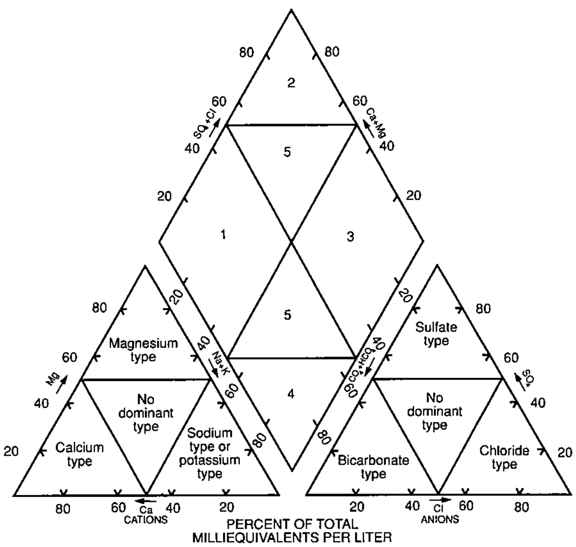
Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
PORTER COUNTY - Countinued																					
257.	USGS 322	37N	5W	9	12	CAL	5/86	8.2	.	19.0	7.7	0.7	0.3	.	.	60.4	1.8	19.0	.	.	85
258.	USGS306 212	37N	5W	9	212	LPC	3/85	7.6	.	41.0	32.0	150.0	6.9	.	.	382.0	120.0	< 2.0	.	.	579
259.	NOAH HAMILT	37N	5W	12	22	LAC	12/81	6.9	208	57.0	16.0	23.0	8.8	3.90	0.32	180.0	31.0	54.0	.	.	302
260.	USGS BL1	37N	5W	11	17	CAL	8/88	6.6	.	320.0	150.0	40.0	0.0	1.90	0.10	438.0	81.0	980.0	0.1	.	1846
261.	USGS 215 B	37N	5W	11	33	CAL	4/81	8.0	120	35.0	8.9	27.0	1.0	< 0.10	< 0.01	101.0	44.0	37.0	< 0.1	0.70	214
262.	USGS BL2	37N	5W	11	12	CAL	8/88	6.8	.	130.0	28.0	440.0	2.2	0.02	< 0.01	302.0	590.0	190.0	0.1	.	1561
263.	AUDREY FRAS	37N	5W	12	13	LAC	12/81	7.0	204	50.0	19.0	25.0	6.8	3.30	0.14	160.0	39.0	55.0	.	.	294
264.	LAUDERDALE	37N	5W	12	16	LAC	12/81	6.8	144	35.0	14.0	6.2	11.0	0.05	0.02	106.0	8.0	61.0	.	.	199
265.	DAN ADNEY	37N	5W	12	20	LAC	12/81	6.8	180	42.0	18.0	57.0	12.0	0.21	0.03	152.0	54.0	76.0	.	.	350
266.	USGS GRT MS	37N	5W	3	8	CAL	4/81	7.1	370	96.0	31.0	45.0	1.6	4.30	0.18	440.0	45.0	7.1	0.3	.	495
267.	USGS 212 A	37N	5W	4	212	LPC	5/80	8.2	280	54.0	36.0	330.0	7.9	0.84	0.06	240.0	540.0	2.0	0.7	0.03	1116
268.	USGS 216	37N	5W	1	49	LAC	10/80	7.6	170	30.0	24.0	85.0	3.3	0.69	0.01	293.0	66.0	0.0	0.4	0.01	386
269.	USGS 216G	37N	5W	1	11	LAC	4/81	7.6	190	44.0	20.0	4.8	1.9	0.52	0.29	213.0	5.2	1.9	0.2	.	207
270.	USGS GRT MS	37N	5W	2	6	CAL	4/81	6.0	110	32.0	8.3	72.0	7.5	0.01	0.35	39.0	100.0	79.0	< 0.1	5.70	328
271.	USGS BL4	37N	5W	2	6	CAL	8/88	5.9	71	18.0	6.3	46.0	1.5	0.03	0.03	25.0	52.0	54.0	0.1	.	193
272.	USGS GRT MS	37N	5W	2	14	CAL	4/81	6.4	180	50.0	14.0	4.3	1.1	16.00	0.43	166.0	12.0	40.0	< 0.1	.	238
273.	NORBERG-USG	37N	5W	1	30	CAL	4/74	7.0	110	27.0	10.0	16.0	8.0	.	.	58.0	12.0	65.0	.	.	173
274.	CASTEL-USGS	38N	5W	36	105	LPC	4/74	8.0	180	33.0	23.0	47.0	4.2	.	.	249.0	13.0	0.5	.	.	270
275.	USGS 214 B	38N	5W	35	26	CAL	4/81	7.1	180	45.0	16.0	24.0	2.4	0.72	0.04	133.0	41.0	57.0	< 0.1	.	266
276.	USGS 217 SH	38N	5W	36	13	CAL	4/81	6.8	41	12.0	2.7	1.9	0.5	0.65	0.03	44.0	1.2	8.2	< 0.1	.	54
277.	MCKINN-USGS	38N	5W	36	28	CAL	10/73	8.0	120	34.0	9.4	33.0	5.3	.	.	159.0	20.0	10.0	.	.	207
278.	WARDEN-USGS	38N	5W	36	96	LPC	10/73	8.2	71	19.0	5.8	76.0	3.2	.	.	202.0	22.0	1.6	.	.	249
LAPORTE COUNTY																					
279.	PURDUE-WVLL	36N	4W	9	155	VM	3/73	7.7	342	85.0	32.0	3.0	1.0	2.10	0.08	296.0	2.0	43.0	0.2	< 0.10	346
280.	E HAYMAN	37N	4W	21	85	LAC	10/87	7.5	278	77.1	20.7	2.3	0.4	1.00	0.10	279.1	7.9	21.2	0.1	< 0.02	298
281.	JONGKIND	37N	3W	19	272	VM	11/74	7.8	326	82.0	30.0	5.0	2.0	1.00	0.10	288.0	4.0	36.0	0.2	0.10	333
282.	USGS 201 A	37N	4W	9	205	LAC	4/80	7.8	260	39.0	40.0	54.0	5.8	0.20	0.03	350.0	23.0	6.9	0.7	0.03	392
283.	USGS 201 B	37N	4W	9	30	LAC	4/80	7.0	710	86.0	120.0	33.0	2.6	1.90	0.03	530.0	97.0	94.0	0.3	0.01	753
284.	CITGO STATI	37N	3W	2	185	VM	9/87	6.7	278	75.0	22.0	4.0	0.4	1.20	0.10	242.4	16.8	36.8	< 0.1	< 0.02	302
285.	USGS 202 A	37N	4W	5	150	LAC	4/80	7.3	190	35.0	26.0	59.0	4.5	0.89	0.00	300.0	20.0	0.5	0.6	0.02	327
286.	USGS 202 B	37N	4W	5	23	CAL	4/80	6.8	220	60.0	18.0	9.1	0.5	2.00	0.21	150.0	7.3	71.0	0.2	0.02	258
287.	C NOWAK	38N	3W	32	90	LAC	9/87	7.1	232	63.7	17.7	6.4	0.4	1.70	0.10	246.4	6.8	9.0	< 0.1	< 0.02	254

Appendix 9. Results of chemical analysis from selected water wells – Continued

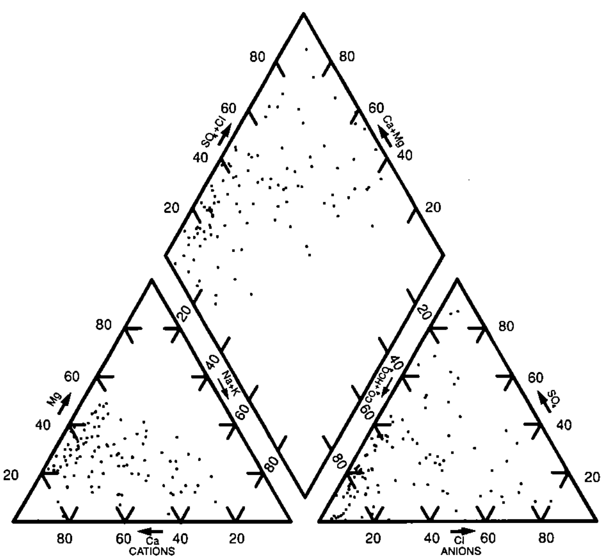
Location Number	Well Owner	Township	Range	Section	Well Depth (feet)	Aquifer System	Date Sampled	pH[1]	Hardness as $CaCO_3$	Calcium	Magnesium	Sodium	Potassium	Iron	Manganese	Alkalinity as $CaCO_3$[2]	Chloride	Sulfate	Fluoride	Nitrate as Nitrogen	Total Dissolved Solids[3]
LAPORTE COUNTY - Contiinued																					
288.	G BLADECKI	38N	2W	36	116	KK	9/87	7.5	390	108.0	29.6	3.4	0.6	0.10	0.30	376.6	22.1	41.3	0.1	1.20	433
289.	USGS 203 A	38N	4W	31	193	LPC	4/80	7.3	170	31.0	23.0	72.0	8.3	0.52	0.01	306.0	24.0	0.9	0.6	0.02	344
290.	USGS 203 B	38N	4W	31	33	CAL	4/80	7.8	150	42.0	12.0	27.0	1.0	0.97	0.22	190.0	7.3	3.3	0.3	0.02	207
291.	TRAIL CREEK	38N	4W	34	40	CAL	9/87	8.3	279	74.9	22.4	51.5	1.8	0.10	0.10	201.0	78.9	97.0	< 0.1	< 0.02	447
292.	PALMER DAIR	38N	4W	25	188	LAC	7/54	7.7	207	42.0	25.0	79.0	2.5	0.83	0.00	307.0	49.0	1.4	0.5	0.14	385
293.	F EVANS	38N	2W	26	153	KK	9/87	6.4	283	74.0	23.8	2.1	0.3	1.10	0.10	269.5	8.6	35.1	0.1	< 0.02	307
294.	A LISIECKE	38N	3W	22	91	LAC	9/87	8.3	246	57.1	25.1	14.3	0.8	1.30	< 0.10	301.6	1.8	1.8	0.4	< 0.02	284
295.	R KENNEDY	38N	2W	18	44	LAC	9/87	9.5	295	71.8	28.2	9.6	0.7	1.40	< 0.10	308.4	8.2	20.1	0.2	< 0.02	325
296.	L POVLOCK	38N	2W	15	110	VM	9/87	8.5	251	64.6	21.9	2.0	0.3	0.10	< 0.10	225.5	0.6	42.4	0.1	< 0.02	267
297.	E KOVAS	38N	1W	17	57	VM	9/87	6.8	317	82.6	26.8	3.1	0.5	2.60	0.10	304.4	3.2	41.4	0.2	< 0.02	343

[1] Results in standard p.H. units.
[2] Laboratory analysis.
[3] TDS values are the sum of major constituents expected in an anhydrous residue of a ground-water sample with bicarbonate converted to carbonate in the solid phase.

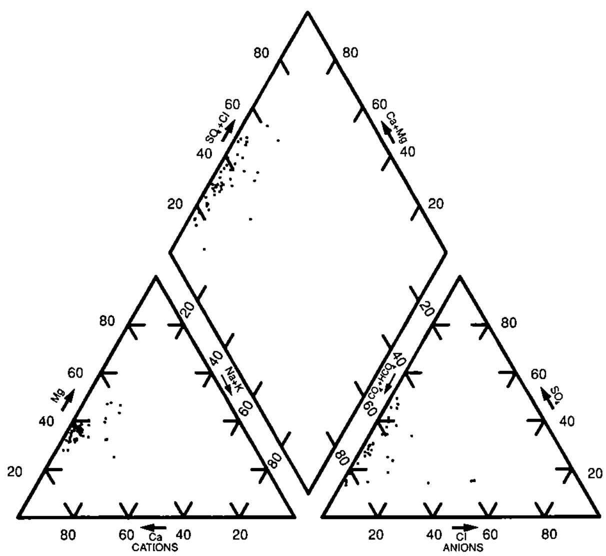
Appendix 10. Piper trilinear diagrams of ground-water quality data for major aquifer systems



CALUMET AQUIFER

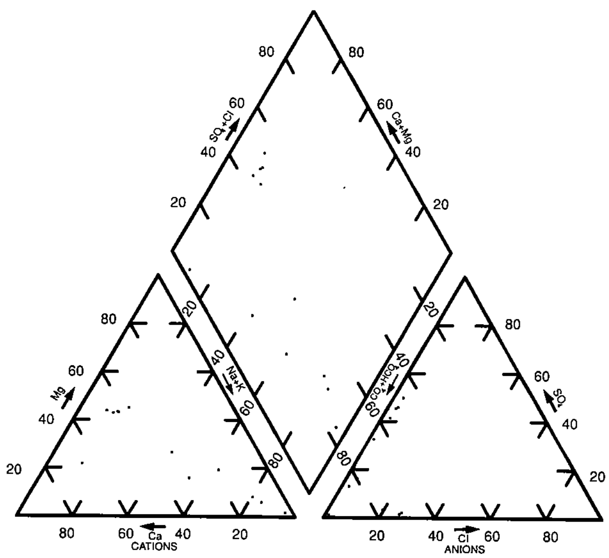


VALPARAISO AQUIFER

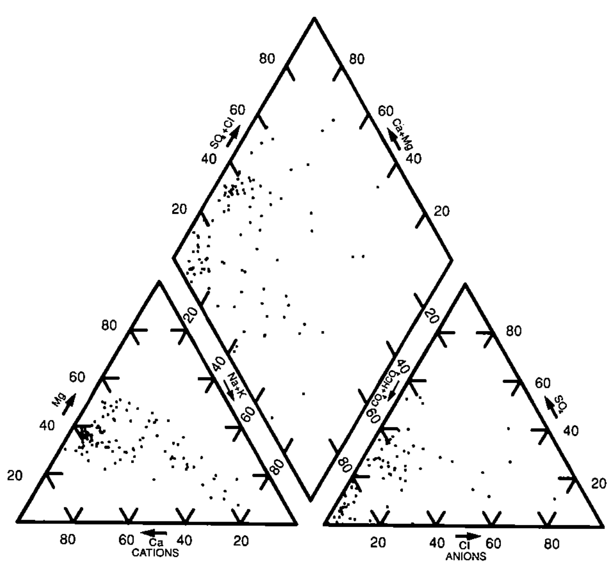


Appendix 10. Piper trilinear diagrams of ground-water quality data for major aquifer systems - Continued

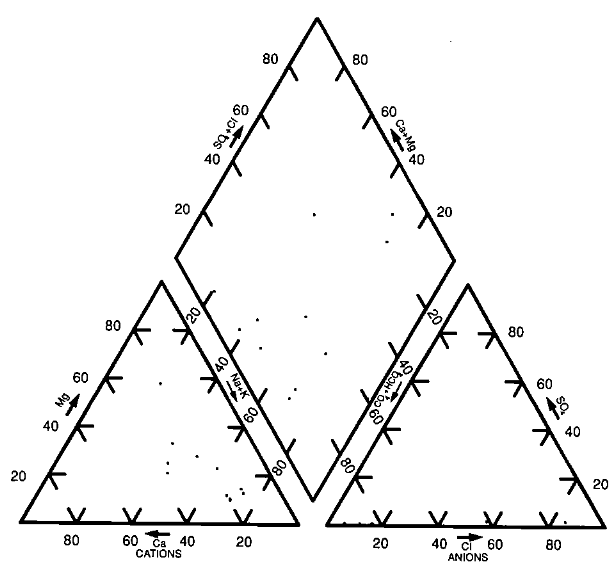
SILURIAN-DEVONIAN AQUIFER



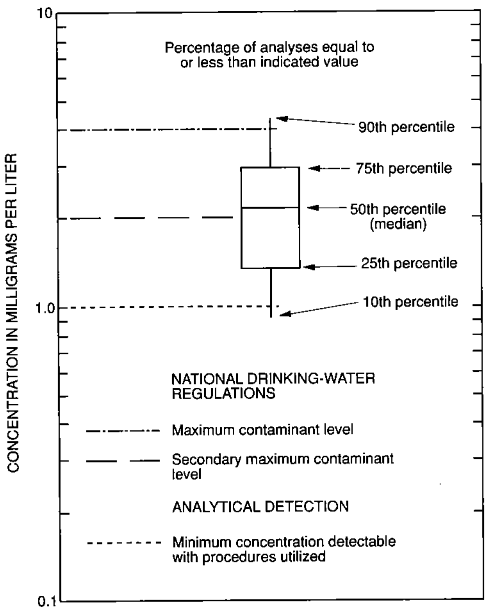
LACUSTRINE PLAIN AQUIFER



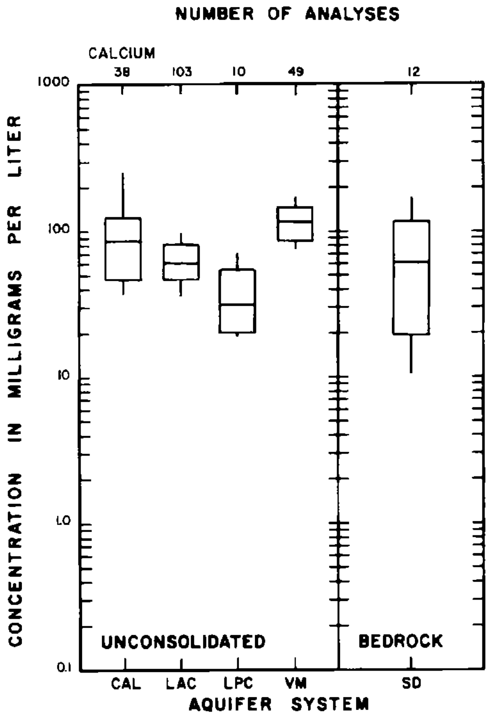
LACUSTRINE PLAIN UNDER THE CALUMET

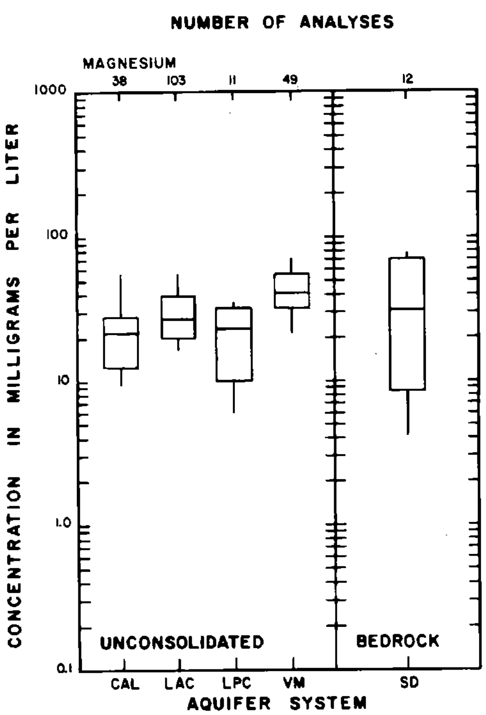


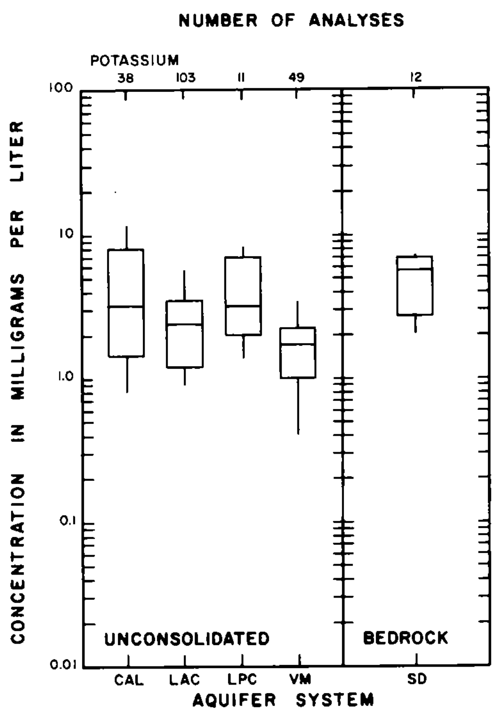
Appendix 11. Statistical analysis of calcium, magnesium, and potassium in ground water of the major aquifer systems



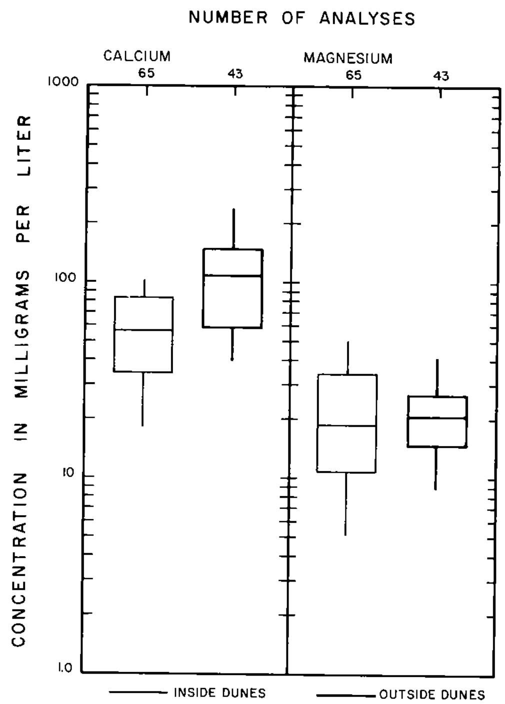
CAL Calumet Aquifer system
LAC Lacustrine Plain Aquifer system
LPC Lacustrine Plain Aquifer system underlying the Calumet
VM Valparasio Moraine Aquifer system
SD Silurian and Devonian Bedrock Aquifer system

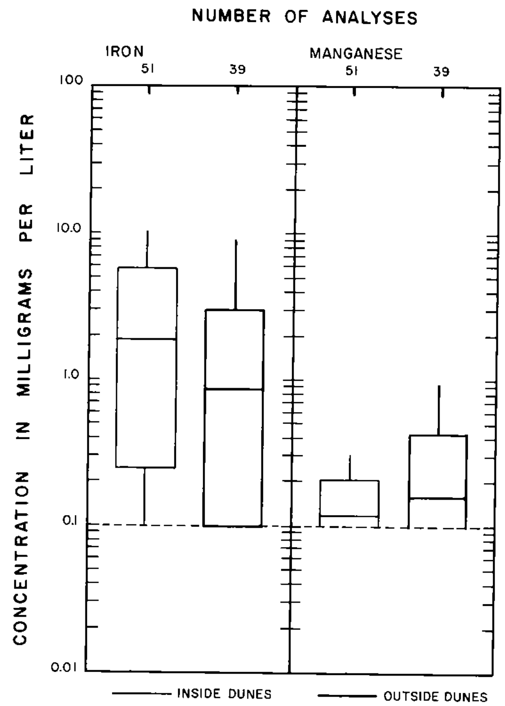


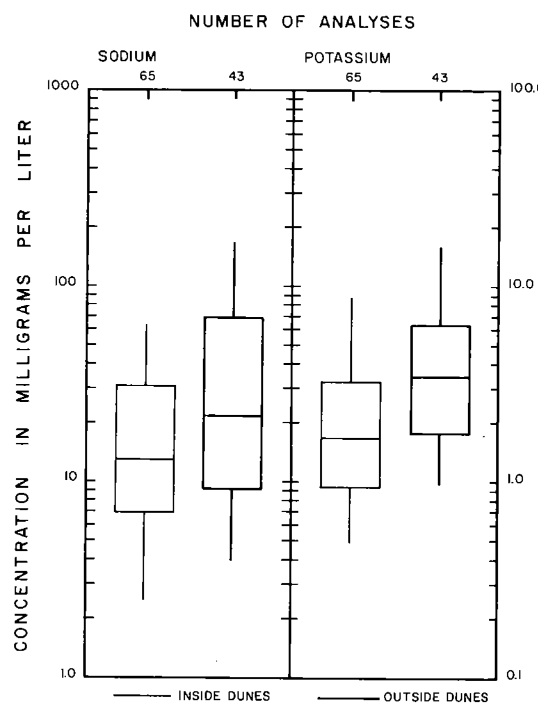


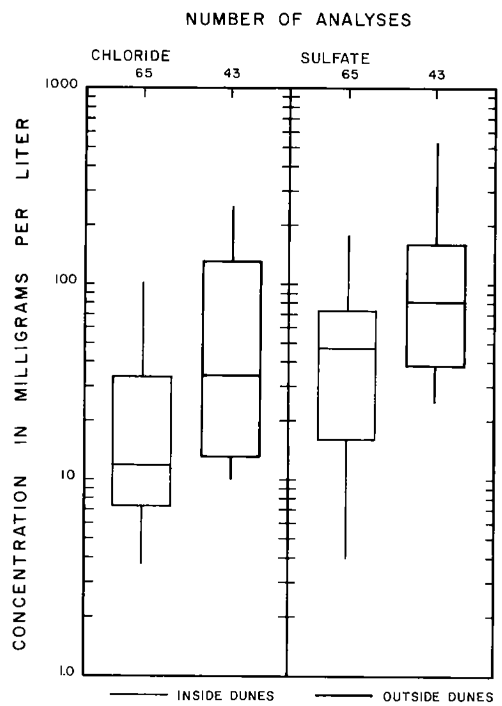


Appendix 12. Statistical analyses of selected constituents inside and outside the boundaries of the Indiana Dunes National Lakeshore

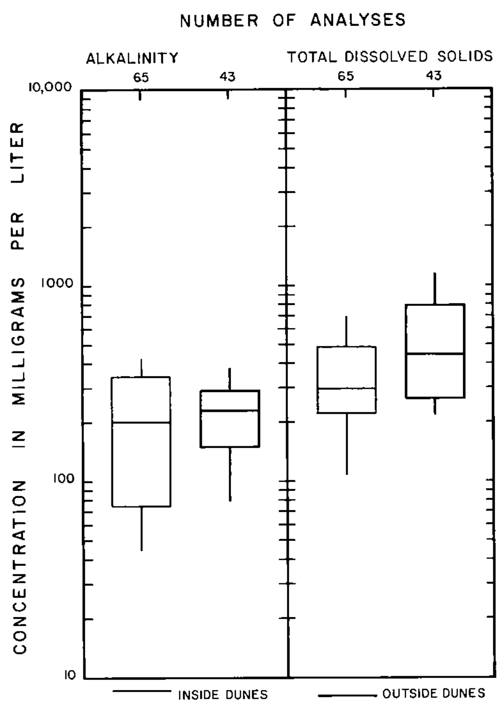


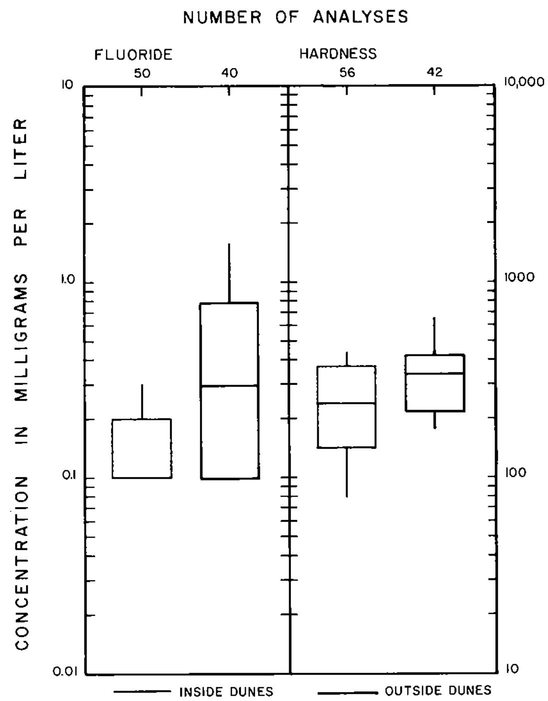






Appendix 12. Statistical analyses of selected constituents inside and outside the boundaries of the Indiana Dunes National Lakeshore – Continued





Appendix 13. Registered water-use data by type, county, and source (1990)

{Numbers denote water use in million of gallons. County data refer to areas within the Region only.}

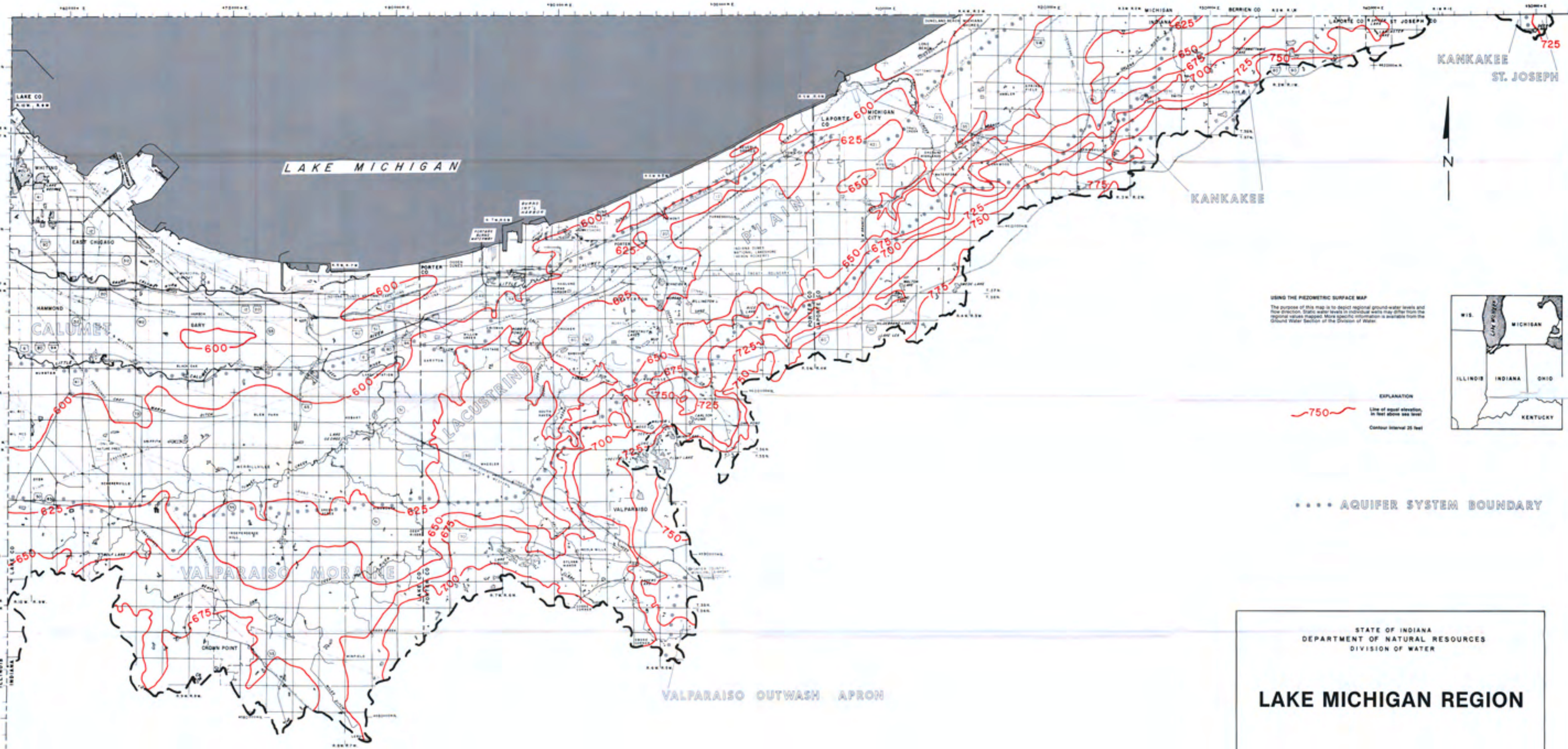
County	Source	Industrial	Energy Production	Public Supply	Miscellaneous	Agricultural	Total Water use
LAKE	surface	515443.2*	289372.0	26491.8	7.3	259.3	831573.6*
	ground	1282.8	-	1432.2	1226.0	42.9	3983.9
	combined	516726.0*	289372.0	27924.0	1233.3	302.2	835557.5*
LAPORTE	surface	-	29909.0	2735.2	0.6	14.9	32659.7
	ground	15.5	-	15.6	6.9	-	38.0
	combined	15.5	29909.0	2750.8	7.5	14.9	32697.7
PORTER	surface	163395.9	92669.0	999.9[1]	1.4	37.2	257103.4
	ground	1451.5	-	799.4[1]	22.1	13.7	2286.7
	combined	164847.4	92669.0	1799.3[1]	23.5	50.9	259390.1
TOTAL[2]	surface	678839.1*	411950	30226.9	9.3	311.3	1121336.6*
	ground	2749.7	-	2247.2	1255.0	56.8	6308.7
	combined	681588.9*	411950	32474.1	1264.3	368.2	1127645.6*

[1] Excludes withdrawals for the city of Valparaiso because the facilities are outside the Region.
[2] Totals may not equal sum of county values because of differences in rounding.
* Totals reflect 1991 estimates for a surface-water intake of # 45-00839-IN.

DIVISION OF WATER

EVAN BAYH, GOVERNOR
DEPARTMENT OF NATURAL RESOURCES
PATRICK R. RALSTON, DIRECTOR

RESOURCE ASSESSMENT No. 4
PLATE 1



USING THE PIEZOMETRIC SURFACE MAP

The purpose of this map is to depict regional ground-water levels and flow direction. Static water levels in individual wells may differ from the regional values mapped. More specific information is available from the Ground Water Section of the Division of Water.

EXPLANATION

750 — Line of equal elevation, in feet above sea level

Contour interval 25 feet

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

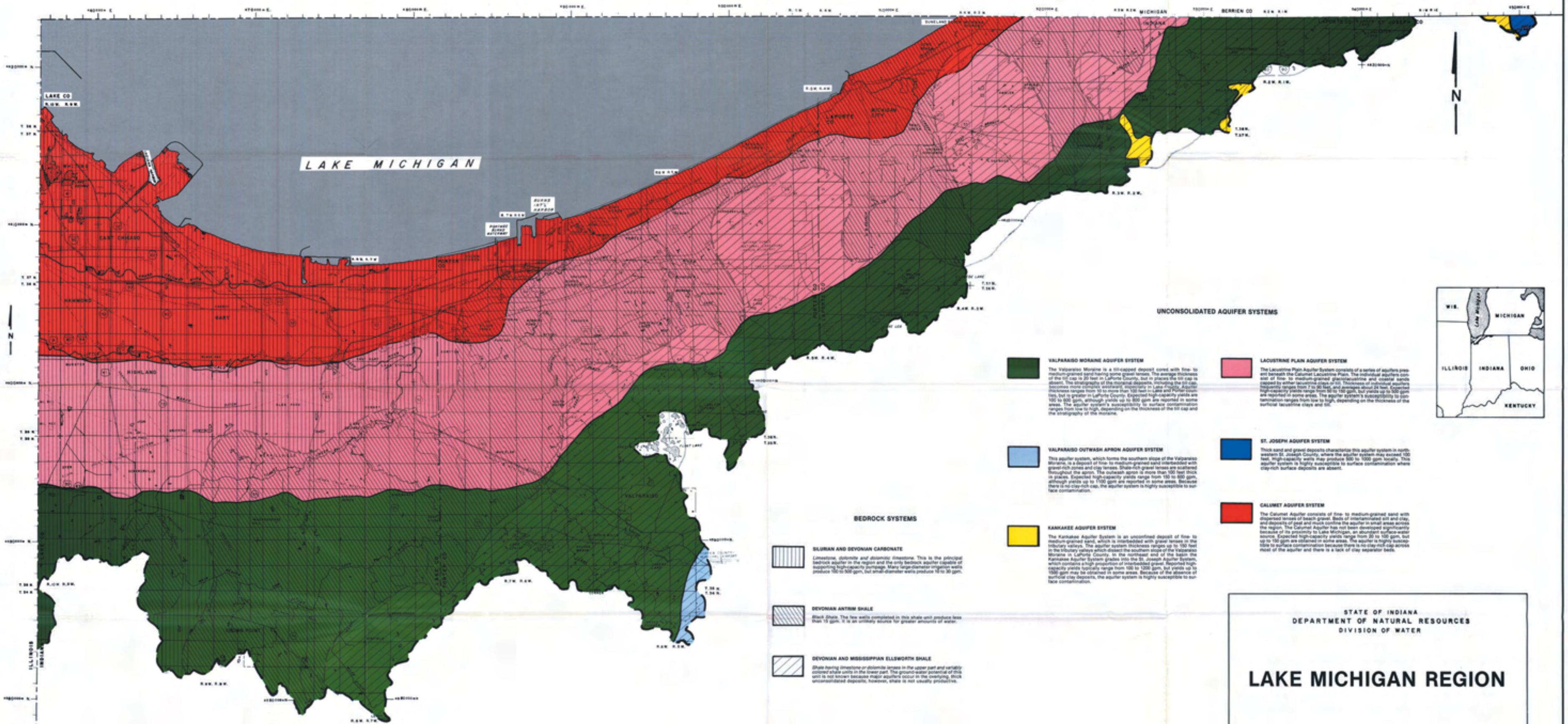
LAKE MICHIGAN REGION

PLATE 1. GENERALIZED PIEZOMETRIC SURFACE OF UNCONSOLIDATED AQUIFERS

DIVISION OF WATER

EVAN BAYH, GOVERNOR
DEPARTMENT OF NATURAL RESOURCES
PATRICK R. RALSTON, DIRECTOR

RESOURCE ASSESSMENT No. 4
PLATE 2



UNCONSOLIDATED AQUIFER SYSTEMS

VALPARAISO MORAINE AQUIFER SYSTEM

The Valparaiso Moraine is a till-capped deposit cored with fine- to medium-grained sand having some gravel lenses. The average thickness of the till cap is 20 feet in LaPorte County, but in places the till cap is absent. The stratigraphy of the morainal deposits, including the till cap, becomes more complex westward, especially in Lake County. Aquifer thickness ranges from 10 to more than 100 feet in Lake and Porter counties, but is greater in LaPorte County. Expected high-capacity yields are 100 to 600 gpm, although yields up to 800 gpm are reported in some areas. The aquifer system's susceptibility to surface contamination ranges from low to high, depending on the thickness of the till cap and the stratigraphy of the moraine.

VALPARAISO OUTWASH APRON AQUIFER SYSTEM

This aquifer system, which forms the southern slope of the Valparaiso Moraine, is a deposit of fine- to medium-grained sand interbedded with gravel-rich zones and clay lenses. Shale-rich gravel lenses are scattered throughout the apron. The outwash apron is more than 100 feet thick in places. Expected high-capacity yields range from 150 to 600 gpm, although yields up to 1100 gpm are reported in some areas. Because there is no clay-rich cap, the aquifer system is highly susceptible to surface contamination.

KANKAKEE AQUIFER SYSTEM

The Kankakee Aquifer System is an unconfined deposit of fine- to medium-grained sand, which is interbedded with gravel lenses in the tributary valleys. The aquifer system thickness ranges up to 150 feet in the tributary valleys which dissect the southern slope of the Valparaiso Moraine in LaPorte County. In the northeast end of the basin the Kankakee Aquifer System grades into the St. Joseph Aquifer System, which contains a high proportion of interbedded gravel. Reported high-capacity yields typically range from 100 to 1200 gpm, but yields up to 1500 gpm may be obtained in some areas. Because of the absence of surficial clay deposits, the aquifer system is highly susceptible to surface contamination.

LACUSTRINE PLAIN AQUIFER SYSTEM

The Lacustrine Plain Aquifer System consists of a series of aquifers present beneath the Calumet Lacustrine Plain. The individual aquifers consist of fine- to medium-grained glaciolacustrine and coastal sands capped by either lacustrine clays or till. Thickness of individual aquifers frequently ranges from 7 to 90 feet, and averages about 24 feet. Expected high-capacity yields range from 50 to 150 gpm, but yields up to 500 gpm are reported in some areas. The aquifer system's susceptibility to contamination ranges from low to high, depending on the thickness of the surficial lacustrine clays and till.

ST. JOSEPH AQUIFER SYSTEM

Thick sand and gravel deposits characterize this aquifer system in northwestern St. Joseph County, where the aquifer system may exceed 100 feet. High-capacity wells may produce 500 to 1000 gpm locally. This aquifer system is highly susceptible to surface contamination where clay-rich surface deposits are absent.

CALUMET AQUIFER SYSTEM

The Calumet Aquifer consists of fine- to medium-grained sand with dispersed lenses of beach gravel. Beds of interlaminated silt and clay, and deposits of peat and muck confine the aquifer in small areas across the region. The Calumet Aquifer has not been developed significantly because of its proximity to Lake Michigan, an abundant surface-water source. Expected high-capacity yields range from 20 to 100 gpm, but up to 150 gpm are obtained in some areas. The aquifer is highly susceptible to surface contamination because there is no clay-rich cap across most of the aquifer and there is a lack of clay separator beds.

BEDROCK SYSTEMS

SILURIAN AND DEVONIAN CARBONATE

Limestone, dolomite and dolomitic limestone. This is the principal bedrock aquifer in the region and the only bedrock aquifer capable of supporting high-capacity pumpage. Many large-diameter irrigation wells produce 100 to 500 gpm, but small-diameter wells produce 10 to 30 gpm.

DEVONIAN ANTRIM SHALE

Black Shale. The few wells completed in this shale unit produce less than 15 gpm. It is an unlikely source for greater amounts of water.

DEVONIAN AND MISSISSIPPIAN ELLSWORTH SHALE

Shale having limestone or dolomite lenses in the upper part and variably colored shale units in the lower part. The ground-water potential of this unit is not known because major aquifers occur in the overlying, thick unconsolidated deposits; however, shale is not usually productive.

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

LAKE MICHIGAN REGION

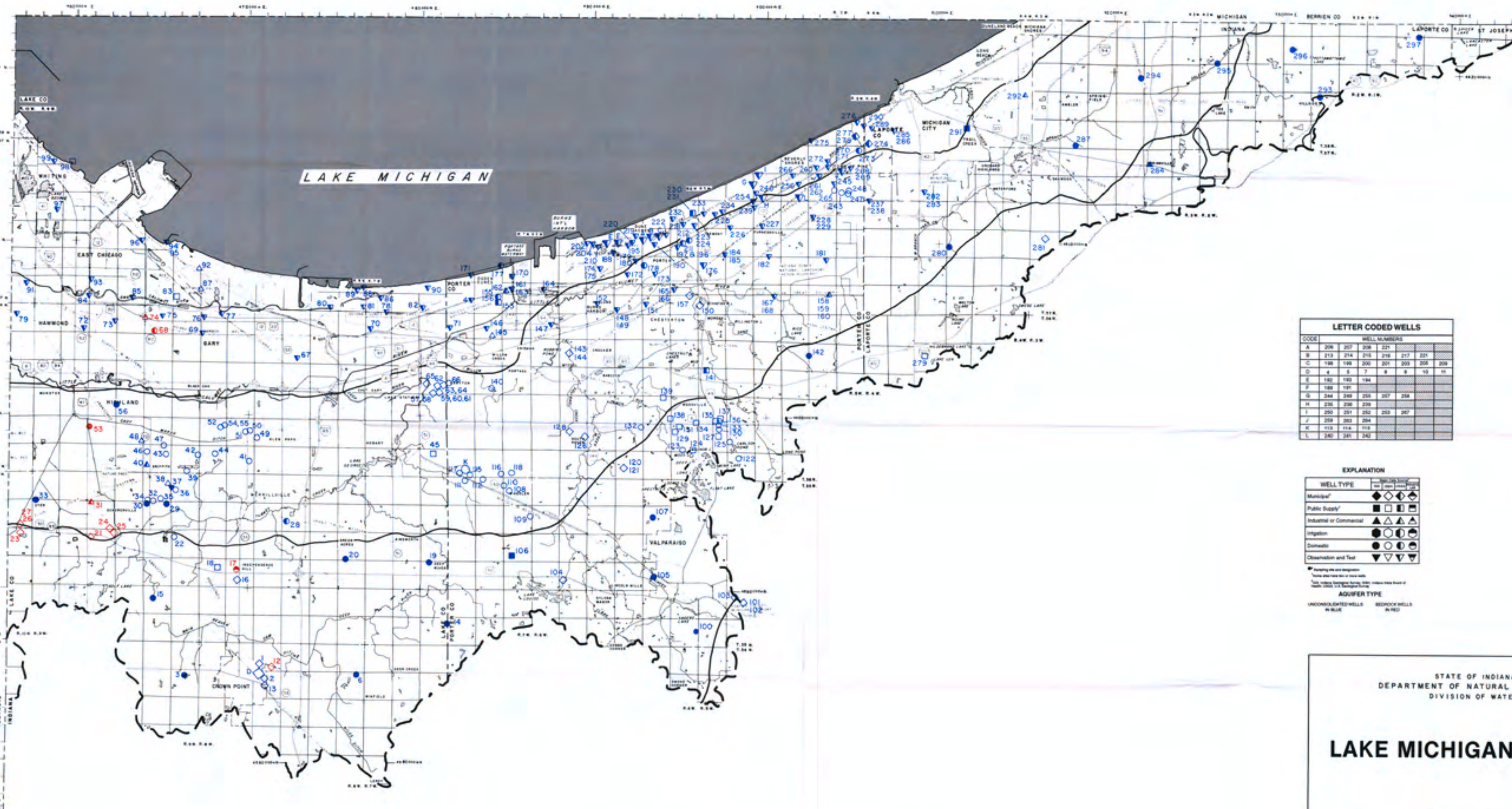
1 0 1 2 3 4 MILES
5000 0 5000 10000 15000 20000 FEET
1 0 1 2 3 4 5 6 KILOMETERS

PLATE 2. UNCONSOLIDATED AND BEDROCK AQUIFER SYSTEMS (GEOHYDROLOGIC UNITS)

DIVISION OF WATER

EVAN BAYH, GOVERNOR
DEPARTMENT OF NATURAL RESOURCES
PATRICK R. RALSTON, DIRECTOR

RESOURCE ASSESSMENT No. 4
PLATE 3



LETTER CODED WELLS

CODE	WELL NUMBERS						
A	206	207	208	221			
B	213	214	215	216	217	221	
C	198	199	200	201	203	205	209
D	4	5	7	8	9	10	11
E	192	193	194				
F	189	191					
G	244	249	255	257	258		
H	235	236	239				
I	250	251	252	253	267		
J	259	263	264				
K	113	114	119				
L	240	241	242				

EXPLANATION

WELL TYPE
Municipal
Public Supply
Industrial or Commercial
Irrigation
Domestic
Observation and Test

AQUIFER TYPE

UNCONSOLIDATED WELLS IN BLUE

BEDROCK WELLS IN RED

STATE OF INDIANA
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF WATER

LAKE MICHIGAN REGION

PLATE 3. LOCATION FOR GROUND-WATER CHEMISTRY ANALYSIS