5 ENVIRONMENTAL SETTING AND RESOURCES OF THE GREAT LAKES BASIN

The following sections summarize the current state of knowledge regarding the distribution and nature of resources and environmental conditions within the Great Lakes Basin. Rather than detailed descriptions of the various resources as they currently exist throughout the Great Lakes Basin, the discussions summarize the current nature and distribution of natural resources, and land and water uses within the Great Lakes Basin. Subsequent discussions of the potential environmental effects (Section 6) of oil and gas development will focus on those natural resources located in the offshore and onshore locations associated with oil and gas resources and where infrastructure development (and subsequent operation) may be expected to occur to support oil and gas development. This report does not address the potential environmental effects of refineries and other oil and gas infrastructure, much of which already exists in many of the Great Lakes states.

5.1 PHYSICAL ENVIRONMENT OF THE GREAT LAKES

Individually, the Great Lakes are among the largest, deepest lakes in the world. Together they are the largest freshwater body in North America and the second largest in the world after Lake Baikal in Siberia (exclusive of the polar ice caps). This section provides summaries of the geological and hydrological settings of the Great Lakes Basin and identifies the known and suspected oil and gas reservoirs beneath the Great Lakes.

5.1.1 Geologic History and Setting

The Great Lakes Basin lies principally within two major physiographic provinces, the Superior Upland and the Central Lowland (Figure 5.1) (Fenneman 1946). Small parts of the Great Lakes Basin in New York and along the south side of Lake Erie are within the St. Lawrence Valley, Adirondack, and Appalachian Plateaus provinces. The land area covers approximately 118,000 mi^2 (305,620 km^2), or approximately 60% of the total land and water surface area of the U.S. Great Lakes Basin. The area is a glaciated plateau of varied relief and prominent escarpments. The Basin outlet is through the wide St. Lawrence Valley province (GLBC 1975b). Maps illustrating the bedrock geology and glacial geology are provided later in the section.

The Great Lakes Basin is located in an area of generally low seismic intensity. The New Madrid Fault Zone system, which is south of the Great Lakes Basin, lies within the central Mississippi Valley, extending from northeast Arkansas, through southeast Missouri, western Tennessee, and western Kentucky to southern Illinois. Historically, this area has been the site of some of the largest earthquakes in North America. (St. Louis University Earthquake Center 2004). Studies have shown that the Great Lakes Basin area has experienced little to no shaking and no damage from some of the strongest earthquakes recorded from seismic activities from the New Madrid Fault zone (Hough et. al. 2000; Hough and Martin 2002).

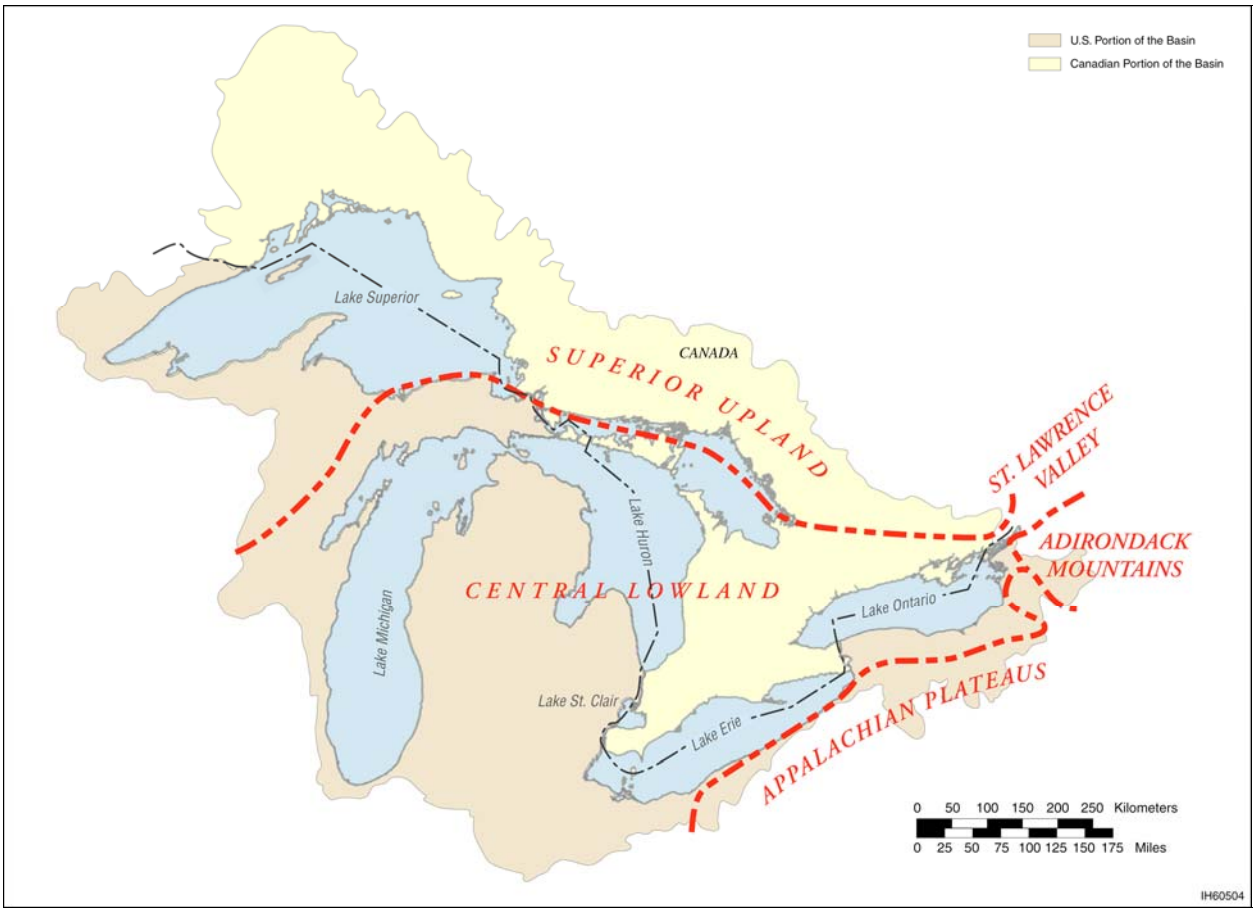

FIGURE 5.1 Physiographic Provinces of the Great Lakes Basin (Source: Fenneman 1946)

The Great Lakes Basin began to form about 3 billion years ago during Precambrian time (Figure 5.2). The Precambrian was a time of significant volcanic activity and tremendous stresses, which formed large mountain systems. The early rock deposits were folded and heated into complex topographic structures. These were later eroded and today appear as the rolling hills and small mountain remnants of the Precambrian Canadian Shield. The Canadian Shield forms the northern and northwestern portions of the Great Lakes Basin. The granitic rocks of the Canadian Shield extend southward beneath younger Paleozoic sedimentary rocks where they form the basement structure of the southern and eastern portions of the Basin (EPA and Government of Canada 1995) (Figure 5.3). An Upper Jurassic rock remnant is preserved in the central part of Michigan. These rocks are informally known as the "Red Beds." They consist mostly of sandstones and shale and some gypsum (Catacosinos et al. 1991).

During the Paleozoic Era, most of central North America was repeatedly flooded by marine seas that were inhabited by various life forms, including corals, brachiopods, and mollusks. The seas deposited lime silts, clays, sand, and salts, which consolidated into limestone,

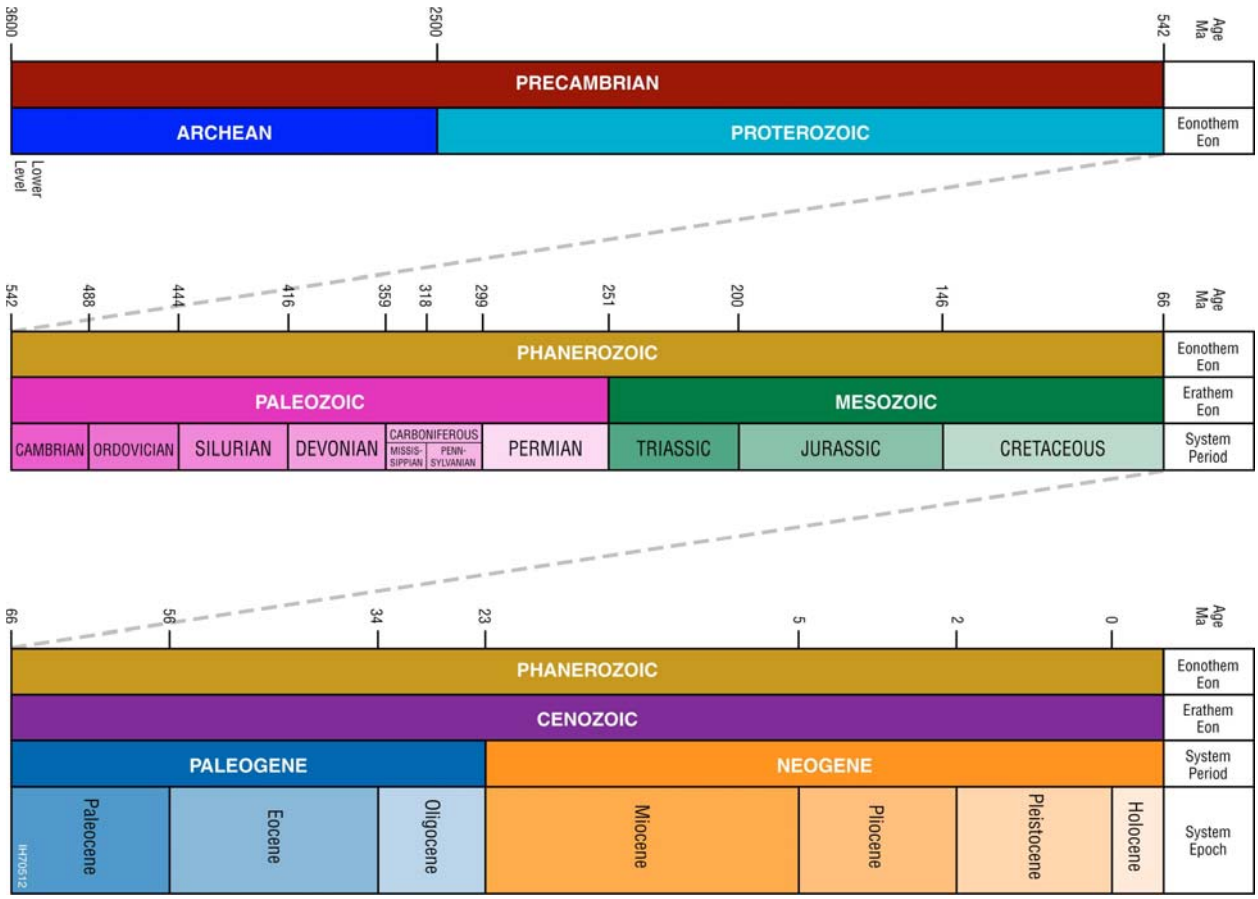

FIGURE 5.2 Geologic Time Scale (Source: Gradstein et al. 2004)

shales, sandstone, halite, and gypsum (EPA and Government of Canada 1995). Major structural features of the bedrock include the deep sedimentary basin centered under Michigan, a shallow sedimentary platform bordering the Appalachian trough in the Lake Erie-Ontario region, and a basement high that extends southward between the Michigan basin and the Appalachian trough. Basement rocks are exposed in the uplands that extend from Minnesota and northern Wisconsin eastward along the northern limits of the Great Lakes Basin into the Adirondack Mountains (GLBC 1975a).

During the Pleistocene Epoch, the entire Great Lakes region was subjected to four major phases of glaciation. The continental glaciers, up to 6,500 ft (2,000 m) thick, advanced over the Great Lakes region from the north. The first glaciers moved forward, scoured the surface of the earth, and leveled hills. Valleys created by river systems of the previous era were deepened and enlarged to form the basins of the Great Lakes.

When the glaciers retreated northward, very large volumes of meltwater were produced. Because the land was depressed during this time from the weight of the glaciers, large glacial lakes formed. As the glaciers receded, the land began to rise. This uplift and the shifting ice

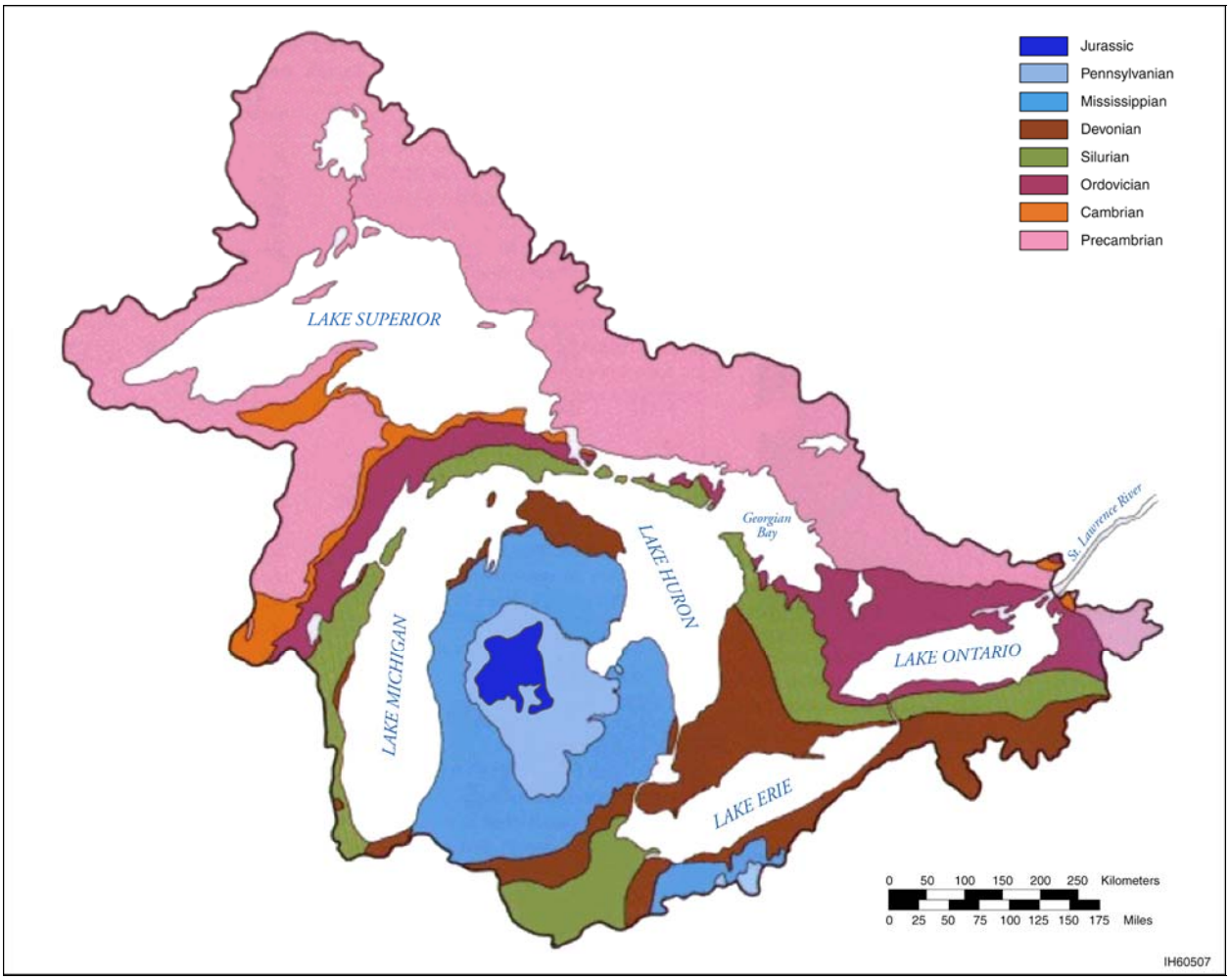

FIGURE 5.3 Geologic Map of the Great Lakes Basin (Sources: Donnan 1961; Catacosinos et al., 1991; EPA and Government of Canada 1995)

fronts caused dramatic changes in the depth, size, and drainage patterns of the glacial lakes (EPA and Government of Canada 1995). Most of the surface of the Great Lakes Basin is covered by unconsolidated glacial deposits of the Pleistocene or Ice Age. The thickness of the glacial deposits varies from zero to several hundreds of feet in the Lower Peninsula of Michigan. The glacial deposits consist of silts and clay, sand and gravel, and till (Figure 5.4). As previously discussed, beneath the glacial deposits lie predominantly Paleozoic Age sedimentary rock formations, except in the northern part of the Basin, where the deposits overlie Precambrian sedimentary, igneous, and metamorphic rocks.

One of the major legacies of the Pleistocene glaciation is the formation of the Great Lakes. The greatest relief in the Basin is in the Adirondack Mountains, where many mountain peaks are more than 2,000 ft (610 m) above mean sea level (amsl). The Adirondack Mountains are located in New York on the eastern edge of the Basin (see Figure 5.1). In most of the Basin,

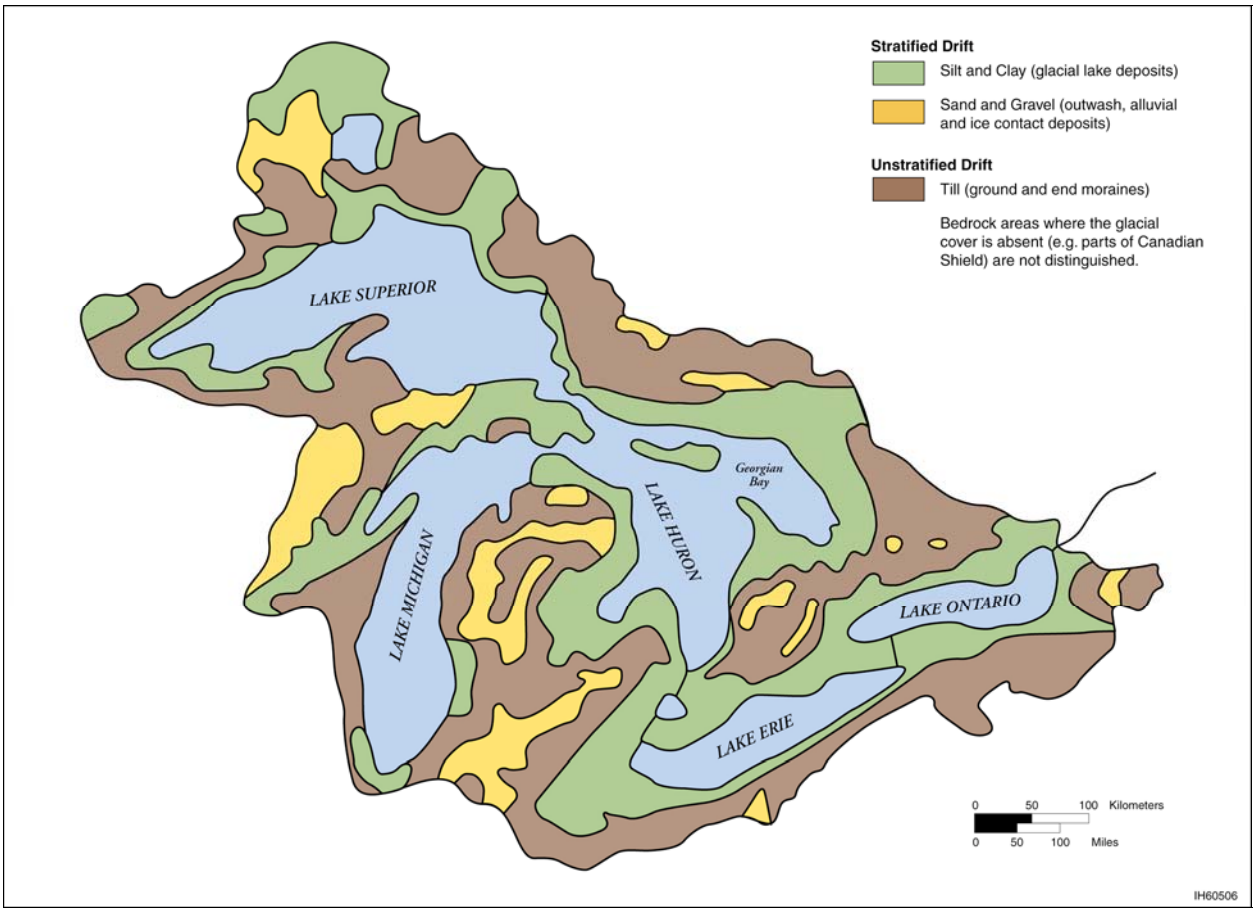

FIGURE 5.4 Glacial Deposits of the Great Lakes Basin (Source: EPA and Government of Canada 1995)

the land surface is less than 1,000 ft (305 m) amsl. The highest point in the headwaters area of Lake Superior is 2,301 ft (701 m) at Eagle Mountain in Minnesota (GLBC 1975b).

Lake Superior is the deepest of the Great Lakes, with an average depth of 483 ft (147 m), while Lake Erie is the shallowest, with an average depth of 62 ft (19 m). Lake Huron is second to Lake Erie in being the shallowest, at an average depth of 195 ft (59 m). The average depths of Lake Michigan and Lake Ontario are similar, at depths of 279 ft (85 m) and 283 ft (86 m), respectively. Further information about the physical features of the Great Lakes is presented in Section 5.1.2.1.

In the Great Lakes Basin, it is the Paleozoic deposits that contain oil and gas resources. Petroleum and natural gas are produced primarily from limestone, sandstone, and reef formations in the Mississippian, Devonian, Silurian, Ordovician, and Cambrian systems (GLBC 1974; Swezey 2002). Petroleum hydrocarbons (i.e., oil and natural gas) were created in the Great Lakes Basin as organic material (comprised of marine life) was buried, heated, and compressed (i.e., subjected to geologic pressures) (Catacosinos et al. 1991). The ancient Silurian Sea, which stretched from what is now New York to Illinois, can be attributed to significant deposits of

evaporates such as halite, gypsum, and anhydrite. The Silurian dolomites and limestones are normally overlain and underlain by deposited salt (halites) and evaporates (gypsum and anhydrite) (Catacosinos et al. 1991).

5.1.2 Hydrologic Setting

The Great Lakes and their connecting channels are the second largest system of fresh, surface water on earth, containing 20% of the world's supply (Figure 5.5). Individually, the five Great Lakes are among the 15 largest freshwater lakes in the world. The lakes contain a combined volume of about 5,500 mi^3 (23,000 km^3) of water covering a total area of 94,000 mi^2 (244,000 km^2) (EPA and Government of Canada 1995).

The Great Lakes Shoreline

The Great Lakes shoreline is equal to almost 44% of the circumference of the earth, and Michigan's Great Lakes coast totals 3,288 mi (5,294 km) — more coastline than any state except Alaska, as well as the combined Atlantic, Gulf, and Pacific coasts of the lower 48 states.

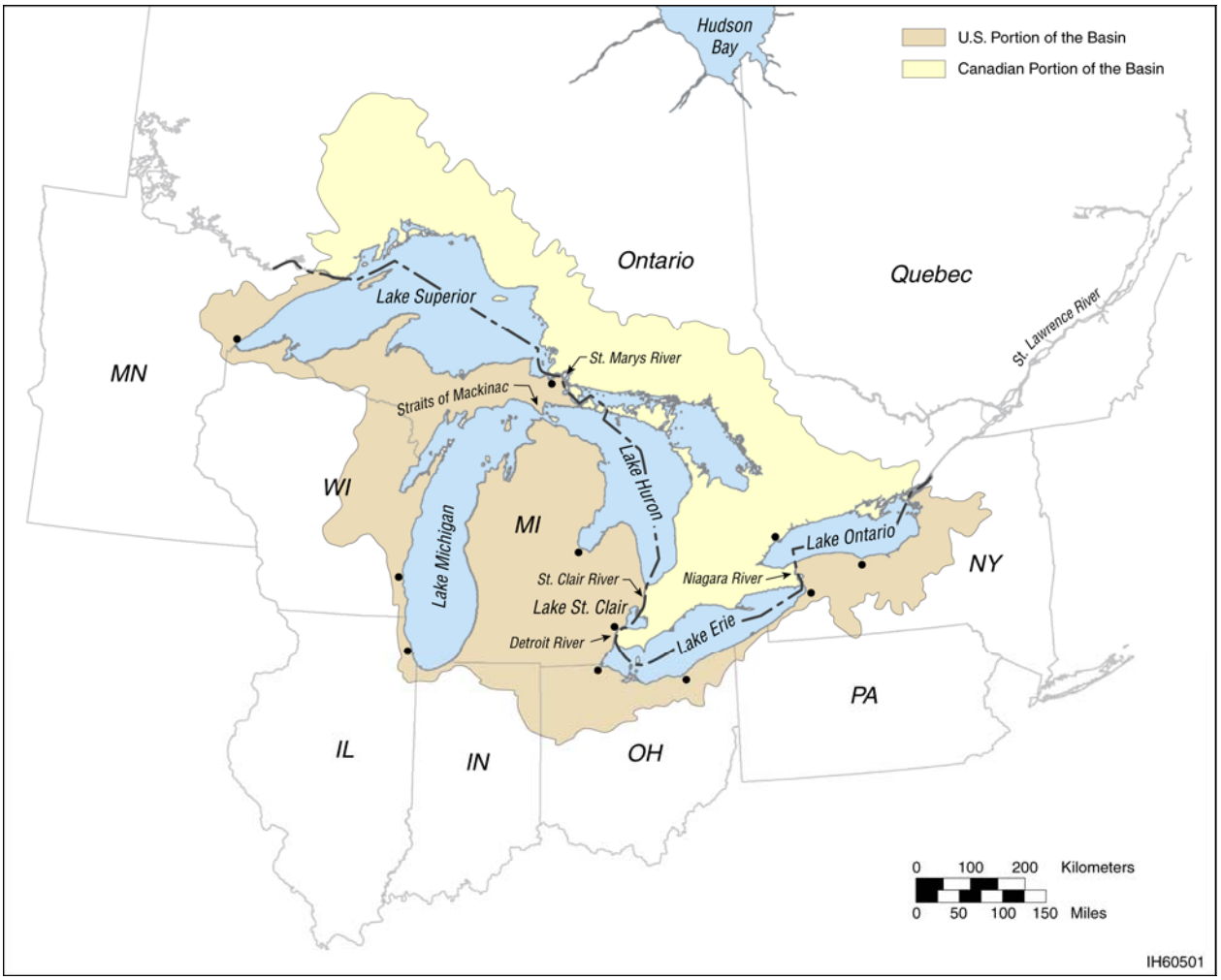

FIGURE 5.5 The Great Lakes and Their Connecting Channels

5.1.2.1 Surface Water

The Great Lakes Basin is unique in that approximately one-third of its area is water surface, and there are no dominant tributary systems (GLBC 1975b). The Great Lakes system is a chain of lakes and connecting channels (the St. Marys River, the St. Clair River, Lake St. Clair, the Detroit River, and the Niagara River) descending like a series of steps toward the Atlantic Ocean (Figure 5.5). Lake Superior is located at the top of the chain and is about 602 ft (183 m) amsl, while Lake Ontario located at the end of the chain is 245 ft (75 m) amsl.

Although part of a single system, each lake is quite different in its physical characteristics. Table 5.1 provides the physical features of each lake. Lake Superior is the largest of the Great Lakes in surface area and volume, while Lake Erie is the smallest in volume. Lake Ontario is the smallest in surface area. For comparison, Lake Superior could contain all the other Great Lakes and three more lakes the size of Lake Erie. The Long Lac and Ogoki diversions in Canada channel water into Lake Superior, which would otherwise flow into Hudson Bay.

TABLE 5.1 Physical Features of the Great Lakes

		Lakes					
Physical Feature[a]	Unit	Superior	Michigan	Huron	Erie	Ontario	Totals
Volume[b]	mi^3	2,900	1,180	850	116	393	5,439
	km^3	12,100	4,920	3,540	484	1,640	22,684
Maximum depth[b]	feet	1,332	925	750	210	802	
	meters	406	282	229	64	244	
Average depth[b]	feet[c]	483	279	195	62	283	
	meters[c]	147	85	59	19	86	
Water surface area[b]	mi^2	31,700	22,300	23,000	9,910	7,340	94,250
	km^2	82,100	57,800	59,600	25,700	18,960	224,160
Lake basin surface area	mi^2	81,000	67,900	74,700	40,050	32,060	295,710
	km^2	209,800	175,800	193,700	103,700	82,990	765,990
Shoreline length[d]	mi	2,726	1,638	3,827	871	712	10,210[e]
	km	4,385	2,633	6,157	1,402	1,146	17,017[c]

[a] Source: Coordinating Committee on Great Lakes Basic Hydraulic and Hydrogeological Data, Coordinated Great Lakes Physical Data, May 1992, unless otherwise noted.

[b] Measured at Low Water Datum.

[c] Source: Michigan Sea Grant Program 1985.

[d] Including islands.

[e] These totals are greater than the sum of the shoreline lengths for the lakes because they include the connecting channels (such as the St. Marys River), excluding the St. Lawrence River.

5.1.2.1.1 Lake Superior. Lake Superior's level is controlled by locks on the St. Marys River. Although most of the water stays in Lake Superior, all of the flow leaves via the St. Marys River to Lake Huron (Great Lakes Information Network [GLIN] 2005d).

5.1.2.1.2 Lake Michigan. Lake Michigan is the second largest of the Great Lakes by volume and the third largest by surface area. It is the only Great Lake entirely within the United States. Many rivers and streams flow into Lake Michigan, and its major tributaries are the Fox-Wolf, Grand, and Kalamazoo Rivers. There is a diversion from the lake into the Mississippi River basin through the Illinois Waterway at the Chicago River (GLIN 2005d).

5.1.2.1.3 Lake Huron. This lake, which includes Georgian Bay and Saginaw Bay, is the third largest of the Great Lakes by volume and second largest by surface area. Since Lakes Michigan and Huron are connected by the broad and deep Straits of Mackinac and stand at virtually the same elevation, they are often referred to hydrologically as one lake (GLIN 2005d).

5.1.2.1.4 Lake Erie. Lake Erie is the shallowest and smallest in volume of the Great Lakes, and the fourth largest in surface area. Water from Lake Huron flows through the St. Clair River, Lake St. Clair, and the Detroit River into Lake Erie. Ninety-five percent of Lake Erie's inflow comes from surface water bodies and the remainder comes from precipitation (GLIN 2005d). The largest tributary of the Great Lakes Basin, the Maumee River, flows into the western basin of Lake Erie.

5.1.2.1.5 Lake Ontario. Lake Ontario is the smallest of the Great Lakes in surface area; however, the average depth of the lake is second only to Lake Superior. Lake Ontario lies below Lake Erie at the base of the Niagara Falls. Lake Erie discharges through the Niagara River and the Welland Canal into Lake Ontario, although the portion of flow diverted to Lake Ontario through the Welland Canal is relatively small (about 4 to 5% of the total Lake Erie outflow). Water from Lake Ontario flows to the Atlantic Ocean through the St. Lawrence River. The outflow is relatively small (less than 1% per year) in comparison with the total volume of water contained in the Great Lakes system. Only outflows from Lake Superior and Lake Ontario are regulated via control structures and may be varied within limits in accordance with their respective regulation plans. The outflows from Lakes Michigan, Huron, and Erie are controlled exclusively by the hydraulic characteristics of their outlet rivers (GLIN 2005d).

5.1.2.2 Groundwater

While groundwater is present throughout the Great Lakes Basin, the quantity that can be withdrawn varies, depending on the characteristics of the aquifers (i.e., the water-bearing rocks and sediments). The unconsolidated glacial material makes up the most productive aquifers. These deposits are as much as 1,200 ft (366 m) thick in parts of Michigan and are several hundred feet thick in buried bedrock valleys in Illinois, Wisconsin, and New York. Most glacial

deposits are composed of sand and gravel, and silt and clay (Figure 5.4). The sand and gravel glacial deposits are the most productive aquifers because they have greater permeability and porosity than do the finer grained deposits (Grannemann et. al. 2000), thereby supporting more groundwater flow and removal. Some areas with finer grained deposits (e.g., silt and clay) contain more permeable deposits at depth and are able to yield moderate to large amounts of water to wells; however, in general, the soil and clay deposits are not aquifers (Grannemann et. al. 2000).

Bedrock aquifers are widespread throughout the Great Lakes Basin and are more continuous than the aquifers in glacial deposits (see Figure 5.6). Some bedrock aquifers in the region extend beyond the Basin boundaries. Carbonate rocks (limestone and dolomite) are the most common bedrock aquifers on the region. The most extensive carbonate aquifer in the region consists of a series of limestone and dolomite deposits that underlie a large part of the upper Midwest. Sandstone aquifers are the next most common bedrock aquifer. An extensive sandstone aquifer underlies much of the northern Midwest and extends under Lake Michigan. In general, shale and igneous and metamorphic bedrock have limited water-yielding capacity, and they are not considered regional aquifers (Grannemann et. al. 2000).

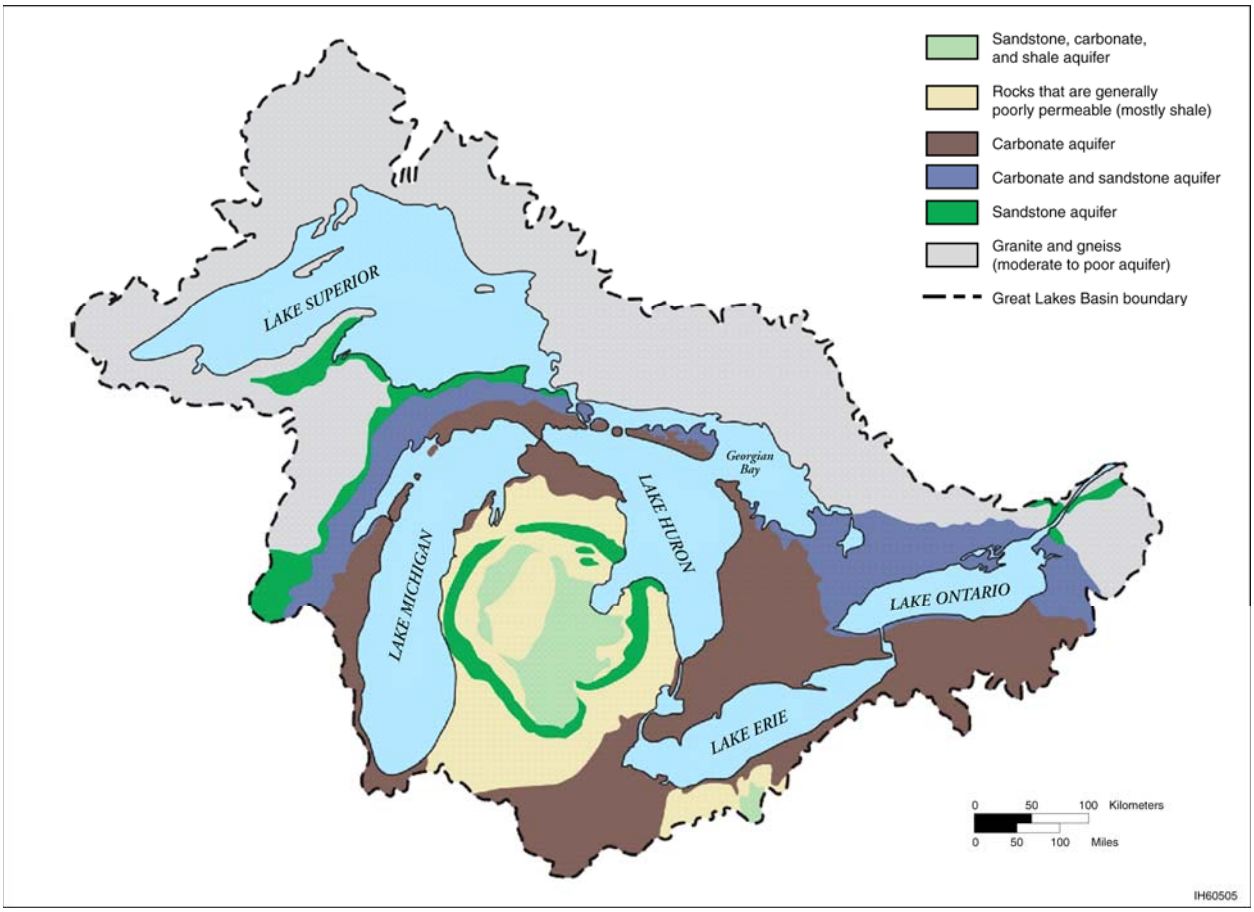

FIGURE 5.6 Bedrock Aquifers of the Great Lakes Basin (Source: GLBC 1975a)

The term "recharge" is used to describe the process of adding water to the groundwater system. The amount of recharge varies greatly throughout the Great Lakes Basin, depending on the soil type, precipitation (i.e., rates, types, and amounts), and other factors such as the extent of impervious surfaces (e.g., paved areas) and storm sewers (Grannemann et. al. 2000). Most groundwater recharge occurs as a result of water percolating through the soil zone during the spring snowmelt period. During the summer, the amount of water lost from evaporation and transpiration (of vegetation) usually exceeds the amount of water retained from rainfall, and little or no recharge occurs. Groundwater recharge resumes in the fall after evaporation and transpiration losses are reduced and may continue through part of the winter (GLBC 1975a).

Urban development may reduce recharge amounts because impervious surfaces (such as roads, buildings, and paved areas) often drain to storm sewers, a situation that increases surface runoff and reduces water infiltration to the aquifers. These processes may significantly alter groundwater conditions in many urban settings by causing water to flow to lakes and streams that would otherwise have infiltrated to the water table. This also may increase flood potential. The effects of urbanization on groundwater recharge are likely to be localized, and the effects on the Great Lakes region as a whole may be minimal, because currently less than 10% of the watershed is classified as urban (Grannemann et. al. 2000).

Discharge of groundwater in near-surface or surficial aquifers occurs principally to streams, lakes, and ponds that intersect the water table. Discharge of the deeper bedrock aquifers occurs when water moves from the aquifer through pervious rock and fractures. The five Great Lakes are natural discharge areas for groundwater from bedrock aquifers as well as surficial aquifers. Groundwater makes an appreciable contribution to the Great Lakes.

5.1.3 Oil and Gas Resources

As discussed in Section 5.1.1, the rocks and sediments of the Great Lakes Basin represent the following geologic periods: the Precambrian Eon, and primarily the Paleozoic, some Mesozoic (i.e., Lake Jurassic Red Beds), and Cenozoic Eras (i.e., Pleistocene) (Figures 5.2 and 5.3). Rocks of the Precambrian Eon, oldest in the Basin, form the basement complex beneath the entire Basin area; however, they are exposed at or near the surface in the extreme eastern and entire northern part of the Basin (see Figure 5.3). The Precambrian system that underlies the entire Great Lakes Basin consists of igneous and metamorphic crystalline complex, mainly granite, gneiss, schist, and a lesser amount of sedimentary rocks (GLBC 1975a).

In the remainder of the Basin, the Precambrian material is overlain by sedimentary rock that was deposited during the Paleozoic era. These deposits consist primarily of horizontal to gently dipping beds of limestone, dolomite, shale, and sandstone that have a maximum thickness of 14,000 ft (4,267 m) in the east-central part of Michigan's Lower Peninsula. Overlying both the Precambrian and Paleozoic bedrock are unconsolidated glacial and post-glacial materials deposited during the Cenozoic era. These deposits form a layer ranging from several inches to several hundred feet in thickness (GLBC 1974).

The distribution of these rocks and sediments from each of the three time periods also defines the type and location of mineral resources and mineral production within the Basin. All the identified metal resources, including iron, zinc, lead, silver, and copper, occur in Precambrian rock. There have been several studies conducted in the Lake Superior region to evaluate the potential for oil and gas within the Precambrian rocks. Specifically, the Nonesuch Formation has been the Precambrian unit most studied on the basis of documented evidence that it is the source of oil seeps in the White Pine Copper Mine, in White Pine, Michigan. The studies to date have determined that the Nonesuch Formation in the outcrop area is not a high-quality hydrocarbon source rock (Dickas and Mudrey 1991). There has been no petroleum production from this formation like there has been from rock formations of the Paleozoic Era within the Great Lakes Basin. In most cases, Precambrian rocks probably will not compose a viable petroleum system because these rocks have been so deformed and altered during the long course of geologic time that any hydrocarbons originally in them have long been destroyed (Dorr and Eschman 1970). Nonmetal deposits of sand gravel, clay, marl, and peat found throughout the Basin are contained in unconsolidated Cenozoic (i.e., glacial Pleistocene) sediments (GLBC 1974).

Oil and gas systems have been found throughout the Paleozoic time period primarily in rocks of Ordovician, Silurian, and Devonian ages. The majority of the oil and gas in the Great Lakes area occurs in porous carbonate rock reservoirs. In most cases, the hydrocarbons found in a carbonate reservoir migrated into the reservoir rock from a source rock (i.e., dead organic matter of both plant and animal origin), rather than having been deposited there originally. Figure 5.7 provides an illustration of the components of an oil and gas system. Research has shown that even in the best petroleum systems, oil and gas apparently are not distributed in sufficient quantities throughout the source interval alone — rather they must have migrated and become concentrated in local reservoirs. In addition, there must be something to stop the movement so that the oil and gas will collect; this feature is often referred to as a “seal rock” or “cap.” Seal rocks are nonporous and relatively impermeable rock formations such as shale and anhydrite.

The U.S. Geological Survey (USGS) has completed an assessment of the undiscovered oil and gas potential of the Appalachian Basin Province, which includes Lake Erie, Lake Ontario, and the eastern part of the Basin from Ohio to New York (Swezey 2002; Milici et al. 2003). The USGS has also completed an assessment of the undiscovered oil and gas resources of the U.S. portion of the Michigan Basin (Swezey et al., 2005). The assessment includes Lake Michigan and the U.S. parts of Lakes Superior and Huron. Identified oil- and gas-producing petroleum systems are currently present in all of the states that border the Great Lakes except Minnesota and Wisconsin (Dorr and Eschman 1970; Ryder and Zagorski 2003; Swezey et al., 2005). Oil and gas systems within these states have been found in formations originating from throughout the Paleozoic time period. On the basis of studies and assessments conducted to date, petroleum systems formed from Ordovician-, Silurian-, and Devonian-age deposits are beneath all of the Great Lakes, with the exception of Lake Superior (Wandrey et al. 1997; Swezey 2002, 2004; Ryder and Zagorski 2003). The USGS is currently estimating petroleum resources beneath the U.S. portions of the Great Lakes.

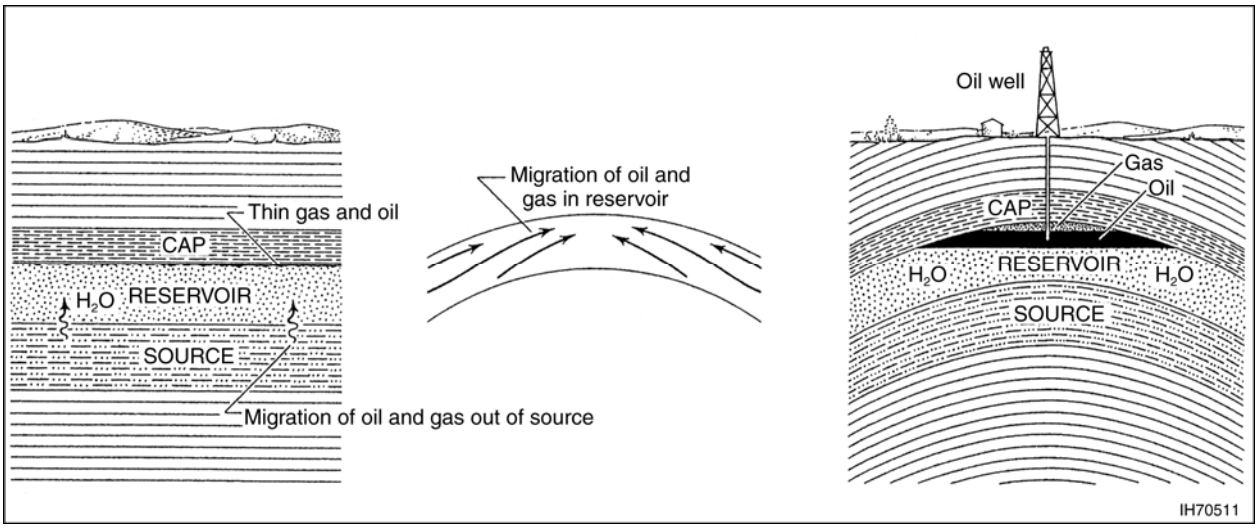

FIGURE 5.7 Essentials of Oil and Gas Accumulation (Left: Migration from source rock into porous and permeable reservoir rock is halted beneath an impermeable seal or cap. Center: Inclination of reservoir boundaries favors movement toward higher regions of a structure, with consequent localization of oil and gas. Right: Simple structure, showing separation of gas, oil, and water at crest of structure in porous reservoir, beneath seal) (Source: Dorr and Eschman 1970)

The general distribution of known and postulated (e.g., probable successful offshore extensions of known oil and gas fields and potential maximum extent of current and future production) Paleozoic petroleum systems in the area of the U.S. Great Lakes is shown in Figure 5.8. The distribution of Paleozoic petroleum systems extends beyond the area of the Great Lakes; Figure 5.8 shows only the distribution within the U.S. part of the Great Lakes Basin. For reasons discussed above, the area outlined in Figure 5.8 excludes the highly uncertain Precambrian system (i.e., Nonesuch Shale). The red boundary line showing the distribution of these systems is determined by the Canadian/U.S. border on the north and northeast, the outcrop boundary between the Cambro-Ordovician and Silurian in Wisconsin and northeast Illinois, and northern New York. The part of the line from southern Lake Michigan to central New York is somewhat arbitrary, approximating the Basin divide between the Michigan basin and the Illinois basin in Illinois, Indiana, and Northwest Ohio. The extension from northwest Ohio to central New York parallels the southern border of the Great Lakes Basin.

Approximately 594 gas wells are in the Canadian waters of Lake Erie and they produce at a total rate of 30 million ft^3/d (1 million m^3/d). These gas wells produce into a 1,553-mi (2,500-km) pipeline network that reaches land at five points along the north shore of the lake. Gas is produced in this area of Lake Erie from the Lower Silurian Grimsby and Whirlpool Formations (Clinton/Medina sandstones) at depths averaging 1,450 ft (442 m). In addition, there is gas production in central and western Lake Erie from the Silurian Guelph Formation reefs (Lockport Dolomite) at depths ranging from 900 to 1,600 ft (274 to 488 m) (Wickstrom 2001).

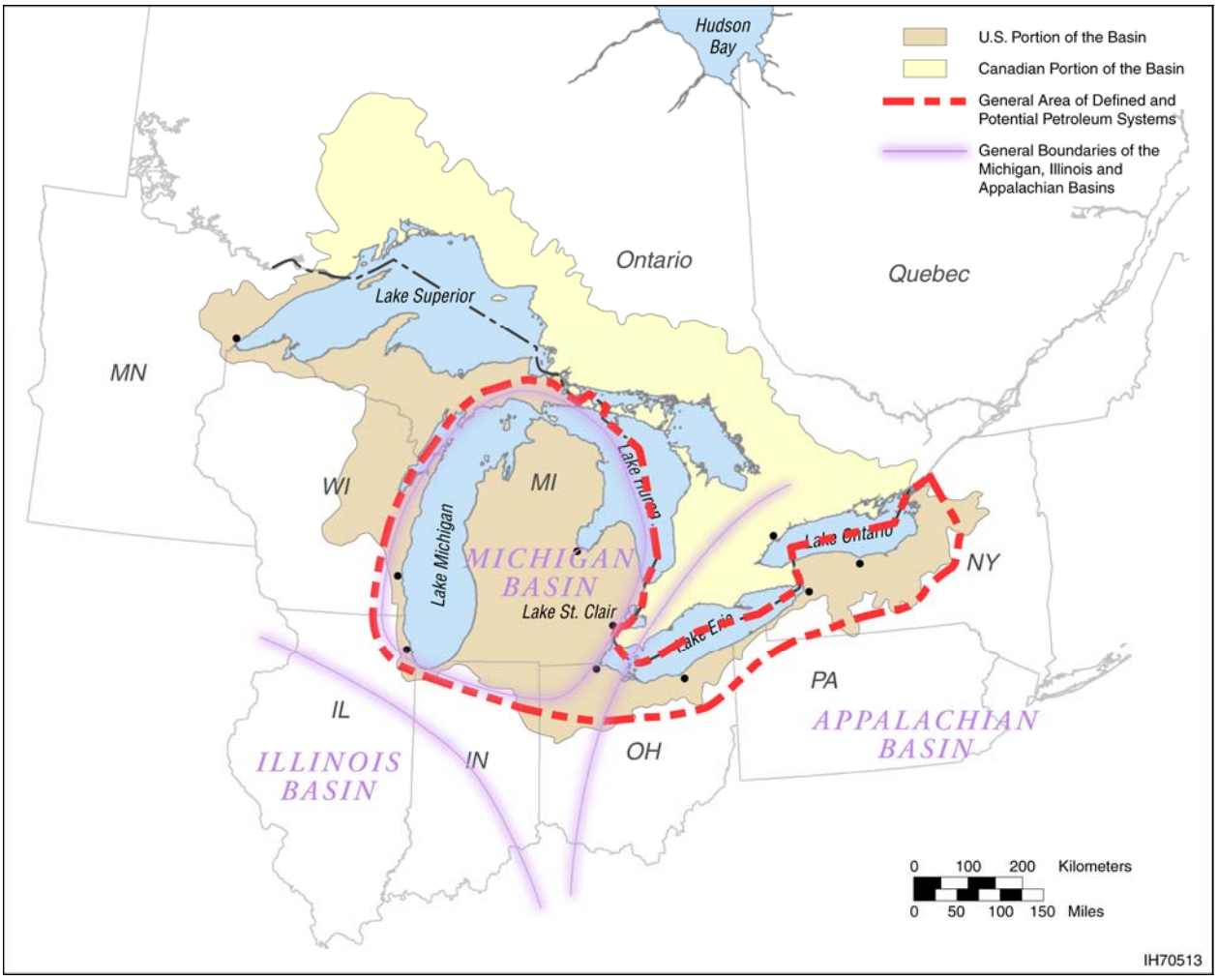

FIGURE 5.8 General Area of Defined and Potential Petroleum Systems within the Great Lakes Basin (Sources: Developed from Swezey 2002, 2004; Milici et al. 2003; Repetski 2004)

It has been estimated that a total volume of 1,101 billion ft^3 (31 billion m^3) of natural gas could be produced from Ohio's part of the central basin of Lake Erie. The total estimated amount of recoverable natural gas to be obtained by land-based directional drilling (within approximately 2.5 mi [4.0 km] from shore) is 187 billion ft^3 (5 million m^3) (Wickstrom 2001). For comparison, the residential use of natural gas in Ohio was 321 billion ft^3 (13 billion m^3) in 2004 (EIA 2005i). The reserve estimates for directional drilling are from the following five geologic Paleozoic formations: (1) Devonian Oriskany sandstone, (2) Silurian Lockport dolomite; (3) Silurian Clinton/Medina sandstones, (4) Cambro-Ordovician Knox/Black River/Trenton carbonates, and (5) Cambrian Pre-Knox clastics and carbonates (Wickstrom 2001).

The Niagaran-Silurian Reef system, which contains oil and gas, is beneath much of west Michigan, the northern Lower Peninsula, and western Lake Erie. Oil and gas have been extracted from the Niagaran Reefs area since the 1960s (Cabala 2001). Since 1997, 13 oil and gas wells have been drilled under Lake Michigan and Lake Huron via horizontal drilling from locations

within northern Michigan. Of the 13 wells drilled, 6 were dry and 7 have cumulatively produced 439,000 bbl of oil and 17.9 billion ft^3 (0.5 billion m^3) of gas (Clark and Dutzik 2002). To date, there is no oil and gas production beneath southern Lake Michigan in Illinois and Indiana (Cabala 2001).

5.2 ECOLOGICAL RESOURCES

The Great Lakes represent the second largest freshwater body in the world (see Section 5.1.2). Coupled with the varied topography and geology of the Basin (see Section 5.1.1), and a climate that ranges from subarctic in the north to humid continental in the south, the Basin provides a wide variety of habitats (many unique) that support a tremendous diversity of plant and animal life. The following sections provide a brief summary of the habitats, plants, and animals found in the Basin.

5.2.1 Great Lakes Ecoregions

Ecoregions denote areas of general similarity in ecosystems and in the type, quality, and quantity of environmental resources (EPA 2005a). They are designed to serve as a spatial framework for the research, assessment, management, and monitoring of ecosystems and ecosystem components. Ecoregions denote areas within which ecosystems (and the type, quality, and quantity of environmental resources) are generally similar. Environmental parameters used to delineate ecoregions include geology, physiography, vegetation, climate, soils, land use, wildlife, and hydrology. The relative importance of each characteristic varies from one ecological region to another and serves as the basis for delineating these regions.

A variety of organizations, agencies, and researchers have developed ecoregion classification schemes (e.g., Bailey 1995; CEC 1997). The ecoregions indicated here are those used in the 1995 Great Lakes Environmental Atlas and Resource Guide (EPA and Government of Canada 1995), as well as corresponding information developed by the EPA for its Level III ecoregion designations (EPA 2005a) and others (e.g., Buttrick 1999). The Level III ecoregions have been developed in collaboration with EPA regional offices, state resource management agencies, and other Federal agencies (EPA 2002a). Figure 5.9 shows the ecoregions of the Great Lakes Basin, while Table 5.2 identifies the ecoregions associated with each of the Great Lakes and provides a brief description of each ecoregion.

Ecologically, these ecoregions encompass expanses of hardwood and coniferous forests in the northwestern portions of the Great Lakes Basin, broad expanses of agricultural plains in the central and southern portions of the Basin, and deciduous forests in the east. The following discussions of the biota of the Great Lakes Basin reflect the influence of the environmental conditions of each ecoregion. Within each ecoregion, it is the terrestrial biota most closely associated with or relying upon coastal habitats that may be most likely to be affected by onshore oil and gas operations. Aquatic biota dependent on nearshore habitats, as well as those closely associated with or dependent on lake bottom habitats, may be most likely to be affected by

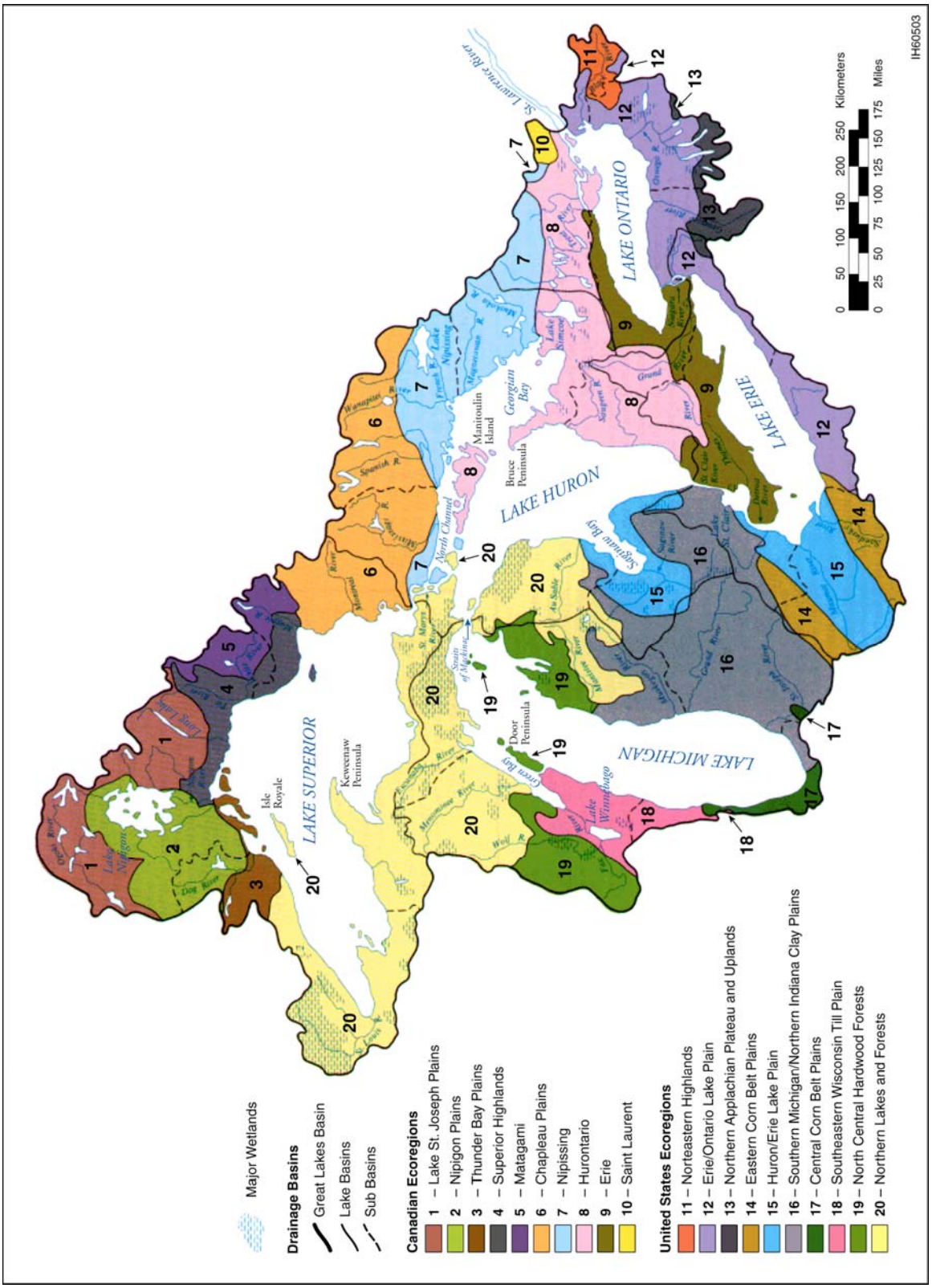

FIGURE 5.9 Ecoregions, Wetlands, and Drainage Basins of the Great Lakes Basin (Source: Modified from EPA and Government of Canada 1995)

TABLE 5.2 Ecoregions of the Great Lakes Basin

Lake	Ecoregion[a,b]	Ecoregion Characteristics
Superior	Northern Lakes and Forests (20)	Encompasses the northern portions of Minnesota, Wisconsin, the lower peninsula of Michigan, and the entire upper peninsula of Michigan. A region of nutrient-poor glacial soils, coniferous and northern hardwood forests, undulating till plains, morainal hills, broad lacustrine basins, and extensive sandy outwash plains. Soils in this ecoregion are thicker than those to the north but are generally less fertile than soils in adjacent ecoregions to the south. The numerous lakes that dot the largely forested landscape are clearer and less productive than those in ecoregions to the south.
Michigan	Northern Lakes and Forests (20)	As described above.
	North Central Hardwood Forest (19)	Within the Great Lakes Basin, this ecoregion encompasses a small portion of central Wisconsin and the western portion of the lower peninsula of Michigan; it extends through central Wisconsin into central Minnesota. A transitional ecoregion between the predominantly forested Northern Lakes and Forests ecoregion to the north and the agricultural ecoregions to the south. Land use/land cover in this ecoregion consists of a mosaic of forests, wetlands and lakes, cropland agriculture, pasture, and dairy operations.
	Southeastern Wisconsin Till Plains (18)	This ecoregion encompasses the southeastern portion of Wisconsin and the northern border of Illinois. It supports a mosaic of vegetation types, representing a transition between the hardwood forests and oak savannas of the ecoregions to the west and the historic tall-grass prairies and current agricultural lands of the Central Corn Belt Plains to the south. Like the Corn Belt Plains, land use is mostly cropland, but the crops are largely forage and feed grains to support dairy operations, rather than corn and soybeans for cash crops.
	Central Corn Belt Plains (17)	This ecoregion encompasses most of northern Illinois and a portion of northeastern Indiana. Within the Great Lakes Basin, this ecoregion occurs largely along the southwestern shore of Lake Michigan. Extensive prairie communities intermixed with oak-hickory forests were native to the glaciated plains of the Central Corn Belt Plains. Beginning in the 19th century, the natural vegetation was gradually replaced by agriculture. Farms are now extensive on the dark, fertile soils of the ecoregion and mainly produce corn and soybeans. Cattle, sheep, poultry, and especially hogs are also raised but are not as dominant as in the drier ecoregion to the west. Agriculture has affected stream chemistry, turbidity, and habitat.

TABLE 5.2 (Cont.)

Lake	Ecoregion[a,b]	Ecoregion Characteristics
	Southern Michigan/ Northern Indiana Clay Plains (16)	This ecoregion covers northern Indiana and most of the southern portion of the lower peninsula of Michigan, extending from Lake Michigan in the west to the St. Clair River and Lake Huron in the east. This ecoregion is less agricultural than those to the south, is better drained and contains more lakes than the agricultural lake plain to the east, and has less nutrient-poor soils than the ecoregion to the north. It is characterized by many lakes and marshes, and an assortment of soil types, soil textures, and landforms, including broad till plains with thick and complex deposits of drift, paleobeach ridges, relict dunes, morainal hills, kames, drumlins, meltwater channels, and kettles. Oak-hickory forests, northern swamp forests, and beech forests were typical. Feed grain, soybean, and livestock farming as well as woodlots, quarries, recreational development, and urban-industrial areas are now common.
Huron	Northern Lakes and Forests (20)	As previously described.
	Huron/Erie Lake Plain (15)	This ecoregion is restricted to northwestern Ohio, extreme southeastern Michigan, and the east-central portion of the lower peninsula of Michigan in the vicinity of Saginaw Bay. It is a broad, fertile, nearly flat plain punctuated by relic sand dunes, beach ridges, and end moraines. Originally, soil drainage was relatively poor, and elm-ash swamp and beech forests were dominant. Oak savanna was typically restricted to sandy, well-drained dunes and beach ridges. Today, most of the area has been cleared and artificially drained and contains highly productive farms producing corn, soybeans, livestock, and vegetables; urban and industrial areas are also extensive. Stream habitat and quality have been degraded by channelization, ditching, and agricultural activities.
	Southern Michigan/ Northern Indiana Clay Plains (16)	As previously described.
Erie	Southern Michigan/ Northern Indiana Clay Plains (16)	As previously described.
	Huron/Erie Lake Plain (15)	As previously described.

TABLE 5.2 (Cont.)

Lake	Ecoregion[a,b]	Ecoregion Characteristics
	Eastern Corn Belt Plains (14)	Only the extreme northeastern portions of this ecoregion occur within the Great Lakes Basin, in northwestern Ohio and southeastern Michigan. Elsewhere, this ecoregion encompasses most of western Ohio and eastern and central Indiana. The Eastern Corn Belt Plains is primarily a rolling till plain with local end moraines; it had more natural tree cover and has lighter-colored soils than the Central Corn Belt Plains. The region has rich soils that are loamier and better drained soils than those of the Huron/Erie Lake Plain, and glacial deposits of Wisconsinan age are extensive. They are not as dissected nor as leached as the pre-Wisconsinan till, which is restricted to the southern part of the region. Originally, beech forests were common on Wisconsinan soils, while beech forests and elm-ash swamp forests dominated the wetter pre-Wisconsinan soils. Today, this ecoregion supports extensive corn, soybean, and livestock production that has affected stream chemistry and turbidity.
	Erie/Ontario Lake Plain (12)	This ecoregion stretches along the southern shores of Lakes Erie and Ontario, and extends eastward through central New York and northern New York along the Saint Lawrence River into western Vermont, and southward along the Hudson River. This glaciated region of irregular plains bordered by hills generally contains less surface irregularity and more agricultural activity and population density than the adjacent Northeastern Highlands (11) and Northern Appalachian Plateau and Uplands (13). Although orchards, vineyards, and vegetable farming are important locally, a large percentage of the agriculture is associated with dairy operations. The portion of this ecoregion that is in closest proximity to the Great Lakes experiences an increased growing season, more winter cloudiness, and greater snowfall, because of the climatic influences of the lake.
	Northern Appalachian Plateau and Uplands (13)	Only the northwestern-most portions of this ecoregion are found within the Great Lakes Basin. Elsewhere, this ecoregion encompasses much of south-central New York and the central portion of northern Pennsylvania. Much of this region is farmed and in pasture, with hay and grain for dairy cattle being the principal crops; large areas, however, are oak and northern hardwood forests.
Ontario	Erie/Ontario Lake Plain (12)	As previously described.
	Northern Appalachian Plateau and Uplands (13)	As previously described.

TABLE 5.2 (Cont.)

Lake	Ecoregion[a,b]	Ecoregion Characteristics
	Northeastern Highlands (11)	This ecoregion occurs only in the extreme eastern portion of the Basin in New York State. The ecoregion is a relatively sparsely populated region characterized by nutrient-poor soils blanketed by northern hardwood and spruce fir forests. Land-surface form in the region grades from low mountains in the southwest and central portions to open high hills in the northeast. Many of the numerous glacial lakes in this region have been acidified by sulfur depositions originating in industrialized areas upwind from the ecoregion.

[a] The numbers in parentheses correspond to the numbered ecoregions shown in Figure 5.9.

[b] Figure 5.9 shows the locations of the ecoregions within the Basin.

Sources: EPA and Government of Canada 1995; EPA 2002a; Bailey 1995; Buttrick 1999; Chaplin et al., 1999b; Kavanagh et al., 1999a,b.

offshore oil and gas drilling and production. The bottom sediments of the Great Lakes are closely related to the lake bottom topography, and are generally composed of muds and clays in the central and deeper portions of the Basin, with sand beds typically located in shallower waters around the outer margins of the lakes and midlake bars of Lake Erie (Bolsenga and Herdendorf 1993; Lewis and Herdendorf 1976). Bedrock forms the substrate in some nearshore areas of Lakes Erie and Ontario, with numerous reefs occurring among the islands of western Lake Erie (Lewis and Herdendorf 1976; Herdendorf 1980). The following sections present an overview of the biota and habitats in these areas of the Great Lakes.

5.2.2 Coastal and Nearshore Habitats

With current technologies, oil and gas resources located beneath the Great Lakes may be accessed by either offshore vertical or onshore directional drilling. For the latter approach, it is expected that onshore facilities would be located as close to the coastline as possible or as permitted by environmental regulations. Thus, it is these nearshore habitats and their biota rather than habitats and biota located a mile or more inland that would be most likely to be affected by onshore oil and gas development.

5.2.2.1 Wetlands

Two major types of wetlands occur in the Basin: (1) coastal (nearshore) wetlands, which occur within 0.6 (1 km) of the lakeshore, or if further inland, are directly influenced by water level changes in the Great Lakes, and (2) inland wetlands (Edsall 1998). The coastal wetlands are more dynamic, display a greater diversity of functions, are less influenced by groundwater inflow than are inland wetlands, and have primarily mineral sediments whereas many inland wetlands have sediments with high organic content. Coastal wetlands are also subject to short-term (hours-long) flooding and draining by storm tides and seiches, as well as seasonal and years- or decades-long changes in lake levels (Edsall 1998). Inland wetlands are not directly influenced by water level changes in the Great Lakes, and generally exhibit a seasonal hydrologic pattern.

Eight Basic Types of Nearshore Wetlands

- Coastal lagoon
- Estuarine
- Kettle lake
- Delta
- Solution basin
- Riverine
- Diked
- Fringing

The development of coastal wetlands is influenced by the geomorphic features of the shoreline and the recent history of water level fluctuations, becoming established in locations protected from waves, ice scour, erosion, and rapid sediment movement (Herdendorf 1990). The Great Lakes coastal wetlands can be categorized as coastal lagoon, estuarine, delta, kettle lake, solution basin, riverine, diked, and fringing (Herdendorf et al 1981; Herdendorf and Fay 1988; Herdendorf 2004).

Coastal lagoon wetlands are the most common types of Great Lakes coastal wetlands and represent about 53% of the total coastal wetland area. They typically form in embayments partially or entirely enclosed by offshore sand and gravel bars, barrier beaches, or spits, and may

support communities of submerged, floating-leaved, emergent, and woody species. As ponds formed from enclosed coastal lagoons change and develop over time, vegetation density and complexity increase.

Estuarine wetlands, about 15% of the wetland area, develop in drowned stream mouths of some Great Lakes tributaries, particularly on the more southerly lakes, such as along the Ohio shore of Lake Erie. Wetlands become established on the flooded flat areas of the estuary margin and islands formed by riverine sediment deposits. Estuarine wetlands may extend several kilometers upstream, where water levels and water quality are affected by the lake.

Delta wetlands, about 18% of the coastal wetlands area, are formed from massive sediment deposits where some tributary streams enter the Great Lakes. Extensive wetlands can develop on these deposits, such as the delta wetlands of Lake St. Clair at the inflow of the St. Clair River. Delta wetlands typically develop on sediments composed of fine sand, with silt and clay generally carried offshore. Branched distributary channels, or in some cases a single channel, extend through the delta into the lake and are generally bordered by natural levees. Shallow ponds and marshes, with mud, detritus, or peat substrates, may be isolated between the levees.

Kettle lake wetlands, less than 1% of the coastal wetland area, occur in basins that formed within glacial drift material. These wetlands, if poorly drained, often support bog communities with floating vegetation mats and peat substrates. Such communities generally include species adapted to acidic environments such as *Sphagnum* mosses, sedges, and trees and shrubs typically found in bogs. Bogs lack surface inflows or outflows and support many Federally listed threatened and endangered species. Kettle lakes that are near the coast and have a hydrologic communication with the larger lake, may support communities similar to coastal lagoon marshes.

Solution basin wetlands, less than 1% of the coastal wetland area, occur in circular shaped lagoons formed in limestone bedrock at the coast line and may have inflows from springs at the bottom. These solution lagoons may sometimes be included within larger wetland systems. Solution basin wetlands may also occur in small lakes near the coast line that are fed by artesian groundwater and include wetland communities along their discharge streams.

Riverine wetlands, about 12% of the wetland area, occur within the channels of the Great Lakes connecting waterways and lower reaches of major tributaries. This wetland type gives way to estuarine wetlands where water levels are controlled by the lake. Riverine coastal marshes are especially prevalent along the Lake Michigan tributaries of Michigan and Wisconsin.

Diked wetlands, about 1% of the wetland area, form in embayments along the lake coast line that are closed off from the lake by constructed stone or earthen dikes. Most of these marshes are managed for waterfowl habitat and some support spawning fish access where breaches have been installed.

Fringing wetlands develop on some sheltered shorelines such as in Lake St Clair.

Inland wetlands can be categorized into four basic wetland types: swamps, marshes, bogs, and fens. Swamps are areas where trees and shrubs live on wet, organically rich mineral soils that are flooded for part or all of the year. Marshes develop in shallow standing water such as ponds and protected bays. Aquatic plants (such as species of rushes) form thick stands, which are rooted in sediments or become floating mats where the water is deeper. Swamps and marshes occur most frequently along the southern and eastern coastlines of the Great Lakes Basin (Maynard and Wilcox 1997).

Bogs form in shallow stagnant water. The most characteristic plant species are the *Sphagnum* mosses, which decompose very slowly and accumulate into mats that may eventually become many meters thick and are excavated and sold as peat moss. Fens develop in shallow, slowly moving water. They are less acidic than bogs and are usually fed by groundwater. Fens are dominated by sedges and grasses, but may include shrubs and stunted trees. Fens and bogs are commonly referred to as "peatlands" and occur most frequently in the cooler northern and northwestern portions of the Great Lakes Basin (Maynard and Wilcox 1997).

Wetlands serve an important ecological role in the overall health and maintenance of the Great Lakes ecosystem. They provide habitats for many kinds of plants and animals, some of which are found nowhere else. For ducks, geese, and other migratory birds, wetlands are often the most important part of the migratory cycle, providing food, resting places, and seasonal habitats. Many of the Great Lakes fish depend on coastal wetlands for their successful reproduction (Goodyear et al. 1982). In addition to providing a desirable habitat for aquatic life, wetlands can also prevent damage from erosion and flooding, as well as controlling point- and non-point-source pollution and supporting good water quality. About 50% of the endangered animal species listed in 1986 depend on wetlands for survival and viability (Mitsch and Gosselink 2000).

Some of the coastal wetlands along the Great Lakes (Figure 5.10) include sites that are recognized internationally for their outstanding biological significance. Examples include the Long Point complex and Point Pelee on the north shore of Lake Erie and the National Wildlife Area on Lake St. Clair. Long Point has been designated a United Nations Educational, Scientific, and Cultural Organization (UNESCO) Biosphere Reserve. Wetlands of the lower Great Lakes region have also been identified as a priority of the Eastern Habitat Joint Venture of the North American Waterfowl Management Plan, an international agreement between governments and non-government organizations to conserve highly significant wetlands (Maynard and Wilcox 1997).

It is estimated that more than two-thirds of the Great Lakes wetlands have already been lost because of agricultural and urban development; some areas have lost as much as 95% of their coastal wetlands. Many of the remaining wetlands are threatened by development, drainage, or pollution (EPA and Government of Canada 1995; Burton and Ingram 2004). Fewer than 296,000 acres (120,000 ha) of Great Lakes coastal wetland remain in the United States, with the largest total number and total area occurring along the shorelines of Lake Michigan

FIGURE 5.10 Kakugon Sloughs, a Coastal Wetland on Lake Superior (Source: EPA 2003a)

(Edsall 1998). By comparison, the lower 48 states are estimated to contain approximately 105.5 million acres (43 million ha) of wetlands in total (EPA 2005b).

5.2.2.1.1 Lake Superior. Lake Superior's coastal wetlands are in comparatively good condition and less affected by human activities than those of the other Great Lakes. The north (Canadian) shore of Lake Superior is a high-energy environment with few areas of sediment deposition. Wetlands are rare here and restricted to the large sheltered embayment (Maynard and Wilcox 1997). Because of their rarity, these wetlands are particularly important to fish and wildlife populations. Along the southern U.S. shore of the lake, coastal wetlands are larger and more numerous than those along the northern Canadian shore. Coastal wetlands occupy approximately 53,393 acres (21,357 ha) along the southern shore; in Wisconsin, many large wetlands remain in relatively pristine condition (Maynard and Wilcox 1997).

5.2.2.1.2 Lake Michigan. Lake Michigan contains about 40% of all Great Lakes wetlands in the United States, with approximately 411 coastal wetlands covering about 121,000 acres (49,000 ha) (Maynard and Wilcox 1997). Most of the wetlands are concentrated along the tributary rivers along Michigan's western shore and in the Green Bay and Door County Peninsula portion of Wisconsin.

5.2.2.1.3 Lake Huron. The wetlands of Lake Huron are generally smaller but more abundant than those in the southern Great Lakes, and over half are wetland complexes (Maynard and Wilcox 1997). The wetlands along the Canadian shore of the lake are common in sheltered embayments and creek mouths and in the lees of large islands. Although an accurate estimate of wetlands in this area is not available, approximately 17,900 acres (7,160 ha) of wetlands have been evaluated on the Canadian side of the lake. Approximately 40,500 acres (16,200 ha) of wetlands occur on the Michigan shore of the lake.

5.2.2.1.4 Lake Erie. The largest concentration of coastal wetlands in Lake Erie is associated with the shallow western basin of the lake (Maynard and Wilcox 1997). While wetlands dominated the western basin of the lake in presettlement times, about 90% of those wetlands have been drained for agricultural and urban development. There are currently about 19,840 acres (7,900 ha) of wetlands along the U.S. shoreline of the lake. Many of these have been diked and are now hydrologically isolated from the lake. The only sizeable remnant wetlands in the western Basin of the U.S. portion of the lake are the shoreline wetlands of the Ottawa National Wildlife Refuge and Crane Creek State Park in Ohio. The freshwater delta marshes of the St. Clair Flats State Wildlife Area in Lake St. Clair at the mouth of the St. Clair River in Michigan form an extensive wetland system (Myers and Finnegan 2002). The coastal wetlands of Lake Erie support the largest diversity of plant and wildlife species in the Great Lakes and provide an important stopover area for migratory waterfowl, shorebirds, and songbirds.

5.2.2.1.5 Lake Ontario. Wetlands are most abundant in the eastern portions of the lake, totaling at least 44,018 acres (17,600 ha) and occurring in river mouths, embayments, and behind sand bars and barrier beaches (Maynard and Wilcox 1997). Along the U.S. shore, an estimated 60% of the wetlands have been lost because of agriculture and urban development.

5.2.2.1.6 Special Aquatic Areas. In addition to wetlands, other special aquatic sites are also described in the CWA that have important and easily disrupted ecological values: sanctuaries and refuges for the preservation and use of fish and wildlife resources (Figure 5.11); mudflats along lakes, ponds, and rivers that are generally unvegetated and periodically inundated by shallow water; vegetated shallows that are permanently inundated and support communities of rooted submerged aquatic vegetation; coral reefs (not present in the Great Lakes); and riffle and pool complexes in steep gradient stream sections with high-velocity flow over coarse substrates and deeper areas of low-velocity flow and finer substrates.

5.2.2.2 Other Nearshore Habitats and Vegetation

Because of the variation in climate, soils, and topography across the Great Lakes Basin, the nearshore area of the basin supports a diverse area of habitat types and associated vegetation communities. The northernmost portions of the basin experience a cold climate and have a

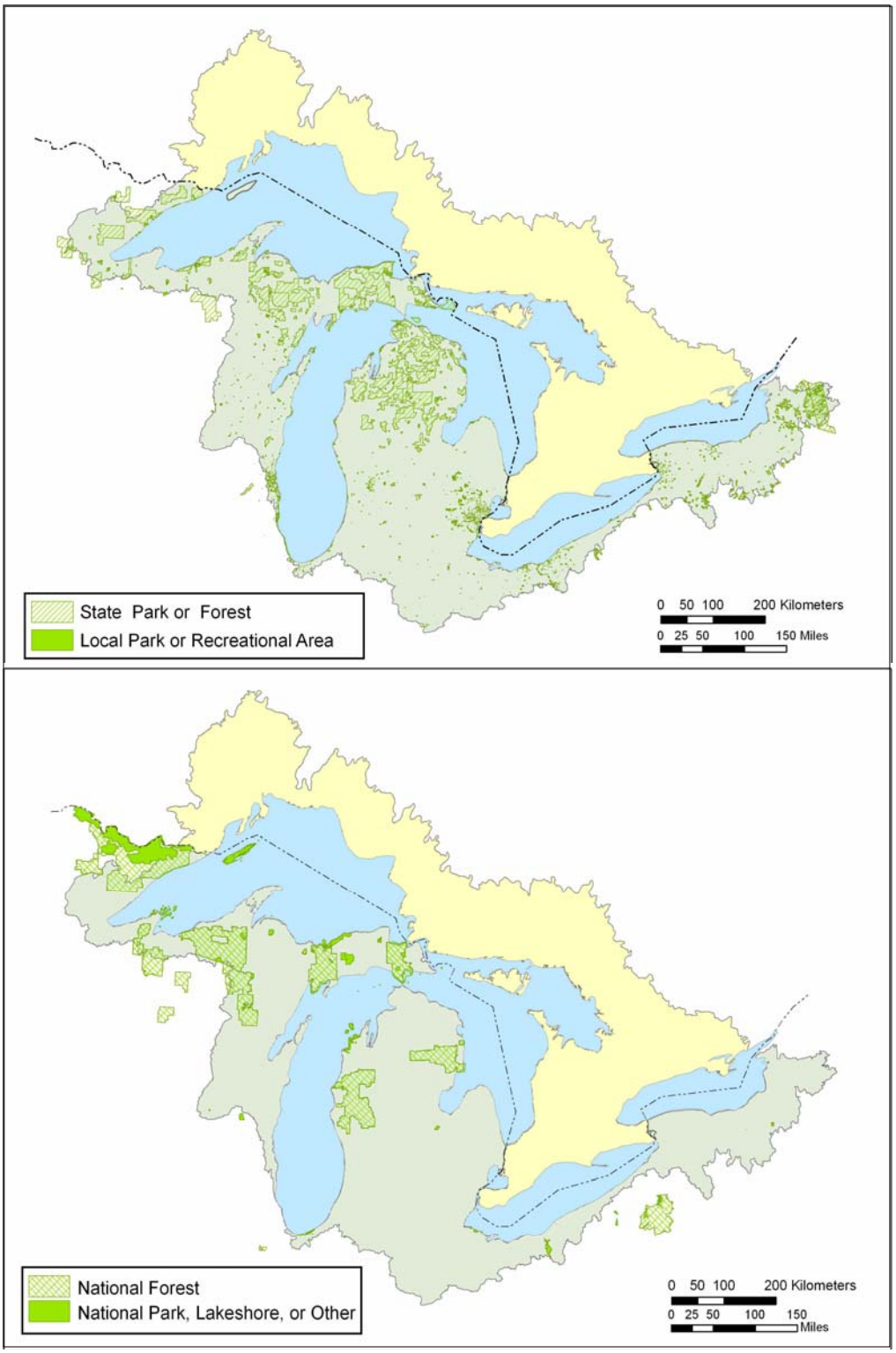

FIGURE 5.11 National Lakeshores, Wildlife Refuges, Forests, Monuments, Historic Sites, State and Local Parks, Preserves, and Natural Areas within the Great Lakes Basin

terrain dominated by granitic and metamorphic bedrock of the Laurentian shield. The vegetation communities of the regions are dominated by coniferous forests growing on generally thin, acidic soils (Reid and Holland 1997). In the south, the climate is warmer, and the terrain is flatter with many areas of fertile soil.

In addition to these general habitat types, the nearshore areas of the Basin include a number of important habitats that support important and unique plant and animal communities. Some of these habitats support species that are endemic (i.e., found nowhere else in the world) not only to the Great Lakes Basin but also to the particular habitat type. These habitats are described below.

5.2.2.2.1 Sand Beaches. Sand beaches form when waves and wind deposit sand eroded from other places on exposed shoreline. The sand settles until storms or ice transport it elsewhere, or until the wind lifts and deposits it inland to form dunes. More than 500 sand beaches are in the U.S. portion of each of the Great Lakes, with the greatest number and extent occurring along the eastern shore of Lake Michigan (Figure 5.12).

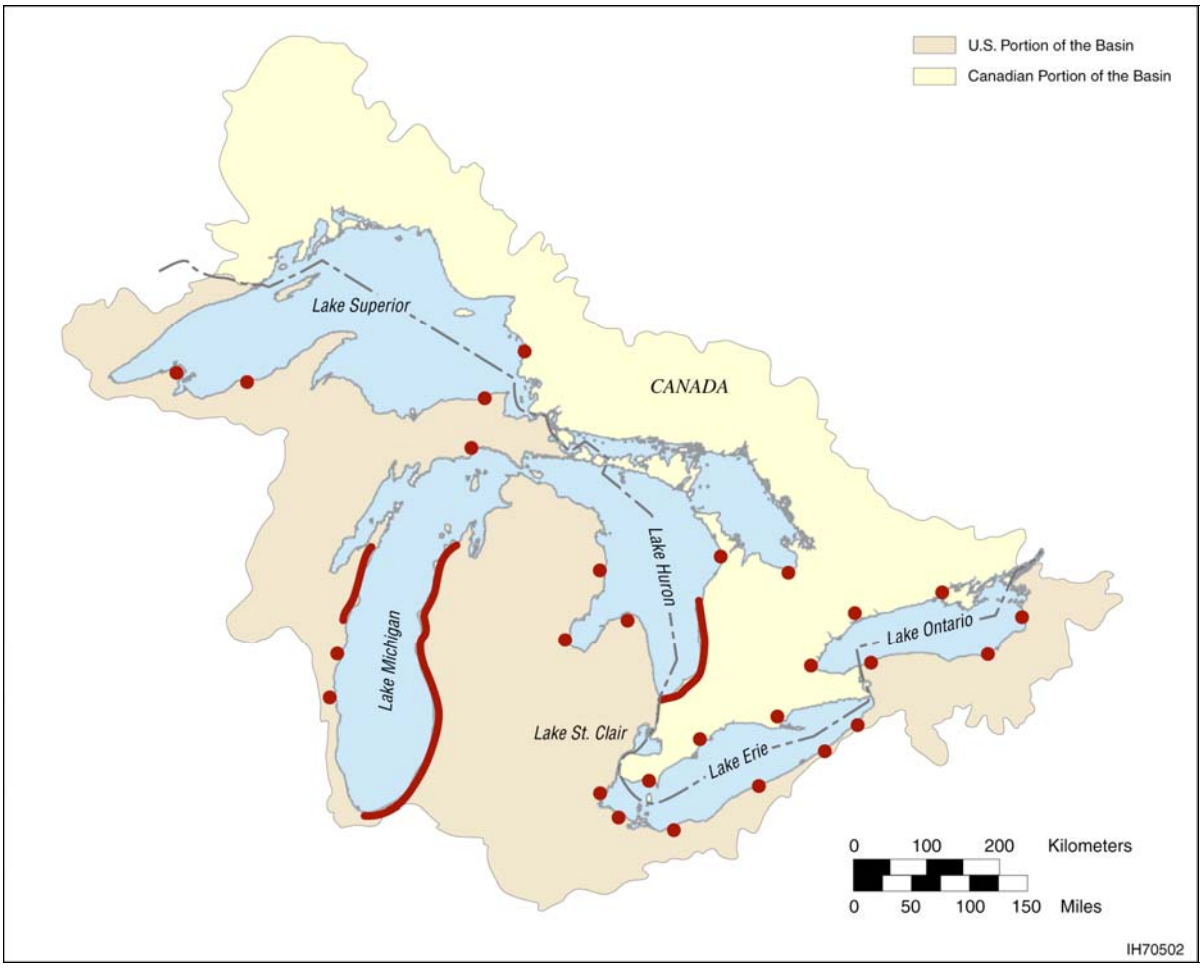

FIGURE 5.12 Great Lakes Sand Beaches (Sources: Reid and Holland 1997; NOAA 1994)

5.2.2.2.2 Sand Dunes. Sand dunes form where sand grains are abundant, wind blows frequently, and there is a place for sand to be deposited. Sand dunes are found at each of the Great Lakes (Figure 5.13), although in the United States, they are largely restricted to the lower peninsula of Michigan along the shorelines of Lakes Michigan and Huron, the extreme western end of Lake Erie, and along the shoreline of Lake Superior in the upper peninsula of Michigan. Several unusual dune types are found in the Great Lakes. Perched dunes rest on a plateau of glacial sediment. Falling dunes form as sand migrates off perched dunes and builds on an adjacent lowland. Deperched dunes form on lowland areas beyond plateaus. Sleeping Bear Dunes National Lakeshore, Lake Michigan, and the Grand Sable Dunes within Pictured Rocks National Lakeshore, Lake Superior, have examples of all three dune types; some are several hundred feet high (Sleeping Bear Dunes National Lakeshore 1991). The coastal dunes support more endemic species than any other part of the Basin (Edsall 1998).

5.2.2.2.3 Bedrock and Cobble Beaches. Bedrock beaches occur where there is exposed rock along the lakeshore; they are shaped by wave and ice erosion. Cracks in the rock contain plant life, and seasonal pools form in low areas carved into the rock. Bedrock beaches may

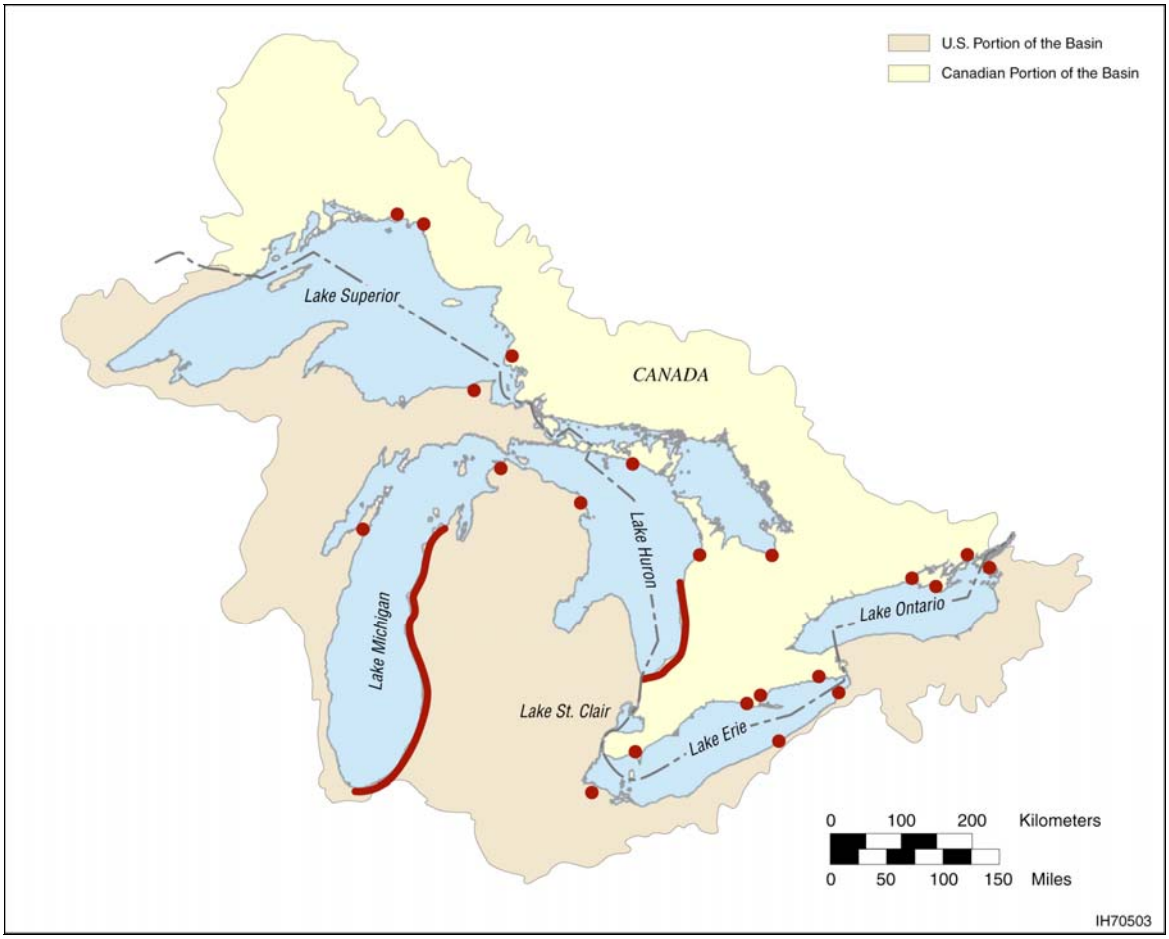

FIGURE 5.13 Great Lakes Sand Dunes (Source: Reid and Holland 1997)

support a variety of plant life, ranging from lichens and mosses to herbaceous and woody vegetation. Cobble beaches, common along rocky shorelines, are composed of rock chunks made up of limestone or other durable rock, and there is little vegetation present because of exposure to severe wave and ice action. Bedrock and cobble beaches are more common on the Canadian shores of the Great Lakes (Figure 5.14).

5.2.2.2.4 Lakeplain Prairies. These prairie areas contain rich and deep soil that supports a variety of grasses, herbs, and forbs, with few trees and shrubs. These lakeplains were formed from sediments deposited as the Wisconsinan glacier receded 10,000 years ago (Reid and Holland 1997). The type of vegetation growing in lakeplain prairies is influenced by local climatic conditions and soil composition and moisture. These areas are dominated by grasses because rainfall is insufficient to support forest. The lakeplain prairies provide birds and other wildlife refuge from flooding as well as habitat for nesting and feeding (The Nature Conservancy Great Lakes Program 1994).

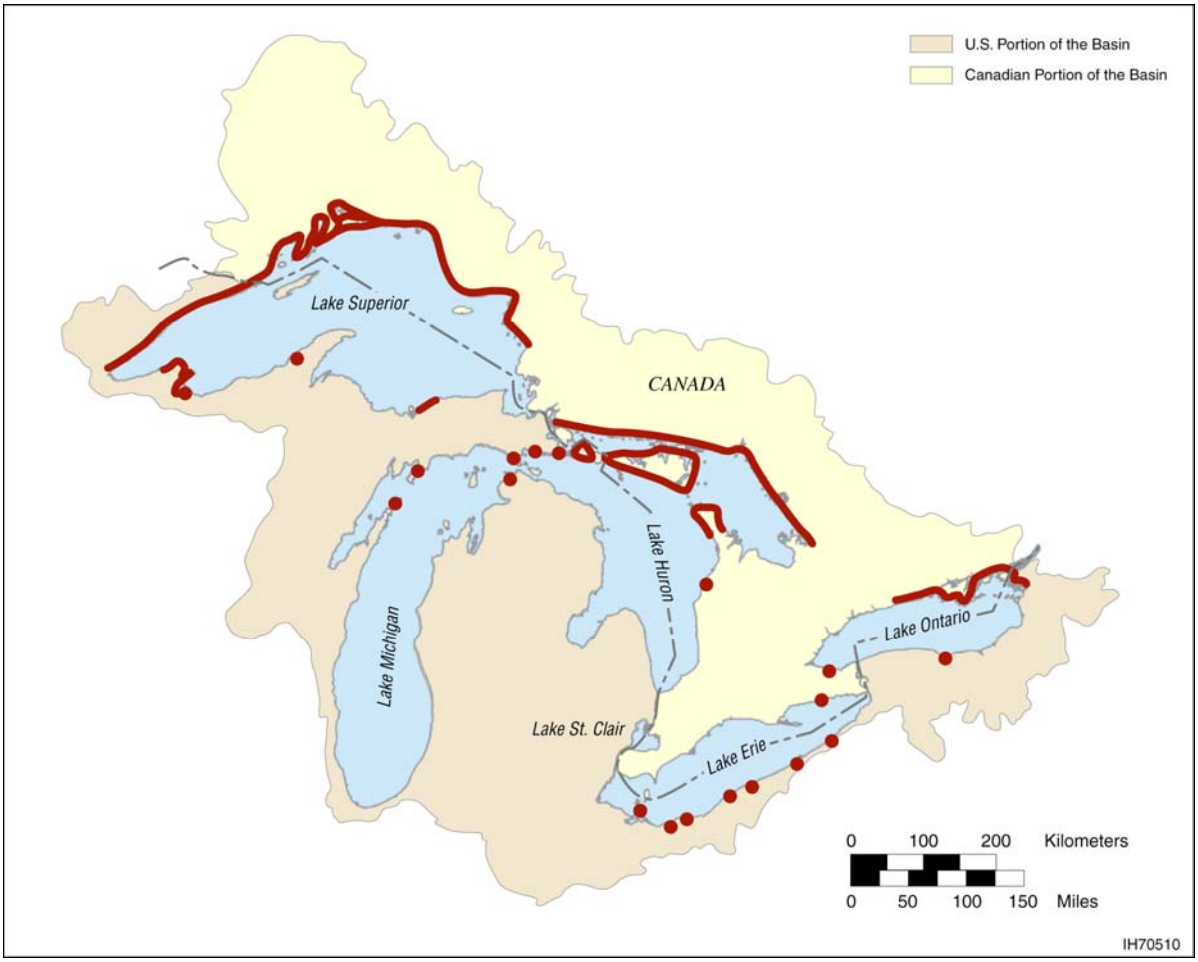

FIGURE 5.14 Great Lakes Bedrock and Cobble Beaches (Sources: Reid and Holland 1987; NOAA 1994)

Before European settlement, the tallgrass prairie extended through the southern Lake Michigan basin in northeastern Illinois and northwest Indiana, throughout the lower peninsula of Michigan and northwestern Ohio to the southeastern part of Ontario. By the late 1800s, most of the lakeplain tallgrass prairie was converted to agricultural use, and today less than 1% of the original prairie peninsula acreage still exists within the Great Lakes Basin (Comer et al. 1995). In Michigan, only about 1,068 acres (433 ha) of lakeplain tallgrass prairie remain. Remnant prairies are located in small fragments in the Saginaw Watershed of Lake Huron, along the southern portion of Lake Michigan in Illinois and Indiana, the extreme western end of Lake Erie in Ohio and Michigan, and the St. Clair River Delta in Michigan (Figure 5.15).

5.2.2.2.5 Sand Barrens. Sand barrens are areas of deep sands with scattered, sometimes scrubby, oak and pine trees and a ground layer of sedges and forbs. "Savannah" is sometimes used interchangeably with "barrens." Barrens, however, are differentiated by their poor, sandy soils and frequent and intense fires (Botts et al. 1994). Barrens are closely associated with other ecosystems such as dunes and prairies. They are dynamic, sometimes open-canopied with prairie-like vegetation; at other times, they are denser and more like woodlands.

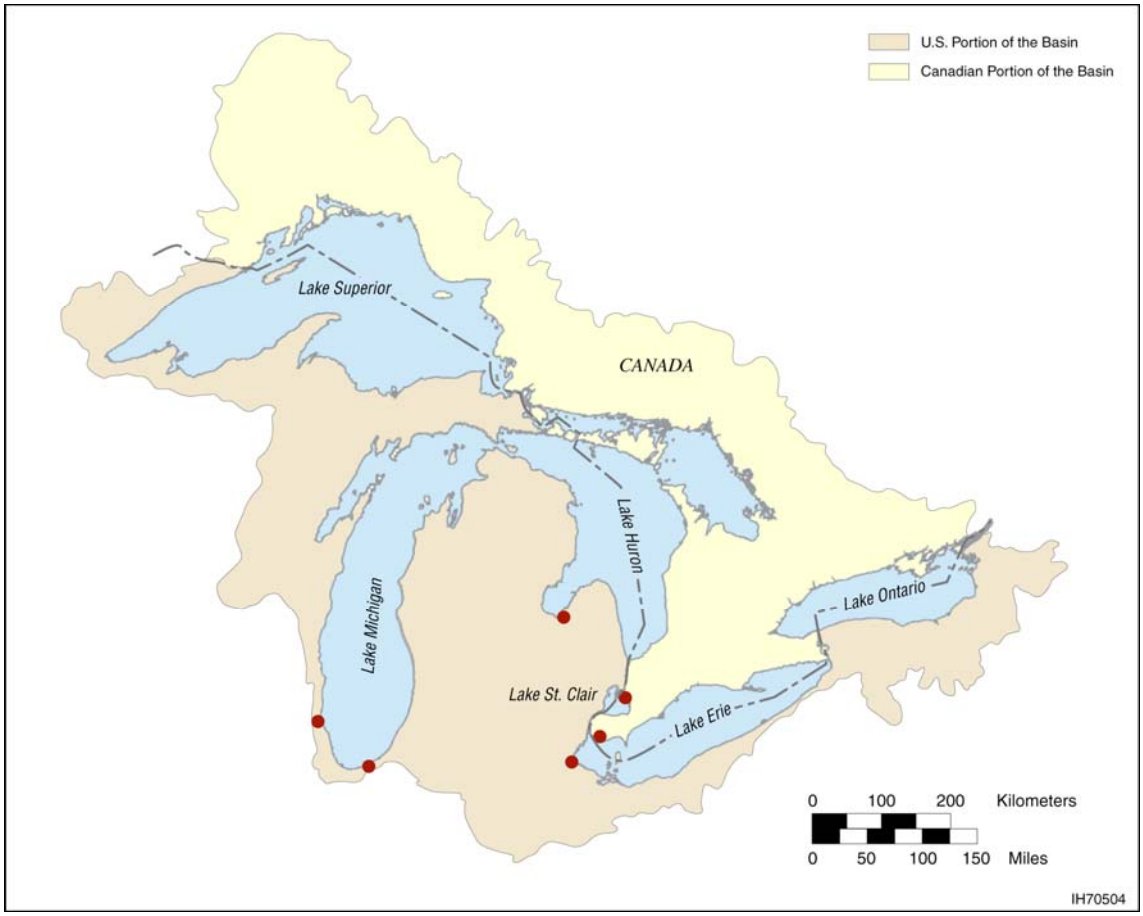

FIGURE 5.15 Great Lakes Lakeplain Prairies (Source: Reid and Holland 1997)

The oak openings of northwestern Ohio near Toledo are examples of oak barrens, much of which have been preserved. They consist of oak communities on dry hills of sandy acidic soils, interspersed with low openings of wet prairie (Forsyth 2003). It is estimated that pre-European jack pine barrens of northern Wisconsin covered about 2.3 million acres (930,000 ha), of which less than 1% remains today (Reid and Holland 1997). Timber harvesting, conversion to agriculture, fragmentation, and fire suppression have been the primary drivers for the loss of this habitat type (Botts et al. 1994). Today, remaining sand barrens associated with the nearshore areas of the Great Lakes are found along the southwestern shore of Lake Superior, around the southern end of Lake Michigan, at the northern tip of the lower peninsula of Michigan, along the Saginaw Bay of Lake Huron, and at the western end of Lake Erie (Figure 5.16).

5.2.2.2.6 Arctic-Alpine Disjunct Communities. As the Wisconsinan glacier retreated, the climate around the Great Lakes gradually changed, and the biota that had adapted to cooler, wetter weather followed the glacier's retreat northward as the southern part of the Basin gradually became warmer and drier. These plants belong to rare arctic-alpine disjunct communities, so called because they are isolated from their primary range which is now located

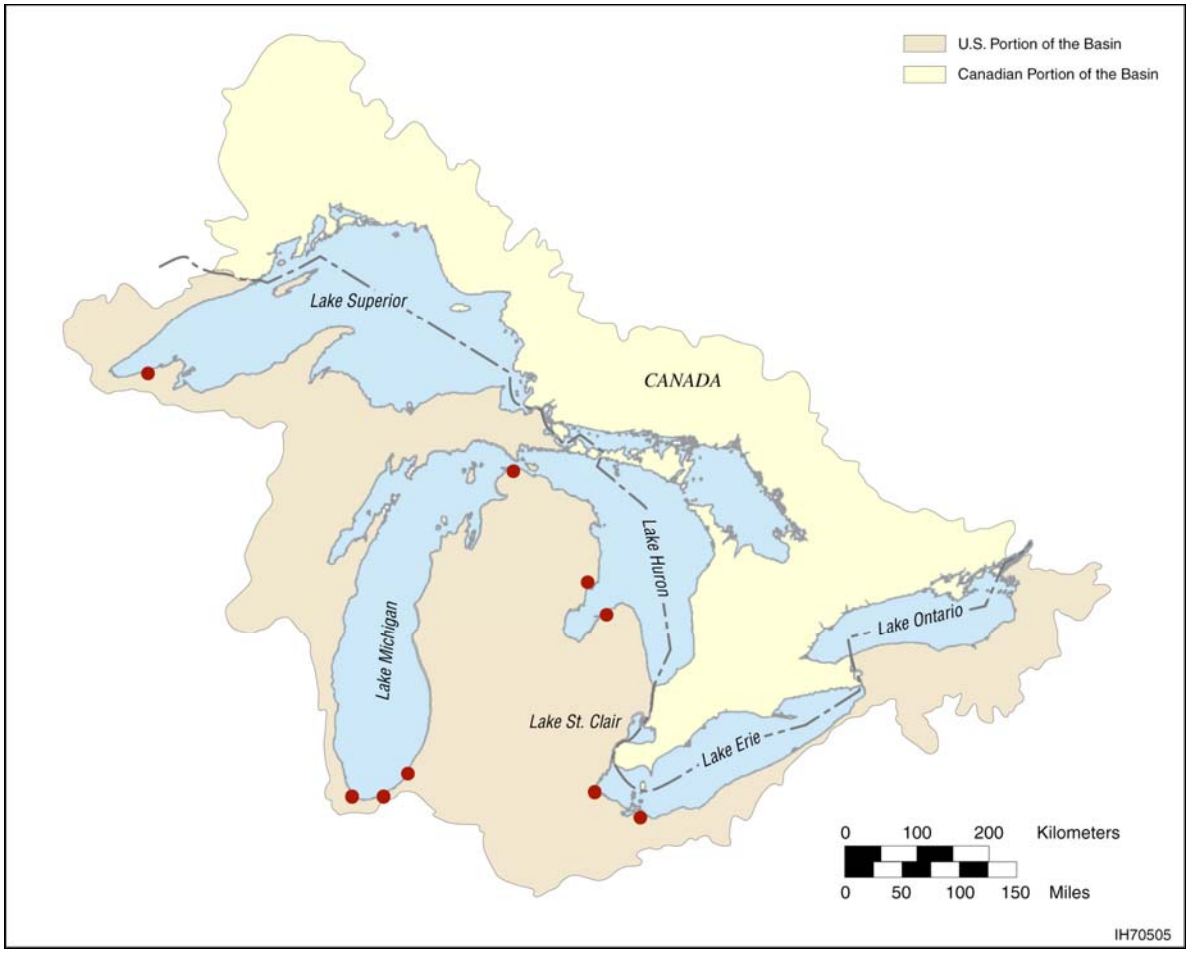

FIGURE 5.16 Great Lakes Sand Barrens (Source: Reid and Holland 1997)

farther north beyond the Great Lakes Basin. In the U.S. portion of the Basin, this type of community is found only in isolated areas on Lake Superior (Figure 5.17) (Reid and Holland 1997).

5.2.2.2.7 Atlantic Coastal Plain Disjunct Communities. In a few lakeplain areas around the Great Lakes, there are communities of plants whose normal distribution lies in a band along the Atlantic coast of the eastern United States. These disjunct species occur primarily on sandy or peaty shores of shallow ponds and small lakes with fluctuating water levels, or sandy, periodically flooded swales near the Greak Lakes (Reznicek 1994). These specialized habitats appear to be relict fragments of previously more extensive sandy shores associated with higher lake levels in the past. These coastal plain species are thought to have migrated into the Great Lakes Basin from the Atlantic coastal plain some 11,000 years ago, dispersing between areas of suitable habitat along major postglacial drainage channels (Reznicek 1994). Atlantic coastal plain communities in the U.S. portion of the Great Lakes are concentrated around the southern end of Lake Michigan and the western end of Lake Erie, with isolated occurrences on the

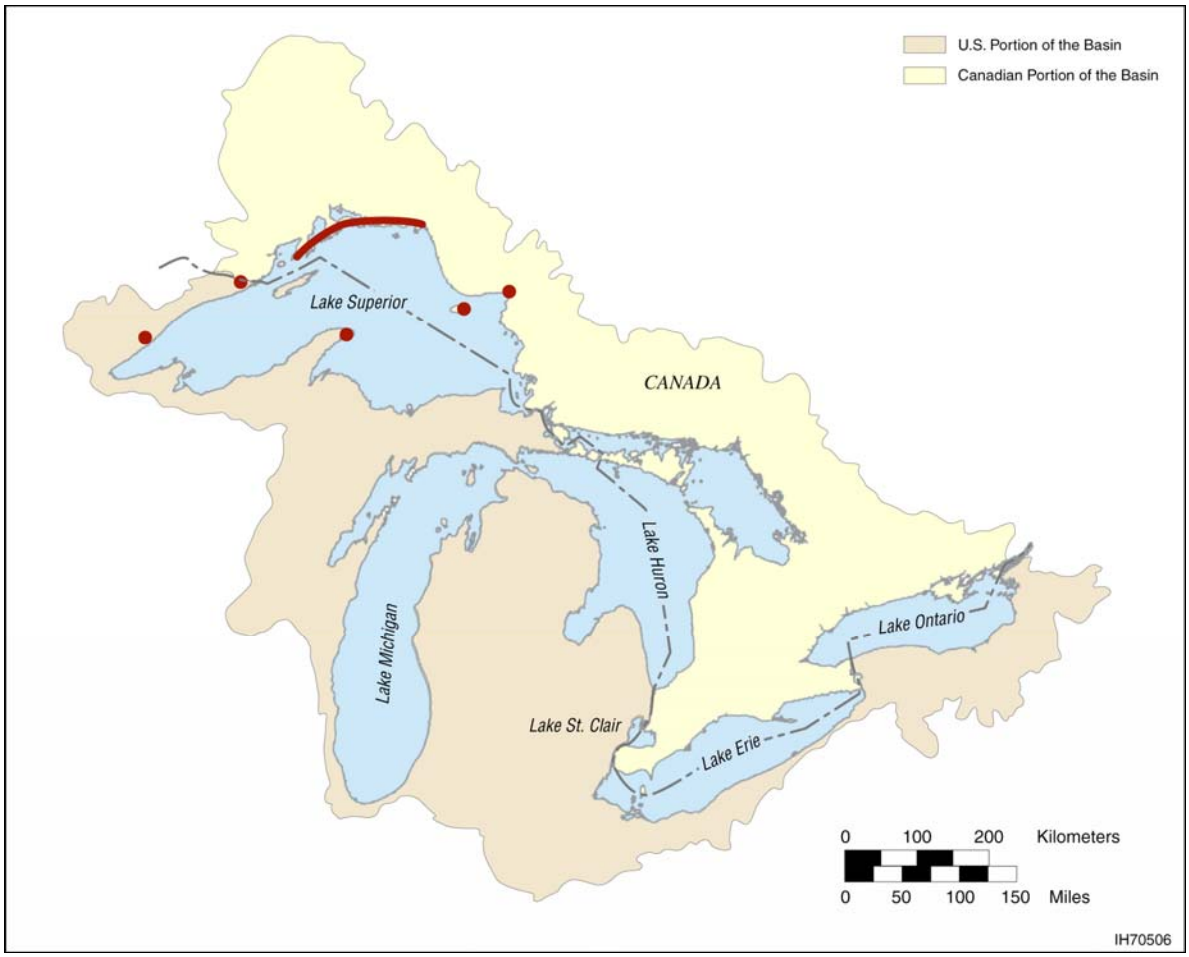

FIGURE 5.17 Great Lakes Artic-Alpine Disjunct Communities (Source: Reid and Holland 1997)

southeastern shore of Lake Superior in the upper peninsula of Michigan and on Lake Huron near Saginaw Bay (Figure 5.18).

5.2.2.2.8 Shoreline Alvars. Alvars are naturally open areas of thin soil over limestone or marble bedrock, which host a distinctive vegetation community, including a considerable number of rare plants. Within North America, alvar systems occur only within the Great Lakes Basin, where they are scattered on the northern shores of Lakes Michigan and Huron along the upper peninsula of Michigan, along the easternmost shore of Lake Ontario in New York, and the western basin of Lake Erie on Marblehead Peninsula and nearby islands (Figure 5.19). While alvar grasslands and savannahs occur at several hundred sites of varying quality, a smaller number are located on or near Great Lakes shorelines in areas of gently sloping limestone bedrock (Catling and Brownell 1995).

Alvar sites undergo periodic flooding followed by drought, and their very shallow soils are subject to high surface temperatures in mid-summer. Alvar habitats support several types of

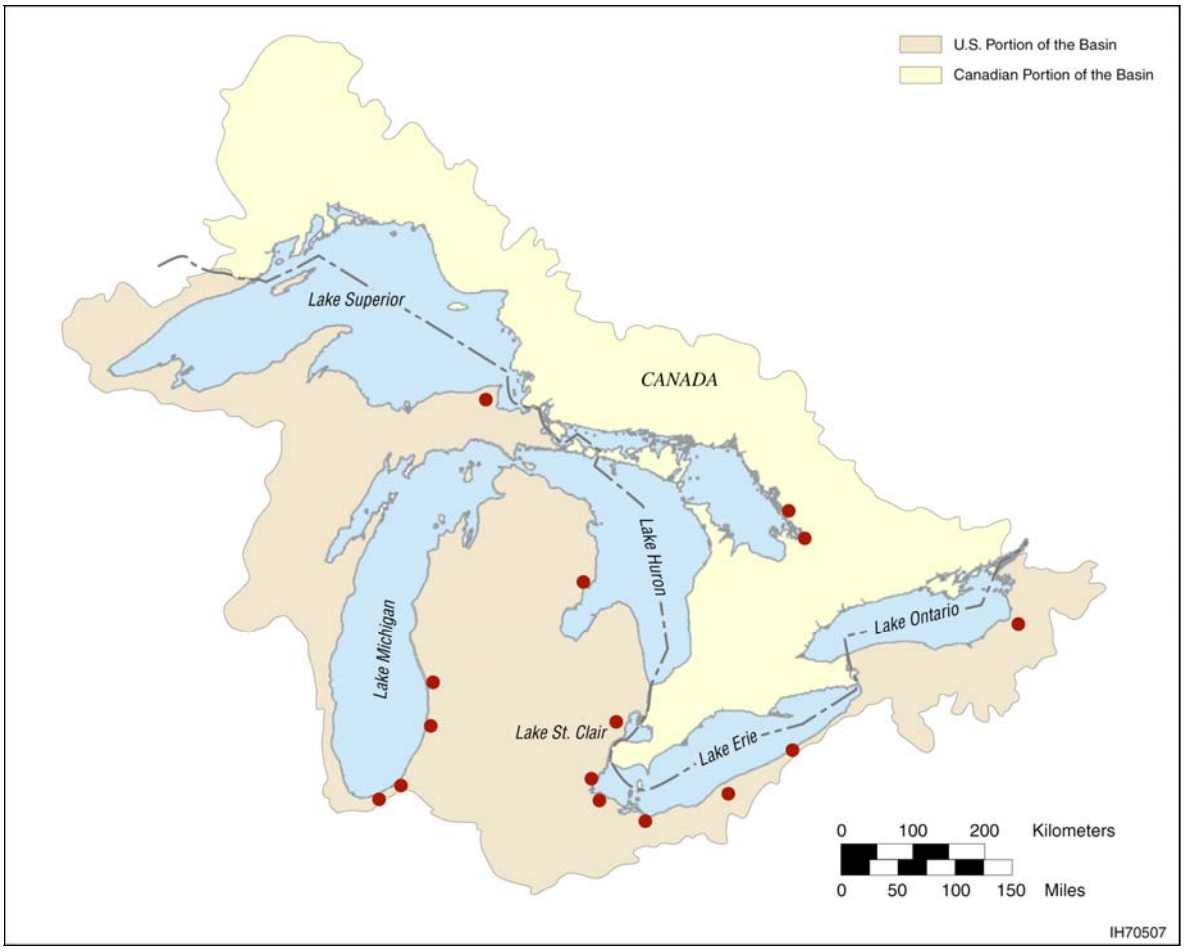

FIGURE 5.18 Great Lakes Atlantic Coastal Plain Disjunct Communities (Source: Reid and Holland 1997)

bedrock pavement, grassland, and savannah communities, which support an unusual blend of boreal and prairie species that appear to be relicts of the cold period following the last glaciers, and of the warmer, drier period that followed (Reid and Holland 1997). One species, the lakeside daisy, occurs nowhere else in the world except on Great Lakes alvars, quarries of Marblehead Peninsula on Lake Erie, and several isolated places in Illinois (DeMauro 1993). Alvars are home to an unusual set of wildlife species as well, including the loggerhead shrike and a large number of distinctive invertebrates such as leaf-hoppers and land snails (Reid and Holland 1997).

5.2.2.2.9 Islands. The Great Lakes contain a large number of islands, up to 35,000 by one estimate (GLIN 2005e). Major groupings of islands in the U.S. waters of the Great Lakes are found in southwestern Lake Superior, northern Lakes Michigan and Huron, western Lake Erie, and eastern Lake Ontario (Figure 5.20). Because of the isolated nature of islands, which tends to simplify wildlife communities and provide protection from predators, the islands serve as important nesting sites for a variety of gulls, cormorants, terns, herons, and egrets (Blokpoel and Tessier 1996). Because the islands tend to have their climates moderated by the surrounding lake

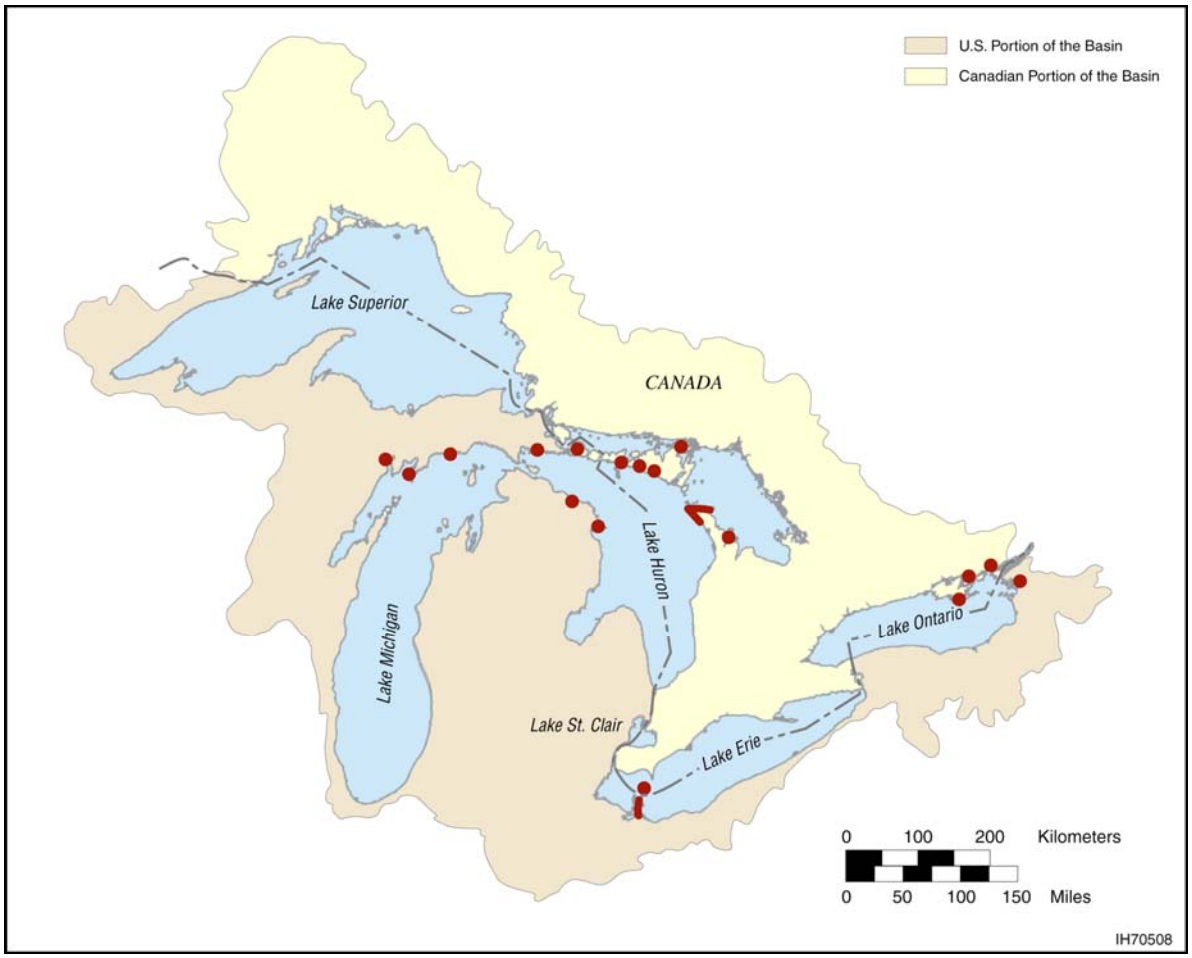

FIGURE 5.19 Great Lakes Shoreline Alvars (Sources: Reid and Holland 1997; Catling and Brownell 1995)

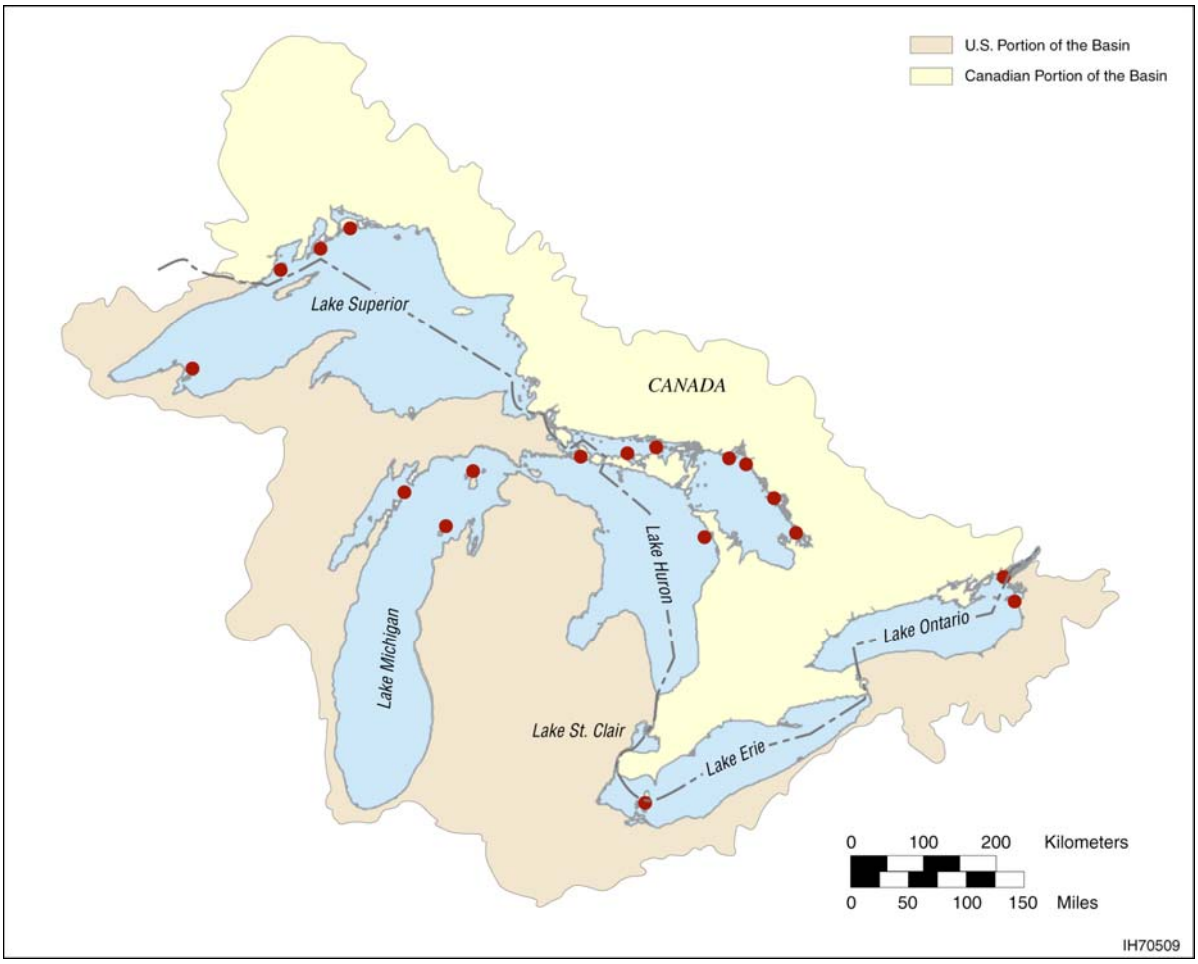

FIGURE 5.20 Great Lakes Island Clusters (Sources: Reid and Holland 1997; NOAA 1994)

waters, many support plant and animal populations that might not be normally expected. For example, the vegetation and wildlife of the western Lake Erie islands is similar to that found much farther south, with such species as shellbark hickory, American lotus, and Carolina wren (McKeating 1989). The Lake Erie watersnake (Federally listed as threatened) is found only on the western Lake Erie Islands.

5.2.3 Inland Habitats and Vegetation

Prior to settlement, most of the inland areas of the Great Lakes Basin consisted primarily of virgin forest habitats in the northern, eastern, and southeastern portions of the Basin and areas of prairie and savannah in the western and southwestern portions (Edsall 1998). Today, these habitats are much less common, with virgin forests occurring only in small protected areas such as parks and reserves. These inland communities have been greatly affected by human activities associated with agricultural and urban development. Table 5.3 summarizes the current nature and extent of inland habitats and vegetation within the U.S. portion of the Great Lakes Basin.

TABLE 5.3 Predominant Inland Habitats and Vegetation of the U.S. Portion of the Great Lakes Basin Ecoregions[a]

Lake Basin	Ecoregion[b]	Predominant Inland Habitats and Vegetation
Superior	Northern Lakes and Forests (20)	Northern coniferous, northern hardwood, boreal hardwood-conifer, and swamp forests (Chaplin et al. 1999a). Forest habitats dominated by aspen-birch, maple-basswood-birch, jack-red-white pine, and spruce-fir-red cedar assemblages (Edsall 1998). Timber harvest and management throughout the region.
Michigan	Northern Lakes and Forests (20)	As described above.
	North Central Hardwood Forests (19)	A mosaic of oak, maple, and basswood forest, savannah, and woodland habitats (Chaplin et al. 1999b). Heavily used for agriculture, with urban development increasing.
	Southeastern Wisconsin Till Plain (18)	Similar to the North Central Hardwood ecoregion, but with greater amounts of grassland.
	Central Corn Belt Plains (17)	Historically a savannah area separating the prairies in the west from the eastern deciduous forests. Contains fragments of savannah, prairie, and woodland habitats (Robinson et al. 1999). Most of the ecoregion is intensively farmed.
	Southern Michigan/Northern Indiana Clay Plains (16)	Mixture of sugar maple-beech and oak-hickory forests, with relict prairie grasslands and oak savannahs (Kavanagh et al. 1999a). Agricultural, urban, and industrial development have heavily impacted habitats in many areas.
	Eastern Corn Belt Plains (14)	Historically similar to the preceding ecoregion; habitats greatly impacted by conversion to agriculture.
Huron	Northern Lakes and Forests (20)	As previously described.
	Southern Michigan/Northern Indiana Clay Plains (16)	As previously described.
	Huron/Erie Lake Plain (15)	Historically similar to the Southern Michigan/Northern Indiana Clay Plains ecoregion; habitats greatly impacted by conversion to agriculture.
Erie	Eastern Corn Belt Plains (14)	As previously described.
Erie	Huron/Erie Lake Plain (15)	As previously described.
	Erie/Ontario Lake Plain (12)	Similar to Huron/Erie Lake Plain. Extensive agricultural, urban, and industrial development. Eastern deciduous forest woodlots dominated by beech and maple.

TABLE 5.3 (Cont.)

Lake Basin	Ecoregion	Predominant Inland Habitats and Vegetation
	Northern Appalachian Plateau and Uplands (13)	Historically dominated by beech and hemlock forests. Agricultural development and timber harvest have resulted in a forest mosaic of beech, hemlock, birch, and pine (Buttrick 1999).
Ontario	Erie/Ontario Lake Plain (12)	As previously described.
	Northern Appalachian Plateau and Uplands (13)	As previously described.
	Northeastern Highlands (11)	Mixed forest habitats of eastern deciduous species such as beech and maple, and boreal forest species such as spruce, pines, birch, and hemlock (Kavanagh et al. 1999b).

[a] See Figure 5.9 and Table 5.2 for ecoregion locations and descriptions.

[b] The numbers in parentheses correspond to the numbered ecoregions shown in Figure 5.9.

5.2.4 Fish and Wildlife

5.2.4.1 Fish

The Great Lakes constitute the second largest freshwater body in the world. Because of its geologic and hydrologic histories, the Great Lakes Basin supports a very diverse fish fauna. The Great Lakes' fish assemblage was derived from three regions during and post-Pleistocene glaciation (Hubbs and Lagler 1958; Underhill 1986) (see Section 5.1.1). Certain species are relicts of arctic and subarctic waters of the northwest that gained access into the Basin via expansive glacial drainage networks. These cold water species include the whitefish and lake trout. Another colonization source was the upper Mississippi River and Ohio River systems. Wide and high stages of Lakes Superior, Michigan, and Erie became confluent with tributaries of the upper Mississippi and Ohio Rivers, thus allowing fish access to the Great Lakes. These warmer water fishes include sunfish and bass, catfish, minnows and shiners, suckers and perches. The third colonization route was via primary outlets to the Atlantic of the St. Lawrence and Hudson-Mohawk River systems. In addition to these colonization routes, several man-made waterways, such as the Welland, Erie, and the Chicago Drainage Canals, have provided additional passageways for fish to enter the Great Lakes Basin or spread within the Basin (Hubbs and Lagler 1958).

Approximately 177 species have been reported within the Great Lakes and their tributaries (Underhill 1986). Of these, native fish account for 153 species, from 64 genera and 25 families (Bailey and Smith 1981). Within the individual lakes, the number of species ranges from 44 in Lake Superior to 99 in Lake Erie (Table 5.4). A large number of species entered the

TABLE 5.4 Number of Fish Species Reported within Each of the Great Lakes and Their Tributaries

Drainage	Number of Reported Species
Lake Superior	44
Tributaries	70
Lake Michigan	78
Tributaries	130
Lake Huron	87
Tributaries	109
Lake Erie	99
Tributaries	122
Lake Ontario	95
Tributaries	118

Source: Underhill (1986).

Great Lakes from the south and east as the glaciers retreated, and still others entered through the St. Lawrence River. Thirty-six species may have entered the Great Lakes Basin from the Atlantic drainage in the east, 134 from the Mississippi drainage in the south and west, and 22 from both drainages (Bailey and Smith 1981).

Adults of many species occur over a range of depths, and the vast majority of species in the Great Lakes use nearshore areas for at least part of the year or part of their lives (Lane et al. 1996). As a result, fish species diversity and biomass is higher in the nearshore than in the offshore and deepwater areas of the Great Lakes (Edsall and Charlton 1997). Most native species spawn in the tributaries and shallow nearshore areas of the lakes; these latter areas also serve as important nursery habitats for many species (Goodyear et al. 1982).

In addition to its species-rich and genetically diverse native fish fauna, the Great Lakes fish community also includes at least 25 introduced species that have become established and have affected native fish communities (Edsall et al. 1995). These introduced species have altered food webs, nutrient dynamics, and the structure and function of not only the native fish communities but also of the invertebrate and algal communities in the lakes. Rainbow smelt, alewife, threespine stickleback, white perch, and sea lamprey invaded the four western Great Lakes via man-made canals such as the Welland Canal. More recent invaders, such as the round goby and the Eurasian ruffe, have been introduced as a result of ballast water release from intercontinental ships. Some introduced species, such as Pacific salmonids and European trout, have had beneficial effects, such as controlling or reducing populations of introduced alewife and rainbow smelt and supporting popular sport fisheries. Some of these species have also had adverse ecological effects by competing with native fishes for food and preying on smaller native fishes. Other species, such as the sea lamprey, have had serious adverse impacts on the populations of some Great Lakes fishes.

5.2.4.1.1 Lake Superior. Because of its location as the northernmost of the Great Lakes and its large size and depth, Lake Superior supports a more abundant coldwater fish fauna than any of the other Great Lakes. The coldwater fauna includes native lake and brook trout, sturgeon, and whitefish. The lake trout fishery, however, is presently maintained by supplemental stocking and natural reproduction from wild fishes (Hansen 1994). Non-native trout and salmon populations support a stable fishery, whereas brook trout and lake sturgeon populations have not recovered from earlier exploitation and are still at low levels. Lake herring numbers are recovering and non-native rainbow smelt are reduced from earlier levels of peak abundance. Deepwater cisco populations have declined, and lake whitefish are abundant and support a productive fishery. The sea lamprey is reduced to about 10% of its former peak abundance due to the use of lampricides and other control measures, but the ruffe is increasing in abundance (Edsall 1998).

5.2.4.1.2 Lake Huron. The fish community of Lake Huron is recovering but remains unstable after decades of over harvest and the effects of introduced species (Ebener et al. 1995). Stocked lake trout are reproducing in the lake, and populations of lake whitefish and deepwater ciscoes are more abundant than at any other time since the turn of the 19th century. Walleye and yellow perch are once again abundant. Non-native rainbow smelt and alewife populations are stable but are still reduced over former peak levels in the 1970s. In the 1980s, the sea lamprey increased in abundance in the northern end of the lake, adversely affecting lake trout in that area (Edsall 1998).

5.2.4.1.3 Lake Michigan. There are 180 native species of fishes found in Lake Michigan and its tributaries, and bordering states have developed world-class salmon and trout fisheries since initial salmon stocking occurred in 1965 (Lake Michigan Forum 2000). This lake supports the largest sport fishery on the Great Lakes, along with small commercial whitefish and yellow perch fisheries (Wisconsin Sea Grant 1998). Efforts to restore the extirpated (locally extinct) lake trout populations have been ongoing for years, and substantial numbers of stocked, breeding-age lake trout are present in lake trout refuges at several locations throughout the lake. Spawning and fry production by stocked fish have been recorded at several locations in the lake, and wild yearling and older lake trout have been found in the lake; however, substantial numbers of adult wild fish have not been produced (Edsall 1998). Pacific salmon abundance is sharply reduced over peak levels reached in the 1970s to the mid-1980s, and populations of two major forage fishes, the alewife and rainbow smelt, have declined considerably since the 1970s (Edsall 1998).

5.2.4.1.4 Lake Erie. Lake Erie has the most fish species of any of the Great Lakes. This lake currently supports the second-largest sport fishery on the Great Lakes and is generally considered to have one of the best walleye fisheries in the world (Wisconsin Sea Grant 1998). However, the abundance of the major forage fish species in Lake Erie (such as rainbow smelt, spottail shiners, emerald shiners, gizzard shad, and alewives) seems to be declining (Edsall 1998). This decline has been attributed to a decline in plankton because of the establishment of the zebra mussel.

5.2.4.1.5 Lake Ontario. In Lake Ontario, the fish community has improved considerably from a low point in the 1960s (Kerr and LeTendre 1991; Ontario Ministry of Natural Resources and NYSDEC 1994). Reductions in nutrients and other pollutants entering the lake brought about major improvements in the lake's overall fish community by the 1980s. Although alewife and rainbow smelt abundance declined in the 1980s, this decline was in response to trout and salmon predation. In the 1990s, stocking of trout and salmon was reduced to bring them into better balance with their food supply. In addition, some native fishes are recovering from low levels observed in the 1960s. For example, lake whitefish, which typically had been most abundant in the eastern end of the lake, were nearly absent there from the catch in the 1970s. In the 1980s, the species began increasing and were 30- to 40-fold more abundant there in the 1990s (Edsall 1998).

5.2.4.2 Amphibians and Reptiles

A variety of amphibian and reptile species can be found within the Great Lakes Basin (Table 5.5). Salamanders, frogs, turtles, and snakes are represented by the greatest number of species, and toads and lizards by the fewest (Edsall 1998). There are also another dozen or more subspecies and hybrids (mostly snakes, salamanders, and frogs, not represented in Table 5.5). The greatest number of species is found in Illinois (63) and the lowest in New York (44). The southeastern Georgian Bay of Lake Huron and the islands of western Lake Erie in particular support an outstanding diversity of amphibians and reptiles (Reid and Holland 1997). The high number of species in Illinois, Indiana, Ohio, and Pennsylvania is remarkable because the areas of those states that are in the Great Lakes Basin are relatively small (Figure 1.1) and have been heavily affected by agricultural, urban, and industrial development. Minnesota and Michigan,

TABLE 5.5 Numbers of Amphibian and Reptile Species in the Great Lakes Region

	Total by State							
Taxa	Minnesota	Wisconsin	Illinois	Indiana	Michigan	Ohio	Pennsylvania	New York
Amphibians								
Salamanders	5	7	10	11	11	15	13	12
Toads	3	1	2	2	2	2	1	4
Frogs	11	11	10	9	10	9	8	11
Reptiles								
Lizards	3	4	4	3	1	1	0	1
Turtles	9	11	14	10	9	8	9	9
Snakes	17	20	23	18	18	20	16	13
Total	48	54	63	53	51	55	49	44

Source: Edsall (1998).

states with large land masses in the Basin, have relatively low numbers of species (48 and 51, respectively) because the climate is generally less suitable for amphibians and reptiles in those states than in the other states in the Basin. Many of the amphibians and reptiles that occur in Minnesota are at the northern end of their range.

Amphibian species that occur throughout the Basin include the eastern newt, eastern red-backed salamander, mudpuppy, American toad, chorus frog, spring peeper, gray treefrog, bullfrog, green frog, pickerel frog, northern leopard frog, and wood frog. Widespread reptile species include the common snapping turtle, painted turtle, common map turtle, smooth green snake, racer snake, rat snake, milk snake, common garter snake, DeKay's brown snake, red-bellied snake, and northern water snake. The lizards have the most restricted distributions, with the greatest number of species occurring in the four westernmost states of the Basin.

5.2.4.3 Birds

Because of the variety of habitats found within the Great Lakes Basin, this area represents one of the richest habitats for breeding birds in North America. Beach areas as well as islands and coastal wetlands provide important stopover areas for migratory shorebirds and waterfowl, and also provide important nesting habitats for a variety of waterfowl, shorebirds, and gulls (Table 5.6). Migratory birds of prey generally do not migrate over open waters; instead, they make use of updrafts from shoreline bluffs to migrate around the Great Lakes. Migratory passerines (songbirds) also make use of shorelines but concentrate at spits and island chains while waiting for favorable weather conditions to cross open waters of some lakes. For example, such areas as Point Pelee in Ontario and the islands in the Port Clinton and Sandusky, Ohio,

TABLE 5.6 Number of Bird Species Reported from the Great Lakes States

State	Species Reported	Waterfowl (Ducks, Geese, Cormorants)	Wading Birds and Shorebirds (Herons, Egrets, Sandpipers)	Gulls and Terns
Minnesota	423	45	37	27
Wisconsin	424	42	52	28
Illinois	430	45	58	36
Indiana	407	41	56	32
Michigan	425	43	53	31
Ohio	412	36	46	18
Pennsylvania	390	39	51	10
New York	332	37	48	25

Sources: Illinois Ornithological Society (2003); Indiana Bird Records Committee (2005); Michigan Bird Records Committee (2005); Minnesota Ornithologists' Union (2005); New York Department of Environmental Conservation (2003); Ohio Bird Records Committee (2003); Pennsylvania Ornithological Records Committee (2005); and Wisconsin Department of Natural Resources (2004).

areas of Lake Erie are renowned North American locations for observing migrating songbirds crossing Lake Erie. The islands of the Great Lakes also provide important nesting habitats for colonial birds such as the ring-billed gull, double-crested cormorant, and great blue heron.

5.2.4.4 Mammals

More than 75 species of mammals have been reported from the Great Lakes Basin, with 28 species widely distributed throughout the Basin (Burt 1967; Kurta 1995). A variety of mice, voles, shrews, and moles occur within the Basin, as well as numerous bat species, such as the little brown bat, keen bat, and silver-haired bat. Larger species of herbivorous mammals found within the Basin include the eastern cottontail, white-tailed deer, moose, and several species of squirrel, while the muskrat and beaver are common and widespread in aquatic habitats (wetlands) in many areas of the Basin. Larger omnivorous mammals are represented by the raccoon, opossum, the red and grey fox, coyote, striped skunk, and black bear. Carnivorous species include badger, wolverine, river otter, bobcat, lynx, marten, fisher, weasel, and grey wolf. Many of these larger species are absent or uncommon from those areas of the Basin where urbanization, industrialization, and agricultural development have occurred.

5.3 RARE, THREATENED, AND ENDANGERED SPECIES

More than 130 species and natural communities have been identified by numerous Federal, state, and local agencies and private organizations (such as The Nature Conservancy) as imperiled (vulnerable to extinction throughout its range) in the Great Lakes Basin. Several of these species are endemic to the Great Lakes. These include the Michigan monkey flower of northern Michigan, Kirtland's warbler of the jack pine habitats of the northern lower peninsula of Michigan (The Nature Conservancy Great Lakes Program 1994), the dwarf lake iris, and ram's head lady's slipper orchid on the shores of Lakes Michigan and Huron (Guire and Voss 1963). Other plants include the moonwort, a dune plant found on Lake Superior (The Nature Conservancy Great Lakes Program 1994), the Lake Huron locust, the lakeside daisy from the shores of Lakes Huron and Erie, and the Pitcher's thistle from beaches and dunes on Lakes Huron, Michigan, and Superior (USFWS 2002).

Table 5.7 identifies the number of species that occur in each of the states that include portions of the Great Lakes Basin and that are listed as threatened or endangered, or candidates for such listing, under the ESA. These species numbers should be viewed with caution, since the numbers listed in this table are for the entire geographic extent of each state, and Michigan is the only state that occurs entirely within the Great Lakes Basin. Minnesota and Wisconsin, which are the Basin states least disturbed by agricultural, urban, and industrial development, contain the fewest Federally listed species.

Species and communities may be rare for a variety of reasons. Many species and communities are at their range limits within the Great Lakes Basin. These include a variety of species associated with boreal forest, tallgrass prairie, or eastern deciduous forest habitats, and

TABLE 5.7 Federally Threatened or Endangered, and Candidate Species Occurring in States That Include Portions of the Great Lakes Basin[a]

	ESA Listing Status					
	Threatened		Endangered		Candidate	
State	Plants	Animals	Plants	Animals	Plants	Animals
Minnesota	3	4	1	5	0	4
Wisconsin	6	3	0	6	0	3
Illinois	8	2	1	15	0	3
Indiana	2	4	2	19	1	3
Michigan	7	3	1	10	0	2
Ohio	5	5	1	14	0	3
Pennsylvania	2	3	1	11	0	3
New York	5	7	1	13	1	2

[a] For each state, the numbers include species that occur within the Great Lakes Basin of the state, and also species that occur within the state but outside of the Great Lakes Basin of that state.

Source: USFWS (2005).

communities such as the Arctic-alpine and Atlantic coastal plain disjunct communities (see Section 5.2.2). Some species and communities may be rare because they occupy habitats, such as sand dunes or sand barrens (see Section 5.2.2), with very limited distributions around the lakes. Finally, some species and communities have become rare because of habitat destruction from agricultural and urban development, overexploitation for human use, and contaminant effects.

5.4 CULTURAL RESOURCES

Cultural resources include archaeological sites and historic structures and features that are protected under the National Historic Preservation Act of 1966 (NHPA), as amended (P.L. 89-665). Cultural resources also include traditional cultural properties, properties that are important to a community's practices and beliefs and are necessary for maintaining the community's cultural identity. Cultural resources refer to both man-made and natural physical features associated with human activity and, in most cases, are finite, unique, fragile, and nonrenewable.

Cultural resources that meet the eligibility criteria for listing on the *National Register of Historic Places* (NRHP) are considered "significant" resources and must be taken into consideration during the planning of Federal projects. Federal agencies are also required to consider the effects of their actions on sites, areas, and other resources (e.g., plants) that are of

religious significance to Native Americans[1] as established under the American Indian Religious Freedom Act (P.L. 95-341). Native American cultural items (e.g., human remains, funerary objects, sacred objects, objects of cultural patrimony) are protected by the Native American Graves Protection and Repatriation Act (P.L. 101-601).

The prehistoric and historic contexts that follow describe the types of cultural resources likely to be present in the Great Lakes region. They are primarily derived from the following sources: Mason (1981), Cleland (1992), and Tanner (1987). Halsey (2002) and Gordon and Malone (1994) also provided background information on underwater archaeology and industrial development in the Great Lakes region, respectively. The ethnohistorical context was developed from Trigger (1978) and O'Leary and Levinson (1991). Additional sources of information regarding the archaeology of each state and portions of Canada adjacent to the Great Lakes are presented in Table 5.8.

Prehistoric Time Periods

Paleo-Indian Period	10,000–8,000 BC
Early Archaic Period	8,000–6,000 BC
Middle Archaic Period	6,000–3,000 BC
Late Archaic Period	3,000–1,000 BC
Early Woodland Period	1,000–300 BC
Middle Woodland Period	300 BC–AD 400
Late Woodland Period	400–AD 1650

5.4.1 Prehistoric Context

The earliest evidence for human occupation of the Great Lakes area occurs circa 10,000 to 8,000 BC, during what is called the Paleo-Indian period, when the glaciers from the last ice age were still in the process of retreating. The Paleo-Indians were nomadic hunters and gatherers who traveled in small bands. Paleo-Indian sites are typically identified by the presence of specific types of stone tools characteristic of the early time period (e.g., fluted points). Formal or ritualized burials are reported for sites dated as early as the late Paleo-Indian period (Buckmaster and Paquette 1988; Deller and Ellis 1984).

During this time period, there were only four lakes rather than the five present today. The region was dominated by Lake Algonquin, which encompassed the area of both present-day Lakes Michigan and Huron. During this time, the glaciers still covered the Upper Peninsula of Michigan and had created Lake Duluth at the western end of the Lake Superior basin. A shallower Lake Erie and a much shallower Lake Ontario were also present. The configuration of the lakes during this time is important for understanding where archaeological sites from this time period may be located. Archaeological sites associated with the Paleo-Indian culture are found, for example, in southern Wisconsin and Michigan in areas well inland from today's shorelines, while other sites from this time period are likely inundated by today's higher lake levels of Lakes Erie and Ontario.

The complete retreat of the glaciers coincided with the development of the Archaic cultural time period (8,000 BC to 1,000 BC). The lakes achieved their lowest water levels during

[1] These acts refer specifically to Native Americans, Native Alaskans, and Native Hawaiians.

the Early Archaic Period (8,000 BC to 6,000 BC), when all five lakes were present. As a result of the low water levels, many archaeological sites from the Early Archaic Period are likely inundated with today's higher lake levels. The Middle Archaic Period (6,000 BC to 3,000 BC)

TABLE 5.8 Additional Archaeological References for the Great Lakes Region

State (or Canadian Province)	Source
Illinois	Bluhm, E.A. (editor), 1959, *Illinois Archaeology*, Bulletin No. 1, Illinois Archaeological Survey, University of Illinois, Urbana, Ill.
	Illinois Association for the Advancement of Archaeology and the Illinois Archaeological Survey, 2004, *Discover Illinois Archaeology*, Illinois Association for the Advancement of Archaeology, Champaign, Ill.
Indiana	Kellar, J.H., 1993, *An Introduction to the Prehistory of Indiana*, Indiana Historical Society, Indianapolis, Ind.
Michigan	Halsey, J.R., 1999, *Retrieving Michigan's Buried Past: The Archaeology of the Great Lakes State*, Bulletin No. 64, Cranbrook Institute of Science, Bloomfield Hills, Mich.
Minnesota	Arzigian, C.M., and K.P. Stevenson, 2003, *Minnesota's Indian Mounds and Burial Sites: A Synthesis of Prehistoric and Early Historic Archaeological Data*, Publication No. 1, Minnesota Office of the State Archaeologist, St. Paul, Minn.
	Johnson, E., 1969, *The Prehistoric Peoples of Minnesota*, Minnesota Historical Society, St. Paul, Minn.
New York	Ritchie, W.A., 1969, *The Archaeology of New York State*, The Natural History Press, Garden City, New York, N.Y.
Ohio	Converse, R.N., 2003, *The Archaeology of Ohio*, Archaeological Society of Ohio, Plain City, Ohio.
Pennsylvania	Kent, B.C., 1994, *Discovering Pennsylvania's Archeological Heritage*, Pennsylvania Historical and Museum Commission, Harrisburg, Pa.
Wisconsin	Birmingham, R.A., et al. (editors), 1997, "Wisconsin Archaeology," *The Wisconsin Archeologist* 78(1–2).
Ontario	Dawson, K.C.A., 1983, *Prehistory of Northern Ontario*, Thunder Bay Historical Museum Society, Thunder Bay, Ontario, Canada.
	Ellis, C.J., and N. Ferris, 1990, *The Archaeology of Southern Ontario to A.D. 1650*, Occasional Publication No. 5, London Chapter, Ontario Archaeological Society.
	Wright, J.V., 1995, *A History of the Native People of Canada*, 2 vols., Paper No. 52, Mercury Series, Archaeological Survey of Canada, Canadian Museum of Civilization, Hull, Quebec, Canada.

had a much warmer and drier climate than previously or than today, and as a result, the pine forests that covered the region during the Early Archaic Period were replaced by hardwood forests. This period is marked by the first use of throwing spears rather than the thrusting spears found in the Paleo-Indian and Early Archaic periods. It is also when ground stone tools are first found in the region as well as evidence of fishing.

During the Late Archaic Period (3,000 BC to 1,000 BC), the glaciers continued retreating, and today's drainage patterns of the Basin became generally established. With these drainage patterns and inflow of glacial meltwater, lake levels increased, and as a result, Lakes Superior, Michigan, and Huron combined into one large lake, Lake Nipissing. The human population of the region during this time became more sedentary. The archaeological sites pertaining to this period are larger in size than those of previous periods and can be found on the remnant shorelines of Lake Nipissing that are still visible along the Great Lakes. The discovery of a dugout canoe in Ohio dating to approximately 1,600 BC at the head of a river that flows into Lake Erie has led researchers to suggest that Archaic peoples pursued waterborne trade in the Great Lakes region (Herdendorf et al. 2004).

At about the time of the next cultural period, the Woodland Period (1,000 BC to AD 1650), lake levels lowered, and Lake Algoma was formed. Like the Lake Nipissing shoreline, the Lake Algoma shoreline is still evident today in some areas. Archeological sites from the Early Woodland Period (1,000 BC to 300 BC) found along the old Lake Algoma shoreline contain the first pottery ever found in the Great Lakes and show evidence of the first limited use of domesticated plants. The Great Lakes achieved their current configuration at the beginning of the Middle Woodland Period (300 BC to AD 400) (Mason 1981). The Middle Woodland Period is dominated by the Hopewell and related cultures best known for the burial mounds that are found from western New York to Minnesota in the North and East, Florida and Louisiana in the South, and Missouri in the West. This period is also notable for the expansion of a trade network begun no later than the Middle Archaic that brought a wide range of exotic materials to the Midwest from areas as geographically remote as Wyoming and Florida. The cause for the collapse of the Hopewell culture and the ending of long-distance trade is currently unknown, but these events mark the beginning of the Late Woodland Period (400 to AD 1650). The Late Woodland Period is also defined by the appearance of the bow and arrow, horticulture, an increase in the presence of sedentary communities, and opportunities for a steadier and more diversified diet (Cleland 1992). Archaeological sites from this and later periods are found along the shorelines of each of the modern Great Lakes.

It should be noted that the transition to the Woodland culture is not found in the northern parts of Michigan, Wisconsin, and Ontario. The northern region continues a culture more consistent with the Archaic way of life until AD 1. This has been attributed to the colder climate found in the northern portions of the Basin. Agriculture was difficult in the northern areas because the soils were sandy, there was insufficient rainfall, and the minimum requirement for several crops of 140 frost-free days did not occur (although they did cultivate 90-day corn); therefore, many of the advancements associated with the Woodland culture did not occur in the northern portions of the Great Lakes Basin. When pottery was introduced to the northern regions in 100 BC, the resulting tradition is referred to by archaeologists as Laurel. Laurel sites are

associated with increased fishing for subsistence and are found near the mouths of rivers. The Laurel tradition persisted until the European contact period in AD 1600.

The arrival of Europeans after AD 1600 increased the knowledge of Native American cultures of the Basin and also brought about significant changes to those cultures. The eastern Great Lakes were home to the Iroquois-speaking people. The Iroquoian groups lived around Lakes Erie and Ontario, and the eastern side of Lake Huron, and included the Mohawk, Oneida, Onondaga, Cayuga, Seneca, Susquehannock, Erie, Neutral, Parker, and Huron/Petun Tribes. The largest group of Native Americans were the Algonquin-speaking tribes that lived in the Lower and Upper Peninsulas of Michigan, Indiana, and northern Wisconsin. Most of central Wisconsin consisted of the Siouxian-speaking Oneota group that includes the Winnebago Tribe.

The many smaller western Native American groups became condensed after a series of Iroquois raids during the 1640s. These raids were an attempt to revitalize the Iroquoian groups that had been devastated by disease brought by the Europeans. Native American warfare often involved the taking of hostages who would be integrated into the group. After these raids by the Iroquois, several mixed groups, formed by Tribes taking in various refugees, emerged. The affected American groups included the Ojibwa (Chippewa), Ottawa, Potawatomi, Miami, Shawnee, Sauk, Fox, Wyandot, and Menominee. The Iroquois continued to live in the Lake Ontario and Lake Erie areas; the Potawatomi in southern and eastern Michigan; the Ottawa in western Michigan; the Menominee and Winnebagos in northeastern Wisconsin; and the Sauk and Fox in central Wisconsin.

5.4.2 Historic Context

During the European era, control and ownership of the Great Lakes were disputed between the French and the English. The first French outpost that was instrumental in exploring the Great Lakes was Quebec, established by Cartier in 1608. From this outpost, Champlain reached Lake Huron in 1616. The French traded extensively with the Huron and the Ottawa tribes for furs, a prized commodity for the Europeans. Several traders and explorers investigated the Great Lakes in the 1620s and 1630s. The French began establishing missions in the region after the Iroquois wars. A key mission was established at the Straits of Mackinac in 1671 by Father Jacques Marquette at present-day St. Ignace, Michigan. French influence in the western Great Lakes continued throughout the late 1600s and early 1700s.

English outposts were first established on the east coast of the North American continent in the 1590s. English traders established contacts with the Iroquois by the mid-1600s and attempted to take control of the fur trade in the western lakes. Tensions between the French and British culminated in the French and Indian War (1756 to 1760), and Native American groups were divided between the two European powers during this war. Groups from the eastern lakes allied with the English, and those from the western lakes allied with the French. The war ended with the Treaty of Paris in 1763, which granted possession of the entire Great Lakes region to the British. British control of the Great Lakes lasted only 20 years. The American Revolution (1776 to 1781) ended with the southern Great Lakes region being ceded to the United States of America by the Treaty of Paris of 1783. British garrisons remained in portions of the

Great Lakes until Jay's Treaty of 1794, which required the removal of the outposts by 1796 (Tanner 1995). British desires to control the entire Great Lakes continued until the War of 1812 between the British and the Americans. Several crucial battles were undertaken on forts located on both Lakes Erie and Ontario, at Mackinac Island in Lake Huron, on the River Raisin, Monroe County, Michigan, as well as naval battles on Lake Erie. Hostilities ended in 1815 with the Treaty of Ghent, whereby the British relinquished all claims on the southern half of the lower Great Lakes.

During the early American period (1795 to 1836), a series of treaties was signed ceding Native American lands around the Great Lakes to the United States. Most of the southern portions of Lakes Erie and Ontario were ceded by 1805. Most of the land around Lakes Michigan and Huron were ceded between 1821 and 1836. The last portion ceded was the western portion of Lake Superior in 1854.

Industrial development in the Great Lakes was centered on shipping and the exploitation of natural resources. The opening of the Erie Canal in 1825 connected the large eastern markets and the international ports on the east coast to the Great Lakes system and greatly hastened settlement in the Great Lakes region. In addition, the opening of the Soo Locks (originally known as the St. Marys Falls Canal) in 1855 provided a passage for ships around the St. Marys Rapids. The St. Marys River is the only waterbody connecting Lakes Superior to Lakes Michigan and Huron, and in the section of the St. Marys Rapids there is a drop of 21 ft from the level of Lake Superior to the other lakes. This drop was not navigable without the construction of the canal and locks.

Timber, iron, and copper from the upper Great Lakes provided the natural resources needed by the growing nation. This was augmented by the coal deposits from Pennsylvania and West Virginia. Access to raw materials allowed the cities of Chicago, Detroit, Cleveland, and Buffalo to grow dramatically. These cities grew at ever-increasing rates because of the (1) maritime opportunities for moving immigrant populations and for transporting minerals and other trade goods, and (2) expanding railroad networks that connected these towns to the remainder of the nation. Large influxes of foreign workers during the mid- and late-19th century provided a steady workforce to feed the growing economy around the Great Lakes. By the late-1800s, the railroad networks had expanded to the upper Great Lakes, thereby lessening the cost of transporting raw materials and reducing the risk posed by shipping across the lakes.

The 20th century saw the continued rise of heavy industry and the birth of the assembly line system for mass manufacturing. Steel mills and factories located at major ports around the lakes from Buffalo to Chicago fueled the continued expansion of the nation. These industries continued to expand throughout the 20th century. Not until the late 20th century would a decline begin throughout these large industrial lake towns.

5.4.3 Archaeological Sites, Historic Structures, and Traditional Cultural Properties

Knowledge of the location and number of cultural resources across the Great Lakes Basin varies from state to state (Table 5.9). It is likely that completed surveys along the coasts have

been concentrated on land owned by the Federal government, including several national lakeshores and national forests. Most of these areas are situated in the sparsely populated northern portion of the Great Lakes. Many significant historic period forts, industrial sites, and lighthouses have been identified, and some are undergoing preservation efforts at a national, state, or local level. Surveys for underwater cultural resources also vary from state to state.

TABLE 5.9 Approximate Numbers of Recorded Archaeological Sites in Coastal Counties[a]

State	Number of Coastal Counties	Total Number of Recorded Archaeological Sites
Illinois	2	1,829
Indiana	3	1,522
Michigan	42	10,948
Minnesota	4	3,980
New York	9	NA[b]
Ohio	7	2,745
Pennsylvania	1	310
Wisconsin	15	5,758
Total	83	More than 27,000

[a] As of July 22, 2005, these are the total site counts as reported by individual State Historic Preservation Offices (SHPOs).

[b] NA = not available.

Michigan has recorded 1,438 shipwrecks in its state databases. Underwater resources in the state also include inundated terrestrial sites, dugout canoes, shipping freighters, and World War II fighter planes in Lake Michigan. Ohio has also identified approximately 2,000 shipwrecks in Lake Erie and several have been documented archaeologically.

Consultations with Native American governments with historic ties to the region would be required to determine the presence of traditional cultural properties, since these locations are not necessarily recorded. Several reservations abut the coast of the Great Lakes.

Because information on archaeological sites is protected and is not, in general, publicly accessible, it is not possible to fully discuss the numbers and locations of sites or surveys conducted within the Great Lakes Basin; it is also not practical given the extent of the area. When needed (i.e., at a site- and project-specific level), the relevant information may be obtained

by an archaeologist through the appropriate State Historic Preservation Offices (SHPOs). The NRHP lists historic structures by address and some archaeological sites, but it does not sufficiently characterize the range of sites present and eligible for listing (many eligible properties may not have been nominated to the NRHP). Traditional cultural properties, sites of significance to Native Americans, are also not common knowledge, and acquiring information about them may even be difficult for site-specific projects. Government-to-government consultation is required by the project's lead agency under Section 106 of the NHPA in order to determine if development could impact areas significant to Native American cultures (this government-to-government consultation is not the responsibility of the SHPO).

5.5 LAND AND WATER USE

5.5.1 Land Use

Land use patterns across the Great Lakes Region are broadly characterized by industrialization, a number of large urban centers (>100,000 population), agricultural development, recreation, some residential development, and hardwood and conifer forests (Table 5.10).

TABLE 5.10 Land and Shoreline Uses in the Great Lakes, 1985

		Percent of Lake				
		Superior	Michigan	Huron	Erie	Ontario
Basin land use	Agricultural	6	44	40	63	33
	Residential	3	9	6	12	8
	Forest	80	41	52	23	53
	Other	11	6	2	2	6
Shoreline use	Residential	NA[a]	39	42	45	40
	Recreational	NA	24	4	13	12
	Agricultural	NA	20	15	14	33
	Commercial	NA	12	32	12	8
	Other	NA	5	7	16	7

[a] NA = not available.

Source: EPA and Government of Canada (1995).

The northern areas have colder climates, poor soils for farming, and are heavily forested. The more northern locations were previously characterized by industrial development in the latter parts of the 19th and early 20th centuries for their timber and metal deposits. Exploitation

of these resources largely ceased by the middle of the 20th century and resulted in the land reverting to the government. The southern areas have a warmer climate and good farming soils.

The southern portion of the lakes experienced development as early as the 17th century, which has continued to expand at increasing rates. The major urban areas on the southern lakes include Chicago, Detroit, Toledo, Cleveland, Buffalo, and Rochester. Much of the population of the Great Lakes is concentrated around the major urban centers such as Chicago, Detroit, Milwaukee, Cleveland, and Buffalo (Figure 5.21). The Great Lakes states include

Great Lakes Population

- Approximately 25 million people reside within the U.S. portion of the Basin.
- The Coastal Basin population accounts for about 17% of the total U.S. coastal population.
- Coastal Basin population densities range from 22/mi^2 in Minnesota to more than 4,000/mi^2 in Illinois.
- In 1988, the Basin coastal areas had the highest population density per mile (3,835) of any coastal area in the United States
- Most of the population is within 11 major metropolitan areas.

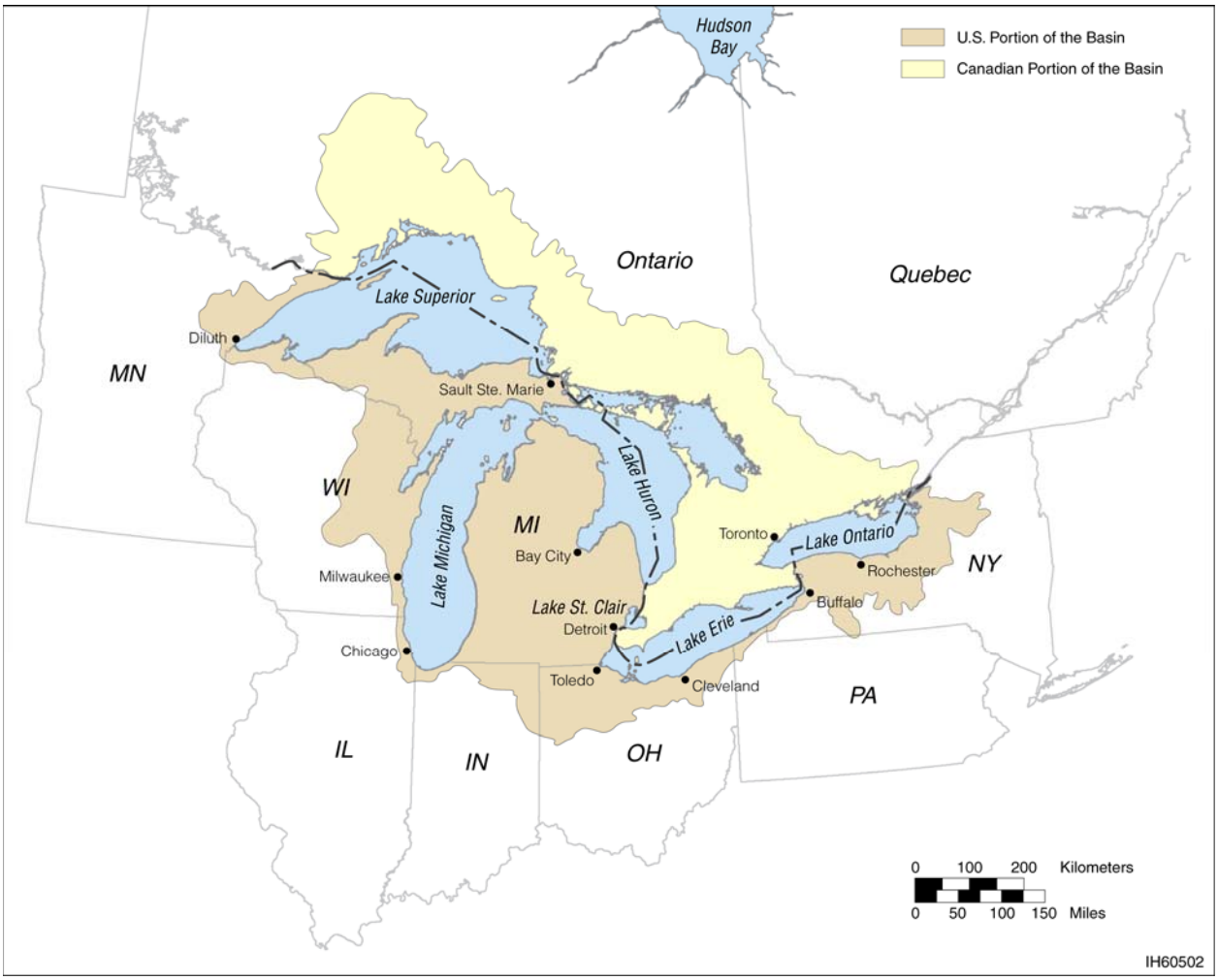

FIGURE 5.21 Major Urban Centers on the Great Lakes Basin

83 coastal counties with approximately 19 million residents, representing about 17% of the total U.S. coastal population. Coastal population density varies within the Basin, from a low of 22 people per square mile in Minnesota to more than 4,000 people per square mile in Illinois (Thorp et al. 1997). On the basis of shoreline mile, the Great Lakes shoreline counties in 1988 had the highest average number of persons per mile (3,835) for a major coastal area in the United States; Illinois' two coastal counties (Cook and Lake) lead the nation with more than 91,000 people per mile of shoreline.

Recreational opportunities are present throughout the Great Lakes region in the form of national forests, lakeshores, and wildlife refuges; national, state, and local parks (Figure 5.11); water-based activities such as fishing; and resort and vacation developments.

Common land use patterns are present throughout the region; however, each lake region has its own balance of land uses. Within the Basin states, land use patterns also differ dramatically on the basis of whether a particular land use occurs in a coastal or inland location (Table 5.10). The following sections discuss land use on a lake-by-lake basis.

State and National Parks in the Great Lakes

- 678 State Parks, 110 directly on the coast.
- Apostle Islands National Lakeshore, Lake Superior
- Cuyahoga Valley National Park, Lake Erie
- Indiana Dunes National Lakeshore, Lake Michigan
- Isle Royale National Park, Lake Superior
- Pictured Rocks National Lakeshore, Lake Superior
- Sleeping Bear Dunes National Lakeshore, Lake Michigan
- Thunder Bay National Marine Sanctuary and Underwater Preserve, Lake Huron
- Great Lakes Underwater Bottomland Preserves, Lakes Michigan and Huron

5.5.1.1 Lake Superior

The majority of the land along the U.S. shoreline of Lake Superior is mixed hardwood/conifer forest, a portion of which is actively managed for timber production. The region contains large tracts of U.S. Forest Service land, two national lakeshores (Apostle Islands and Pictured Rocks) managed by the National Park Service, and one National Park (Isle Royale). Agriculture is limited by a short growing season. The primary U.S. metropolitan area on Lake Superior is Duluth, Minnesota, located at the far western end of the lake. The smaller communities of Marquette and Sault Ste. Marie in Michigan are located on the middle and eastern part of the lake. Some recreational development has occurred along the shore but in smaller amounts than that found on the other Great Lakes. Several fishing communities are present on the southern shore of Lake Superior.

5.5.1.2 Lake Michigan

Lake Michigan has approximately 1,600 mi (2,575 km) of coastline. Disparate land use patterns are evident in the high level of urban and industrial development along the southern Lake Michigan coast in Illinois and Indiana and the largely forested and sparsely populated northern half of the lake. Roughly 45% of the Illinois and Indiana coastline consists of urban development. The Door Peninsula and the Milwaukee region are the two urbanized portions of

Wisconsin's coastline; elsewhere, much of Wisconsin's Lake Michigan shoreline consists of agricultural lands used for crops or livestock. The Michigan coastline is marked by extensive sand beaches, which has led to recreational development in the form of resort towns and vacation communities. Many of these resort areas have experienced recent increases in residential construction. For example, the northwest coast of the Lower Peninsula has undergone rapid development. Development of specialized fruit crops in some areas, such as cherries and grapes in the Traverse Bay area, have sparked specialized regional economies. The northern coast of Lake Michigan was previously used for mining and timber industries. However, much of the land previously used for industrial purposes is now held by the Federal government (primarily the U.S. Forest Service). Recreational development is increasing slightly on the north shore of Lake Michigan, but the harsher climate has somewhat restricted this development. Sleeping Bear Dunes National Lakeshore is located on northern Lake Michigan.

5.5.1.3 Lake Huron

Lake Huron has the largest amount of shoreline of any of the Great Lakes. The majority of Lake Huron's 3,350 mi (5,391 km) of shoreline is in Canada. The Lake Huron shoreline in the United States is in Michigan (934 mi [1,503 km]) and is one of the least-developed shorelines of the Great Lakes. Lake Huron's Manitoulin Island is the largest freshwater island in the world. No major metropolitan areas are located on Lake Huron; the largest cities are Saginaw and Bay City, each with populations under 100,000. Much of the northern coast is forest with agricultural development increasing in the southern portions of the lake. Agricultural land is split between cropland and livestock pasture. Rural development is concentrated along the coast and consists primarily of recreational development with some fishing communities. The Thunder Bay National Marine Sanctuary and Underwater Preserve is located in northern Lake Huron.

5.5.1.4 Lake Erie

Land use around Lake Erie is primarily agricultural with several large metropolitan areas located on the U.S. side of the lake. The largest cities within the Lake Erie subbasin are Detroit, Toledo, Cleveland, and Buffalo. These cities are found at or adjacent to major rivers. Lake Erie supports a large fishing industry and a considerable sport-fishing economy. Unlike Lakes Michigan and Huron, the agricultural development in the Lake Erie portion of the Great Lakes Basin consists almost solely of cropland. Orchards and vineyards are important along the southeastern shore of Lake Erie. Cuyahoga Valley National Park is located on Lake Erie just south of Cleveland. Perry's Victory and International Peace Memorial is located on Lake Erie, as is Old Woman Creek National Estuarine Research Reserve.

5.5.1.5 Lake Ontario

Lake Ontario land use patterns are more similar to those found on Lake Michigan rather than Lake Erie. Agriculture dominates, with the major metropolitan areas being Rochester, Syracuse, and Oswego, all in New York. The largest metropolitan area on Lake Ontario is in

Canada (Toronto area). Agricultural land use is split between cropland and livestock pasture land with some areas along the southern shore supporting orchards and vineyards. Areas of forest are found along Lake Ontario as well, primarily along the northeast coast of the lake and in portions of the southern and eastern parts of the lake.

5.5.2 Water Use

The waters of the Great Lakes Basin are used for a variety of purposes, including public water supply, agricultural irrigation, industry, energy production, and recreation. The vast majority of Great Lakes water use is for hydroelectric energy generation. The percentage of water within the Basin used for these different activities varies by state and lake. Total water use in the United States in 2000 has been estimated at approximately 408 billion gal/d (1,544 billion L/d), with the Great Lakes states accounting for approximately 18% (73 billion gal/d [276 billion L/d]) of that total daily use (Hutson et al. 2004). Both surface and groundwater sources are used, although the surface waters of the Great Lakes represent the bulk of water used within the Basin. Great Lakes water use is projected to increase over time as a result of population growth, increasing water diversions, and climate change. In the U.S. portion of the Basin, the average per capita water use increased approximately 10% from 1985 to 1995 (EPA 2003b). The following subsections discuss the major water uses that occur within the Great Lakes Basin.

5.5.2.1 Public Drinking Water Use

Public drinking water supplies within the Great Lakes Basin use both surface and groundwater, with surface water withdrawn directly from the Great Lakes representing the primary public drinking water for the majority of the 33.5 million U.S. and Canadian inhabitants of the Basin. Among the Great Lakes states, Minnesota uses the least amount of Great Lakes surface water for its public drinking water supply, and Illinois the greatest amount (Table 5.11).

Among the lakes themselves, Lakes Erie and Michigan in 2000 provided the greatest amount (1,189 and 1,572 Mgal/d [4,500 and 5,950 million L/d, respectively]) of water for the public drinking water supply (Table 5.12). The large contribution of Lakes Erie and Michigan is directly related to the many large metropolitan areas located on the shores of these lakes, including Chicago, Milwaukee, Cleveland, Toledo, and Buffalo. In contrast, Lakes Superior and Huron provide the least amount of water for the public drinking water supply (71.4 and 265.7 Mgal/d [270 and 1,006 Mgal/d], respectively) (Table 5.12). These much smaller contributions to public drinking water supplies are related to the much smaller populations that reside around these lakes.

5.5.2.2 Agricultural Water Use

Agricultural water in the Great Lakes Basin includes water used for crop irrigation and watering livestock. As used in this report, agricultural water also includes irrigation water used

TABLE 5.11 Daily Water Withdrawals in 2000 within the Great Lakes Basin, by State, for Public Drinking Water Supply

	Withdrawals (Mgal/d)[a]			
State	Great Lakes Surface Water[b]	Other Surface Water	Groundwater	Total
Illinois	1,095.8	0	0	1,095.8
Indiana	95.1	36.3	56.7	188.1
Michigan	875.7	20.5	247.0	1,143.5
Minnesota	32.8	3.0	4.76	40.5
New York	383.6	285.8	50.4	719.9
Ohio	430.5	129.8	36.3	596.6
Pennsylvania	40.8	1.8	2.1	44.7
Wisconsin	260.6	25.1	83.1	368.8

[a] To convert gallons to liters, multiply by 3.785.

[b] Includes withdrawals from connecting channels (the St. Clair River, the Detroit River, the Niagara River, and the St. Marys River) and the St. Lawrence River.

Source: GLC (2004a,b).

TABLE 5.12 Daily Water Withdrawals in 2000 within the Great Lakes Basin, by Lake, for Public Drinking Water Supply

	Withdrawals (Mgal/d)[a]			
Lake	Great Lakes Surface Water[b,c]	Other Surface Water	Groundwater	Total
Superior	71.4	16.0	20.9	108.3
Michigan	1,571.7	28.0	293.0	1,892.7
Huron	265.7	24.3	49.8	339.8
Erie	1,188.8	286.2	150.1	1,625.1
Ontario	597.8	231.3	49.9	878.9

[a] To convert gallons to liters, multiply by 3.785.

[b] Includes withdrawals from connecting channels (the St. Clair River, the Detroit River, the Niagara River, and the St. Marys River) and the St. Lawrence River.

[c] Includes Canadian withdrawals.

Source: GLC (2004a,b).

for maintaining recreational lands such as parks, golf courses, and baseball fields. Among the Great Lakes states, New York and Michigan have the greatest daily water withdrawals (7.2 and 4.1 Mgal/d [27.3 and 15.5 million L/d], respectively) for agricultural use from the Great Lakes (Table 5.13). In contrast, withdrawals of Great Lakes surface water for agricultural use do not occur in Illinois, Indiana, Pennsylvania, and Wisconsin.

TABLE 5.13 Daily Water Withdrawals in 2000 within the Great Lakes Basin, by State, for Agricultural Use

	Withdrawals (Mgal/d)[a]			
State	Great Lakes Surface Water[b]	Other Surface Water	Groundwater	Total
Illinois	0	0	0	0
Indiana	0	8.6	24.5	33.1
Michigan	4.1	69.0	128.3	201.4
Minnesota	0.7	0.3	0	1.0
New York	7.2	2.0	13.4	22.6
Ohio	0.2	13.2	17.0	30.0
Pennsylvania	0	0.3	0.1	0.4
Wisconsin	0	1.9	74.4	76.2

[a] To convert gallons to liters, multiply by 3.785.

[b] Includes withdrawals from connecting channels (the St. Clair River, the Detroit River, the Niagara River, and the St. Marys River) and the St. Lawrence River.

Source: GLC (2004a,b).

Among the individual Great Lakes, Lakes Huron and Ontario have the greatest surface water withdrawal (5.4 and 5.0 Mgal/d [20.4 and 18.9 million L/d], respectively) for agricultural water use, while Lake Superior supplies the least amount of water for agricultural use (Table 5.14).

5.5.2.3 Industrial Water Use

Industrial water includes water used in the manufacture of metals, chemicals, paper, and allied products, as well as water used in mining to extract or wash ores and minerals. Indiana withdraws the greatest amount of Great Lakes surface water (1,397.9 Mgal/d [5,281.6 million L/d]) for industrial use (Table 5.15), in large part because of the extensive steel and manufacturing industry located in the northeastern corner of the state. In contrast, Wisconsin and Illinois withdraw the least amount of Great Lakes surface water (1.6 and 19.7 Mgal/d [6.1 and 74.6 million L/d, respectively]) for industrial use.

TABLE 5.14 Daily Water Withdrawals in 2000 within the Great Lakes Basin, by Lake, for Agricultural Use

	Withdrawals (Mgal/d)[a]			
Lake	Great Lakes Surface Water[b,c]	Other Surface Water	Groundwater	Total
Superior	0.8	0.8	3.8	5.4
Michigan	1.4	61.0	202.8	265.3
Huron	5.4	26.9	23.1	55.3
Erie	2.6	36.6	60.1	99.3
Ontario	5.0	12.0	18.9	35.9

[a] To convert gallons to liters, multiply by 3.785.

[b] Includes withdrawals from connecting channels (the St. Clair River, the Detroit River, the Niagara River, and the St. Marys River) and the St. Lawrence River.

[c] Includes Canadian withdrawals.

Source: GLC (2004a,b).

TABLE 5.15 Daily Water Withdrawals in 2000 within the Great Lakes Basin, by State, for Industrial Use

	Withdrawals (Mgal/d)[a]			
State	Great Lakes Surface Water[b]	Other Surface Water	Groundwater	Total
Illinois	19.7	0	0	19.7
Indiana	1,397.9	381.1	20.7	1,799.7
Michigan	473.6	115.4	109.3	698.2
Minnesota	278.3	86.9	0	365.2
New York	281.5	49.1	11.5	342.1
Ohio	39.5	126.0	44.5	210.1
Pennsylvania	40.8	0.8	0.2	41.9
Wisconsin	1.6	227.8	37.9	267.3

[a] To convert gallons to liters, multiply by 3.785.

[b] Includes withdrawals from connecting channels (the St. Clair River, the Detroit River, the Niagara River, and the St. Marys River) and the St. Lawrence River.

Source: GLC (2004a,b).

Among the individual Great Lakes, Lake Michigan supplies the greatest amount of water for industrial use (1,532.5 Mgal/d [5,801.4 million L/d]), supplying nearly twice as much as Lake Erie, which provides the next greatest amount of water for industrial use (802.0 Mgal/d [632.2 million L/d]) (Table 5.16). In contrast, Lake Ontario supplies the smallest amount of water for industrial use: 167.0 Mgal/d [632.2 million L/d], which is approximately 10% of the amount supplied by Lake Michigan.

TABLE 5.16 Daily Water Withdrawals in 2000 within the Great Lakes Basin, by Lake, for Industrial Use

	Withdrawals (Mgal/d)[a]			
State	Great Lakes Surface Water[b,c]	Other Surface Water	Groundwater	Total
Superior	465.3	87.0	0.4	552.7
Michigan	1,532.5	697.1	138.9	2,368.5
Huron	208.4	15.2	4.6	228.1
Erie	802.0	139.6	79.1	1,020.8
Ontario	167.0	135.2	3.1	305.3

[a] To convert gallons to liters, multiply by 3.785.

[b] Includes withdrawals from connecting channels (the St. Clair River, the Detroit River, the Niagara River, and the St. Marys River) and the St. Lawrence River.

[c] Includes Canadian withdrawals.

Source: GLC (2004a,b).

5.5.2.4 Water Use for Energy Production

Water use for energy production represents the greatest use of water in the Great Lakes Basin and includes water used for the generation of thermoelectric and hydroelectric energy.

5.5.2.4.1 Thermoelectric Energy Generation. Thermoelectric energy is generated using either nuclear or fossil fuels (coal and natural gas). When used in the generation of thermoelectric energy, water from the Great Lakes is withdrawn from a lake, heated to generate steam, which, in turn, drives turbines to generate electricity, and is returned to the lake minus evaporative loss. Water withdrawals from the Great Lakes for thermoelectric energy production varies from none in Pennsylvania to 7,454.8 Mgal/d (28,219.5 million L/d) in Michigan (Table 5.17).

TABLE 5.17 Daily Water Withdrawals in 2000 within the Great Lakes Basin, by State, for Thermoelectric Energy Production

	Withdrawals (Mgal/d)[a]			
State	Great Lakes Surface Water[b]	Other Surface Water	Groundwater	Total
Illinois	731.3	0	0	731.3
Indiana	1,156.9	0	0.3	1,157.2
Michigan	7,454.8	250.4	2.9	7,708.1
Minnesota	0.6	173.2	0.1	173.9
New York	2,962.9	408.9	0	3,371.8
Ohio	2,285.3	6.4	0	2,292.1
Pennsylvania	0	0	0	0
Wisconsin	5,870.8	15.6	0.1	5,886.5

[a] To convert gallons to liters, multiply by 3.785.

[b] Includes withdrawals from connecting channels (the St. Clair River, the Detroit River, the Niagara River, and the St. Marys River) and the St. Lawrence River.

Source: GLC (2004a,b).

Lake Michigan provides the greatest amount of water (9,928.9 Mgal/d [37,581.6 million L/d]) for thermoelectric energy production, while Lake Superior provides the least amount (Table 5.18). The relatively small level of withdrawals from Lake Superior is a reflection of the relatively low population density and few major (> 100,000 population) urban centers located within the lake's drainage basin.

5.5.2.4.2 Hydroelectric Energy Production. Approximately 95% of the Great Lakes water used by the United States and Canada is for hydroelectric energy production (EPA 2003b). Hydroelectric energy production involves both "in-stream use," where water is used on a once-through basis (withdrawn from a water body, passed through a turbine, and returned to the water body), and "off-stream use," where water is recycled through pumped storage systems (GLC 2004a,b). In-stream use represents the primary approach for generating hydroelectric power in the Great Lakes. Among the Great Lakes states, only New York withdraws surface waters from the lakes for hydroelectric energy generation (Table 5.19).

There were no water withdrawals in 2000 for hydroelectric generation from Lakes Superior and Michigan, while withdrawals from Lakes Huron, Erie, and Ontario ranged from about 20,000 to 40,000 Mgal/d (75,708 to 151,417 million L/d) (Table 5.20).

TABLE 5.18 Daily Water Withdrawals in 2000 within the Great Lakes Basin, by Lake, for Thermoelectric Energy Use

	Withdrawals (Mgal/d)[a]			
State	Great Lakes Surface Water[b,c]	Other Surface Water	Groundwater	Total
Superior	578.1	173.2	0.1	751.4
Michigan	9,928.9	266.0	2.0	10,463.0
Huron	5,546.4	0	0.8	5,547.3
Erie	8,062.5	6.4	0.3	8,069.3
Ontario	7,939.6	408.9	0	8,757.4

[a] To convert gallons to liters, multiply by 3.785.

[b] Includes withdrawals from connecting channels (the St. Clair River, the Detroit River, the Niagara River, and the St. Marys River) and the St. Lawrence River.

[c] Includes Canadian withdrawals.

Source: GLC (2004a,b).

TABLE 5.19 Daily Water Withdrawals in 2000 within the Great Lakes Basin, by State, for Hydroelectric Energy Production

	Withdrawals (Mgal/d)[a]			
State	Great Lakes Surface Water[b]	Other Surface Water	Groundwater	Total
Illinois	0	0	0	0
Indiana	0	2,011.2	0	2,011.2
Michigan	0	0	0	0
Minnesota	0	4,094.1	0	4,094.1
New York	117,213.0	179,600.0	0	296,813.0
Ohio	0	0	0	0
Pennsylvania	0	0	0	0
Wisconsin	0	3,631.3	0	3,631.3

[a] To convert gallons to liters, multiply by 3.785.

[b] Includes withdrawals from connecting channels (the St. Clair River, the Detroit River, the Niagara River, and the St. Marys River) and the St. Lawrence River.

Source: GLC (2004a,b).

TABLE 5.20 Daily Water Withdrawals in 2000 within the Great Lakes Basin, by Lake, for Hydroelectric Energy Use

	Withdrawals (Mgal/d)[a]			
State	Great Lakes Surface Water[b,c]	Other Surface Water	Groundwater	Total
Superior	0	42,459.9	0	42,459.9
Michigan	0	5,433.1	0	5,433.1
Huron	20,000.4	13,607.7	0	33,608.1
Erie	40,386.0	0	0	40,386.0
Ontario	33,861.0	88,589.3	0	122,450.3

[a] To convert gallons to liters, multiply by 3.785.

[b] Includes withdrawals from connecting channels (the St. Clair River, the Detroit River, the Niagara River, and the St. Marys River) and the St. Lawrence River.

[c] Includes Canadian withdrawals.

Source: GLC (2004a,b).

5.5.2.5 Recreational Water Use

The surface waters of the Great Lakes support a number of water-based recreational activities, including boating, sport diving, swimming, and fishing. The Great Lakes are home to more than four million U.S.-registered recreational boats, representing about one-third of all registered recreational vessels in the U.S. (GLWMF 2005), and which arguably comprise the largest pleasure fleet in the world. Virtually all communities located on the coast have one or more marinas, and approximately 1,000 regattas and sanctioned sailboat races are held annually in the Great Lakes. There are also about 300 commercial excursion vessels, dinner boats, and ferries operating the Great Lakes (GLWMF 2005). Two daily car ferry services operate in Lake Michigan. A cruise ship industry has recently become established in the Great Lakes, and since 1997, the number of cruise passengers traveling the Great Lakes has increased from 1,500 to 14,000 (Great Lakes St. Lawrence Seaway Development Corporation, undated).

The Great Lakes sport fishery is probably the largest in the United States, with an estimated one-third of all sports anglers living near or fishing the Great Lakes (GLWMF 2005). In addition to using personal fishing boats, Great Lakes anglers also use thousands of charter fishing boats to fish the lakes. There is also a substantial sport diving population and industry (dive charters and dive shops) in the Great Lakes, as well as many nondivers who want to experience shipwrecks firsthand.

5.5.3 Economic Setting

The binational Great Lakes region is North America's industrial heartland and also supports a multibillion dollar outdoor recreation and tourism industry, a strong maritime transportation system, and a diverse and extensive agricultural base. The primary economic activities in the region today are agriculture, industrial manufacturing, steel production, shipping, commercial and sport fisheries, and recreation and tourism (GLIN 2005c). In 2002, the economy of the Great Lakes contributed roughly 15.5% of the U.S. Gross Domestic Product, 16.6% of national water transport, 23.4% of U.S. manufacturing, 9.4% of the agricultural production, and 14.5% of recreational and entertainment products (BEA 2005). Gas and oil production accounts for less than 1% of the total regional economy. The primary urban and industrial centers and ports on the Great Lakes include Chicago, Detroit, Duluth, Buffalo, Cleveland, Gary, Milwaukee, Toledo, and Rochester. They serve as manufacturing centers utilizing the natural resources of the upper lakes and the coal deposits of the eastern lake areas, and the limestone deposits of the lower Great Lakes. Economic activity in the Basin (including Canada and the United States) exceeds $200 billion a year (EPA 2005c)

5.5.3.1 Agriculture

Agriculture in the Great Lakes Basin is diverse and productive. About one-third of the land in the basin is used for agriculture, supporting nearly 25% of the total Canadian agricultural production and 9.4% of U.S. production (BEA 2005; EPA 2005c). Within the eight Basin states, agriculture (crop and animal production) accounted for about $13 billion of the total gross state product by $275 billion (BEA 2005). While agriculture in the Basin is dominated by dairy, grain, corn, and livestock production, unique climate conditions within the Basin also support a variety of orchards, vineyards, and other specialty crops.

5.5.3.2 Industry and Manufacturing

Industry within the Great Lakes accounts for more than a third of the combined Canadian and U.S. gross national product (GLWMF 2005). Approximately one-half of Canadian manufacturing and about one-fifth of U.S. manufacturing are based on the region's freshwater coast, and the entire region generates more than 50% of the total U.S. manufacturing output. The binational region accounts for about 60% of steel production in North America. Automotive parts manufacturing and assembly is predominant in Great Lakes urban areas such as Detroit, Toledo, Cleveland, and Toronto. Pulp and paper plants, high-tech and chemical industries, and other light manufacturing contribute to the region's strong economy.

5.5.3.3 Shipping

The Great Lakes and the St. Lawrence River are part of a vast system linking North America's heartland with ports and markets throughout the world. Since 1959, more than (2.2 billion tons [2 billion metric tons (t)]) of cargo estimated at $300 billion have moved to and

from Canada, the United States, and almost 50 other nations, making the system a critical component of the economy. The Great Lakes Basin has 15 major ports and 50 regional ports that are interconnected by numerous highways, rail lines, and airports. Lake Erie has the most major ports, and Lakes Superior and Ontario the fewest (Table 5.21).

The annual commerce exceeds 200 million tons (181 million t); commodities shipped through the lakes include:

- Iron ore for the steel industry;
- Coal for power generation and steel production;
- Limestone for construction and steel industries;
- Grain for overseas markets;
- General cargo, such as iron, steel products, and machinery; and
- Cement, salt, and aggregates for agriculture and industry (GLWMF 2005).

Iron ore, grain, limestone, and steel make up about 80% of cargoes shipped each year, while tankers transport about 50 million bbl of fuel and heating oil annually. About 10% of the Great Lakes shipping travels to and from overseas ports, especially in Europe, the Middle East, and Africa.

TABLE 5.21 Major U.S. Ports in the Great Lakes Basin

Lake	City and State
Superior	Duluth, Minnesota
Michigan	Green Bay, Wisconsin Milwaukee, Wisconsin Chicago, Illinois Burns Harbor, Indiana
Erie	Detroit, Michigan Monroe, Michigan Toledo, Ohio Lorain, Ohio Cleveland, Ohio Ashtabula, Ohio Conneaut, Ohio Erie, Pennsylvania Buffalo, New York
Ontario	Oswego, New York

Source: SLSMC and SLSDC 2005.

As the world's longest deep-draft inland waterway, the system extends from Duluth, Minnesota, on Lake Superior, to the Gulf of St. Lawrence on the Atlantic Ocean, a distance of more than 2,340 mi (3,766 km). This shortcut to the continent's interior was made possible with the construction of a ship canal and lock system opened in 1855 at Sault Ste. Marie, Michigan, the development of the first Welland Canal in 1829, and the completion of the St. Lawrence Seaway in 1959.

5.5.3.4 Fisheries, Recreational Boating, and Tourism

The commercial and sport fishery on the Great Lakes is collectively valued at more than $7.5 billion annually (GLIN 2005b; GLWMF 2005). Recreational boating is a major industry in the Great Lakes Basin. Recreational boating is estimated to provide more than 125,000 jobs and contribute about $9 billion annually to the Basin's economy. The region accommodates more

than 250 million visitors to its parks and recreation areas annually, and an estimated 5.5 million hunters spend more than $2.6 million annually in the Basin (EPA 2005c).

5.6 AREAS OF CONTAMINATED SURFACE WATER, SEDIMENT, AND SOIL

The Great Lakes include many locations, such as harbors and onshore landfills, that are currently being managed to control contaminant risks to human health and the environment. In addition, surface water discharges (typically in the form of storm water runoff and industrial and sanitary sewage releases) from metropolitan areas may result in localized degraded water quality conditions. This section summarizes the nature and distribution of contaminated sites within the Great Lakes, specifically identifying locations of areas with known surface water, sediment, or soil contamination. The section focuses on the major categories of contaminants in the Great Lakes; major issues of concern (human health risk, ecological risks, or both); and general sources of those contaminants (leaking landfills, contaminated sediments, and surface water runoff).

5.6.1 Nature and Distribution of Contaminated Sites

Overall, water quality in the lakes is improving because of the progress that has been made in controlling direct discharges of wastes from municipalities and industries under environmental laws adopted since the 1960s. Nevertheless, some localized areas still suffer serious impairment of beneficial uses (drinking, fishing, swimming, etc.) and fail to meet environmental standards and objectives (EPA and Government of Canada 1995).

The most contaminated sites within the Great Lakes are identified as Areas of Concern (AOCs), which are severely degraded geographic areas within the Great Lakes Basin (GLIN 2005a). AOCs are defined by the U.S.-Canada Great Lakes Water Quality Agreement (GLWQA) as “geographic areas that fail to meet the general or specific objectives of the agreement where such failure has caused or is likely to cause impairment of beneficial use of the area’s ability to support aquatic life.” The U.S. and Canadian governments have identified 43 such areas: 26 in U.S. waters, 17 in Canadian water (5 are shared between the United States and Canada on connecting river systems). The location of each AOC is shown in Figure 5.22. Two AOCs in Lake Huron, Collingwood Harbour, and Severn Sound, have been cleaned up (EC 2004). Table 5.22 provides an example of one of the AOCs (Grand Calumet), and clearly shows the complexity of contaminants and their sources that is typical of most of the AOCs.

The purpose of establishing AOCs is to encourage jurisdictions to form partnerships with local stakeholders to rehabilitate these acute problem areas and to restore their beneficial uses (EPA and Government of Canada 1995). In the AOCs, existing routine programs are not expected to be sufficient to restore ecosystem quality to acceptable levels; thus special efforts are needed. Jurisdictions are implementing Remedial Action Plans (RAPs) to guide specific rehabilitation activities in the 41 remaining AOCs (EC 2004).

Most AOCs are near the mouths of tributaries where cities and industries are located. Several of the areas are along the connecting channels between the lakes. Pollutants are

concentrated in these areas because of long-term accumulation of contaminants deposited from local point- and non-point-sources and upstream sources. Nearly all the AOCs have contaminated sediments (EPA and Government of Canada 1995).

Over the last decade, the nature of the problems associated with some areas has changed. For example, as progress was made in restoring dissolved oxygen levels and reducing the environmental releases of substances such as lead and mercury, it became apparent that the problem of dissolved oxygen had been obscuring other problems of toxic contamination (EPA and Government of Canada 1995).

In the GLWQA as amended in 1987, the United States and Canada agreed to develop and implement, in consultation with state and provincial governments, Lakewide Management Plans

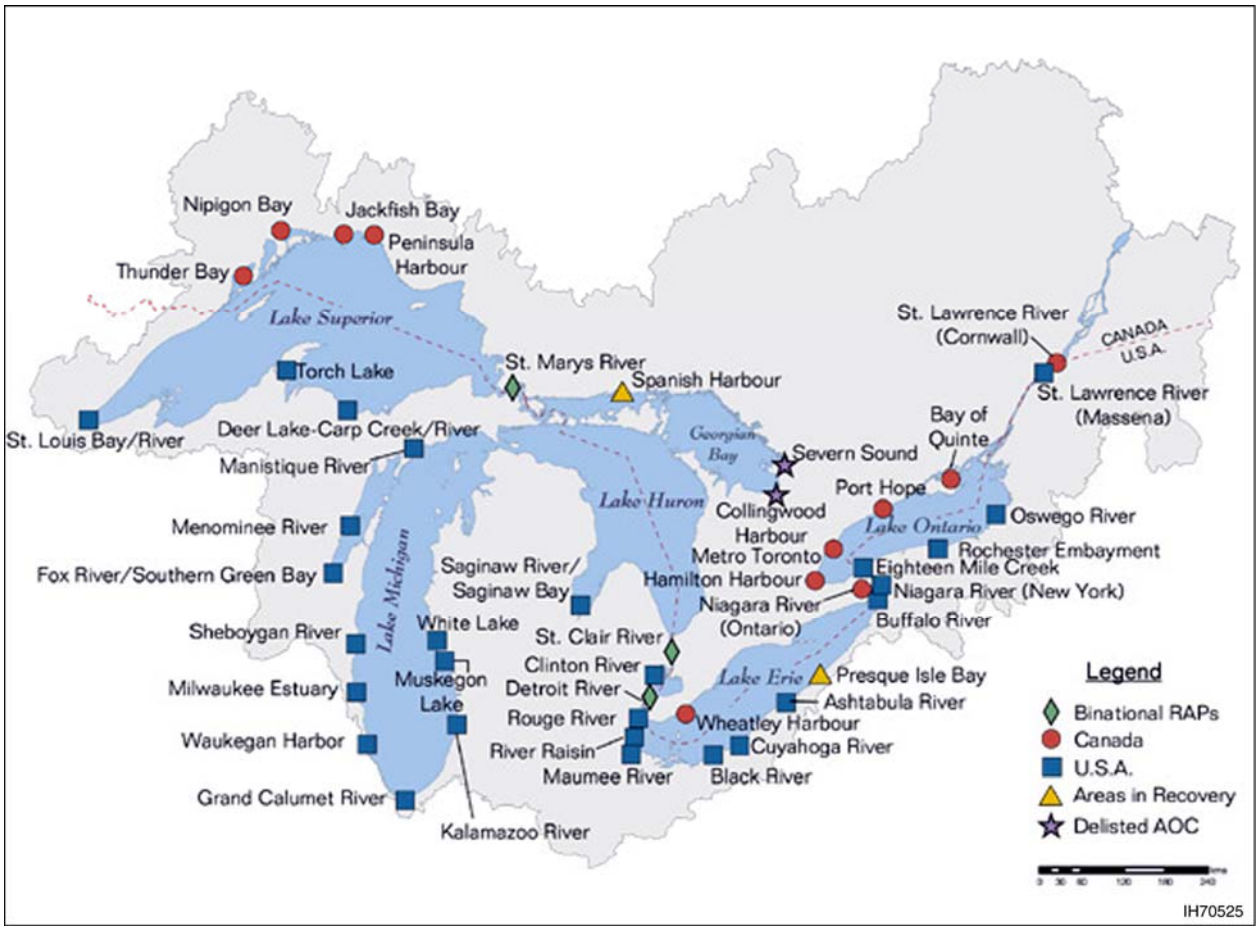

FIGURE 5.22 Areas of Concern in the Great-Lakes-St. Lawrence River Basin (Source: EC 2004)

(LaMPs) for lake waters and RAPs for the AOCs. The LaMPs identify critical pollutants that impair beneficial uses in the lake proper and develop strategies, recommendations, and policy options for restoring beneficial uses (EPA 2004g). The LaMPs for each Great Lake identify the

results of beneficial use impairment assessments that have been conducted. Table 5.23 summarizes the impaired beneficial uses identified for the U.S. portion of the AOCs in the Great Lakes Basin.

5.6.2 Contaminants and Their Sources in the Great Lakes

Contaminants in the Great Lakes originate from both point- and non-point-sources, such as industrial and municipal wastewater discharges, combined sewer overflows (CSOs), contaminated sediment, industrial waste site runoff, CERCLA sites, hazardous waste sites under RCRA, underground storage tanks, atmospheric deposition, urban runoff, and contaminated groundwater (EPA 2001).

Examples of Great Lakes Contaminants

- Chlordane
- DDT
- Dieldrin and aldrin
- Dioxins and furans
- Heavy metals
- Mercury and mercury compounds
- Mirex
- PCBs
- Plant nutrients
- Sediment
- Tritium

The Canada-United States Strategy for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes Basin, known as the Great Lakes Bi-national Toxics Strategy, provides a framework for actions to reduce or eliminate persistent toxic substances from the Great Lakes Basin. The Strategy was developed jointly by Canada and the United States in 1996 and 1997 and was signed April 7, 1997 (EC and EPA 1997).

The Strategy establishes reduction challenges for an initial list (Level I) of persistent toxic substances targeted for virtual elimination: aldrin/dieldrin, benzo(a)pyrene, chlordane, DDT, hexachlorobenzene, alkyl-lead, mercury and mercury compounds, mirex, octachlorostyrene, polychlorinated biphenyls (PCBs), dioxins and furans, and toxaphene (EPA 2004f). These substances have been associated with widespread, long-term adverse effects on wildlife in the Great Lakes, and, through their bioaccumulation, are of concern for human health (EPA 2004f). Additional “Level II” persistent toxic substances were also identified in the Strategy, with the goal of promoting pollution prevention and sound management principles to reduce levels in the environment (EC and EPA 2001). Table 5.24 includes all of the persistent toxic substances that are the focus of the Great Lakes Binational Toxics Strategy.

The following summarizes the categories and general sources of critical contaminants in the Great Lakes (EPA and EC 2003):

- *Chlordane*. Used to control pests on crops (corn, grapes, strawberries, etc.), and to control fleas, ticks, and mange on pets. It is a probable human carcinogen. The United States banned most uses in 1978 and all uses except termite control in 1987; Canada discontinued use in 1990.

TABLE 5.22 Origin of Point- and Non-Point-Sources of Contaminants in the Grand Calumet Area of Concern (AOC)[a]

Source Type	General Contaminant Sources	Specific Contaminant Sources
Non-point	Contaminated sediment	The Grand Calumet River and Indiana Harbor and Canal contain 5 to 10 million yd^3 (3.9 to 7.7 million m^3) of contaminated sediment up to 20-ft (6-m) deep. Contaminants include toxic compounds (e.g., PAHs, PCBs, and heavy metals) and conventional pollutants (e.g., phosphorus, nitrogen, iron, magnesium, volatile solids, oil and grease).
Non-point	Industrial waste site runoff	Storm water runoff and leachate from 11 of 38 waste disposal and storage sites in the AOC, located within .2 mi (.3 km) of the river, are degrading AOC water quality. Contaminants include oil, heavy metals, arsenic, PCBs, PAHs, and lead.
Non-point	CERCLA sites	There are 52 sites in the AOC listed in the Federal CERCLA System. Five of these sites are Superfund sites on the NPL.
Non-point	Hazardous waste sites under RCRA	There are 423 hazardous waste sites in the AOC regulated under RCRA, such as landfills or surface impoundments, where hazardous waste is disposed of. Twenty-two of these sites are treatment, storage, and disposal facilities.
Non-point	USTs	There are more than 460 USTs in the AOC. More than 150 leaking tank reports have been filed for the Lake County section of the AOC since mid-1987.
Non-point	Atmospheric deposition	Atmospheric deposition of toxic substances from fossil fuel burning, waste incineration, and evaporation enter the AOC through direct contact with water, surface water runoff, and leaching of accumulated materials deposited on land. Toxins from this source include dioxins, PCBs, insecticides, and heavy metals.
Non-point	Urban runoff	Rainwater passing over paved urban areas washes grease, oil, and toxic organics such as PCBs and PAHs into AOC surface waters.
Non-point	Contaminated groundwater	Groundwater contaminated with organic compounds, heavy metals, and petroleum products contaminates AOC surface waters. The EPA estimates that at least 16.8 million gal (63.6 million L) of oil float on top of groundwater beneath the AOC.

TABLE 5.22 (Cont.)

Source Type	General Contaminant Sources	Specific Contaminant Sources
Point	Industrial and municipal	Wastewater Discharges. Three steel manufacturers contribute 90% of industrial point-source discharges to the AOC. One chemical manufacturer discharges into the AOC. Permitted discharges include arsenic, cadmium, cyanide, copper, chromium, lead, and mercury. Three municipal treatment works (Gary, Hammond, and East Chicago Sanitary Districts) discharge treated domestic and industrial wastewater into the AOC.
Point	CSOs	Fifteen CSOs contribute untreated municipal waste, including conventional and toxic pollutants, to the AOC. Annually, CSO outfalls discharge an estimated 11 billion gal (41.6 billion L) of raw wastewater into the harbor and river. Approximately 57% of the annual CSO volume is discharged within 8 mi (12.9 km) of Lake Michigan, resulting in nearshore fecal coliform contamination.

[a] Abbreviations: AOC = Area of Concern; CERCLA = Comprehensive Environmental Response and Compensation Act; CSO = combined sewer overflow; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl; RCRA = Resource Conservation and Recovery Act; UST = underground storage tank.

Source: EPA (2001).

TABLE 5.23 Beneficial Use Impairments at the U.S. Great Lakes Areas of Concern

Area of Concern	Restrictions on fish and wildlife consumption	Tainting of fish and wildlife flavor	Degradation of fish wildlife populations	Fish tumors or other deformities	Bird or animal deformities or reproduction problems	Degradation of benthos	Restrictions on dredging activities	Eutrophication or undesirable algae	Restrictions on drinking water consumption or taste and odor problems	Beach closings	Degradation of aesthetics	Degradation of phytoplankton and zooplankton populations	Added costs to agriculture or industry	Loss of fish and wildlife habitat
Ashtabula River, Ohio	X		X	X		X	X							X
Black Lagoon (Detroit River)	X	X		X		X	X		X	X	X			X
Black River, Ohio	X		X			X	X	X	X	X	X			X
Buffalo River, New York	X			X		X	X							X
Clinton River, Michigan	X		X			X	X	X		X	X			X
Cuyahoga River, Ohio	X		X	X		X	X	X		X	X	X		X
Deer Lake, Michigan	X						X							
Detroit River, Michigan	X	X		X		X	X		X	X	X			X

TABLE 5.23 (Cont.)

Area of Concern	Restrictions on fish and wildlife consumption	Tainting of fish and wildlife flavor	Degradation of fish wildlife populations	Fish tumors or other deformities	Bird or animal deformities or reproduction problems	Degradation of benthos	Restrictions on dredging activities	Eutrophication or undesirable algae	Restrictions on drinking water consumption or taste and odor problems	Beach closings	Degradation of aesthetics	Degradation of phytoplankton and zooplankton populations	Added costs to agriculture or industry	Loss of fish and wildlife habitat
Eighteen Mile Creek, New York	X					X	X							
Grand Calumet River, Indiana	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Kalamazoo River, Michigan	X		X		X	X	X			X	X			X
Lower Green Bay and Fox River, Wisconsin	X		X		X	X	X	X	X	X	X	X		
Manistique River, Michigan	X					X	X			X				X
Maumee River, Ohio	X		X	X		X	X	X	X	X	X			X
Menominee River, Wisconsin	X		X			X	X			X				X
Milwaukee Estuary, Wisconsin	X		X	X	X	X	X	X		X	X	X		X

TABLE 5.23 (Cont.)

Area of Concern	Restrictions on fish and wildlife consumption	Tainting of fish and wildlife flavor	Degradation of fish wildlife populations	Fish tumors or other deformities	Bird or animal deformities or reproduction problems	Degradation of benthos	Restrictions on dredging activities	Eutrophication or undesirable algae	Restrictions on drinking water consumption or taste and odor problems	Beach closings	Degradation of aesthetics	Degradation of phytoplankton and zooplankton populations	Added costs to agriculture or industry	Loss of fish and wildlife habitat
Muskegon Lake, Michigan	X		X			X	X							X
Niagara River, New York	X			X		X	X							X
Oswego River/Harbor, New York	X		X					X						X
Presque Isle Bay, Pennsylvania[b]				X			X							
River Raisin, Michigan	X		X		X	X	X	X		X	X			X
Rochester Embayment, New York	X		X		X	X	X	X	X	X	X	X	X	X
Rouge River, Michigan	X	X	X	X	X	X	X	X		X	X			X
Saginaw River and Bay, Michigan	X		X		X	X	X	X	X	X	X	X		X

TABLE 5.23 (Cont.)

Area of Concern	Restrictions on fish and wildlife consumption	Tainting of fish and wildlife flavor	Degradation of fish wildlife populations	Fish tumors or other deformities	Bird or animal deformities or reproduction problems	Degradation of benthos	Restrictions on dredging activities	Eutrophication or undesirable algae	Restrictions on drinking water consumption or taste and odor problems	Beach closings	Degradation of aesthetics	Degradation of phytoplankton and zooplankton populations	Added costs to agriculture or industry	Loss of fish and wildlife habitat
Sheboygan River, Wisconsin	X		X	X	X	X	X	X				X		
St. Clair River, Michigan	X				X	X	X			X	X			X
St. Lawrence River at Massena, New York	X													X
St. Louis River and Bay, Minnesota and Wisconsin	X		X	X		X	X	X		X	X			X
St. Mary's River, Michigan	X		X	X		X	X	X		X	X			X
Torch Lake, Michigan	X					X	X		X		X			X
Waukegan Harbor, Illinois						X	X			X		X		X

TABLE 5.23 (Cont.)

Area of Concern	Restrictions on fish and wildlife consumption	Tainting of fish and wildlife flavor	Degradation of fish wildlife populations	Fish tumors or other deformities	Bird or animal deformities or reproduction problems	Degradation of benthos	Restrictions on dredging activities	Eutrophication or undesirable algae	Restrictions on drinking water consumption or taste and odor problems	Beach closings	Degradation of aesthetics	Degradation of phytoplankton and zooplankton populations	Added costs to agriculture or industry	Loss of fish and wildlife habitat
White Lake, Michigan	X		X			X	X	X	X		X			X

[a] Recently designated as fully recovered for fish tumors.

[b] Area in recovery.

Source: EPA (2005e).

TABLE 5.24 Persistent Toxic Substances That Are the Focus of the Canada-United States Strategy for the Virtual Elimination of Persistent Toxic Substances in the Great Lakes

Level	Persistent Toxic Substance[a]	Level	Persistent Toxic Substance
I	Aldrin/dieldrin	II	Cadmium and cadmium compounds
	Benzo(a)pyrene		1,4 – dichlorobenzene
	Chlordane		3,3'-dichlorobenzidine
	DDT (+DDD+DDE)		Dinitropyrene
	Hexachlorobenzene (HCB)		Endrin
	Alkyl-lead		Heptachlor (+Heptachlor epoxide)
	Mercury and mercury compounds		Hexachlorobutadiene (+Hexachloro-1,3-butadiene)
	Mirex		Hexachlorocyclohexane
	Octachlorostyrene		4,4'-methylenebis(2-chloroaniline)
	PCBs		Pentachlorobenzene
	Dioxins (PCDD) and Furans (PCDF)		Pentachlorophenol
	Toxaphene		Tetrachlorobenzene (1,2,3,4- and 1,2,4,5-)
			Tributyl tin
			Plus PAHs as a group, including but not limited to:
			• Anthracene
			• Benzo(a)anthracene
			• Benzo(g,h,i)perylene
			• Perylene
			• Phenanthrene

[a] Abbreviations: DDE = dichloro diphenyl dichloroethylene; DDT = dichloro diphenyl trichloroethane; PAH = polycyclic aromatic hydrocarbon; PCDD = polychlorinated dibenzodioxine; PCDF = polychlorinated dibenzofurans.

Source: EPA (1997).

- *DDT*. Used in large quantities in the 1950s and 1960s on cotton fields, orchards, and other crops and in unsuccessful extermination campaigns against the Japanese beetle, spruce budworm, gypsy moth, and Dutch elm disease, and bark beetle. DDT (dichloro diphenyl trichloroethane) was also an ingredient in the pesticide Kelthane (Dicofol). DDT breaks down into toxic metabolites, primarily DDE (dichloro diphenyl dichloroethylene). DDT and DDE are probable human carcinogens and endocrine disrupters. The United States banned DDT (except for public health emergencies) in 1973 and Kelthane (unless it contained less than 0.1% DDT) in 1988. Canada discontinued DDT in 1985. DDT is still used in other countries on a limited basis to control mosquito populations in malaria-stricken areas. Only India and China still manufacture DDT.

- *Dieldrin*. Formerly used pesticide that is now banned from use in the Lake Ontario basin and throughout North America. Aldrin, another formerly used pesticide, transforms into dieldrin through natural breakdown processes.

- *Mirex.* Widely used as a pesticide; however, approximately 75% of the mirex produced was used as a flame retardant in a variety of industrial, manufacturing, and military applications. Use and production of mirex, also known as dechlorane and chlordecone, are now banned in North America.

- *Polychlorinated biphenyls (PCBs).* Historically used in electrical equipment such as transformers and capacitors. For example, PCB oil-filled electric switches eliminated electric sparking problems that could trigger explosions at petroleum refineries. PCB oils were used in electrical transformers as a nonflammable electrical insulating fluid. PCBs were also used as industrial lubricating oils to replace earlier types of hydraulic oils that could more easily catch fire under high pressure and temperature conditions. Polybrominated biphenyl, a flame-retardant material, was introduced into the food chain in Michigan in 1973 because of a manufacturing and distribution mistake.

- *Dioxins and furans.* By-products of processes involving chlorine, organic chemicals, and heat, including incineration, pulp and paper bleaching with elemental chlorine, and chemical manufacturing. Dioxins are extremely toxic. They are carcinogenic and may be an important endocrine disrupter. Concentrations from pulp and paper bleaching are dropping as mills switch to alternative technologies. Other processes, including incineration of medical and solid waste, continue to produce significant amounts.

- *Mercury.* Widely used in batteries (its use in alkaline batteries has been banned in most batteries, limited in others), electrical equipment (switches), medical equipment, thermometers, thermostats, and preservatives — even in the silver amalgam dentists use for fillings. Many former uses (as a fungicide, pesticide, and in latex paint) have been discontinued, but it is still needed in some products and processes. Historically, mercury was added to paints as an antimildew agent. Its largest U.S. use today is at chlor-alkali plants that produce chlorine gas and caustic soda. Small concentrations of mercury that exist in natural materials, such as coal, wood, and metal ore, are released when these materials are processed; because such huge quantities of these materials are processed, much mercury is released. Mercury is also released when garbage is burned and can be transformed in aquatic ecosystems into methylmercury, a toxic bioaccumulative form.

- *Alkylated heavy metals.* Heavy metals, such as lead, nickel, copper, and zinc, are common in hazardous waste. They can damage organisms at low concentrations and tend to accumulate in the food chain.

- *Plant nutrients.* Plant nutrients, such as phosphorus and nitrogen, can cause algal blooms and eutrophication problems when present in high concentrations in surface waters. Nitrates are another type of nutrient that at higher concentrations can adversely affect fish and amphibians. Sources of

such nutrients include municipal wastewater treatment plants, some industrial discharges, runoff from agricultural and urban areas, and the atmosphere. Potassium nitrate and sodium nitrate are commonly used and found in fertilizers.

- *Sediment.* Sediment is a solid material, either suspended or settled and both mineral and organic, that has been deposited within a water body. Naturally occurring sediment originates from the erosion of soils and rocks and is distributed by surficial water processes such as rivers, streams, and runoff (EC 1992). Higher than normal concentrations of suspended sediment may adversely affect water quality and aquatic biota. In addition, sediments may also contain chemical contaminants, depending on the source of the sediment. Contaminated sediments originate primarily from non-point-sources, such as agricultural runoff, urban runoff, or stream banks. Sediment loads usually increase because of human-induced changes to the landscape, such as excavation and construction.

- *Tritium.* A radioactive by-product of light-water and heavy-water nuclear reactor operation. The coolants of these reactors produce about 500 to 1,000 Ci/yr and 2×10^4 Ci/yr, respectively, for every 1,000 MW(e) of power.

5.6.3 Issues of Concern — Human Health

The major health issues in the Great Lakes are associated with (1) fish consumption, (2) drinking water, and (3) recreational water. There are also health concerns about related issues such as air and water quality, pollution and contamination, agriculture and industry, and wildlife (EPA and EC 2003). Of particular concern is the presence of persistent bioaccumulative toxic (PBT) chemicals.

Several epidemiologic investigations have been conducted to investigate the association between water pollutants in the Great Lakes and the health of people in the Great Lakes states (ATSDR 2002). These studies have demonstrated increased tissue levels in exposed human populations of toxic substances (body burdens) that may be associated with, or potentially result in, reproductive, developmental, behavioral, neurologic, endocrinologic, and immunologic effects (ATSDR 2002).

5.6.3.1 Fish Consumption

Even though residents of the Great Lakes Basin are exposed to toxic substances from many sources originating within and outside the region, the main routes of human exposure to contaminants in the Great Lakes are ingestion of fish and, to a lesser extent, ingestion of drinking water (National Health and Welfare Canada 1991). Contaminant exposure from fish ingestion has been shown to far outweigh exposures to atmospheric, terrestrial, or water sources (ATSDR 2002).

Fish consumption provides the greatest potential for exposure of humans to toxic substances found in the Great Lakes when compared with other activities such as drinking tap water or swimming. For example, a person who eats one meal of lake trout from Lake Michigan will be exposed to more PCBs in one meal than in a lifetime of drinking water from the lake (EPA and Government of Canada 1995). Many chemical contaminants are present in surface waters at very low concentrations, some of which can bioaccumulate in aquatic organisms via their diet and become concentrated at levels that are much higher than in the water itself. This is especially true for substances that do not break down readily in the environment, for example, PBTs such as mercury and PCBs. While the average person in the Great Lakes Basin may not be at risk of experiencing adverse health effects from exposure to contaminants through fish consumption, some people are at risk. These include those who eat a lot of Great Lakes fish, regularly eat large predator fish (such as salmon and lake trout), eat fish from highly contaminated waters, or eat a large amount of fish over a short period of time. In addition, the developing fetus and young children are at greater risk than adults from the effects of contaminants in fish (EPA and EC 2003).

5.6.3.2 Drinking Water

Some chemical contaminants are of concern in drinking water; these are introduced into the Great Lakes via industrial discharge and agricultural runoff, or through the discharge of treated wastewater. Although there have been sporadic outbreaks of illness associated with the consumption of contaminated drinking water, the drinking water from the Great Lakes is generally of good quality (EPA and EC 2003). Processes commonly used by water treatment plants to disinfect water include the addition of disinfectants such as chlorine to inactivate or kill microorganisms. Chlorine and other disinfectants can combine with naturally occurring organic matter in the raw water to produce chlorination disinfection by-products, for example, trihalomethanes. Research suggests a link between by-products of the chlorination process and increased risk of some cancers and adverse pregnancy outcomes (EPA and EC 2003).

5.6.3.3 Recreational Water

The Great Lakes are an important resource for recreation, including activities such as swimming and sail boarding that involve direct bodily contact with the water. Apart from the risks of accidental injuries, the major human health concern for recreational waters is microbial contamination by bacteria, viruses, and protozoa. For example, because unacceptable levels of bacteria are occurring at beaches throughout the Lake Erie basin, nearshore recreational water quality is impaired from a human health (i.e., bathing use) standpoint. Chemical pollutants may also pose health risks; however, exposure to disease-causing microorganisms from sources such as untreated or poorly treated sewage is a greater risk (EPA and EC 2003). Sport fishing and recreational boating anchor an important marine-coastal recreation sector of the area economies for Lake Michigan. According to a 1991 national fishing and hunting survey, 34% of all Great Lakes anglers fished in Lake Michigan, a close second to the 35% in Lake Erie (EPA and EC 2003).

5.6.3.4 Other Sources of Contaminant Exposure

5.6.3.4.1 Air Pollution. Air pollution is a key human health issue for the Great Lakes Basin. Atmospheric deposition is a significant source of certain toxic pollutants entering the Great Lakes. For example, as much as 90% of some toxic loadings to the Great Lakes are believed to be the result of airborne deposition. Because the transport and deposition of airborne toxics is not localized, this pathway needs to be evaluated and regulated on a regional or even international scale (EPA and EC 2003). Mercury released from fossil-fuel-powered electricity generating plants is an example of an airborne toxin.

5.6.3.4.2 Contaminated Sediments. Sediments that were contaminated before pollutant discharges were regulated are another source of continuing pollution in the Great Lakes. Such in-place pollutants are a problem in most urban-industrial areas. Even where it is possible to remove highly contaminated sediments from harbors, removal can cause problems if the sediments are placed in landfills that may later leak and contaminate wetlands and groundwater (EPA and Government of Canada 1995). Polluted sediments can be resuspended into the water by dredging, the passage of ships in navigation channels, and wind and wave action. Sediments can also be disturbed by fish and other organisms that feed on the bottom (EPA and Government of Canada 1995).

5.6.3.4.3 Agricultural Runoff. Agricultural development has also contributed to Great Lakes pollution, chiefly in the form of eutrophication. Fertilizers that reach waterways in soils and runoff stimulate growth of algae and other water plants. As the plants die and decay, oxygen levels in the water are depleted. Lack of oxygen leads to fish kills, and the character of the ecosystem changes as the original plants and animals give way to more low-oxygen pollution-tolerant species (EPA and EC 2003).

5.6.3.4.4 Radionuclides. There is an ongoing debate as to whether concentrations of radionuclides in Great Lakes water should be regarded as a significant human health issue (EPA and EC 2003). Current concentrations of radionuclides, such as tritium, in water are below existing standards and criteria (EPA and EC 2003).

5.6.3.5 Persistent Bioaccumulative Chemicals

A very significant, overarching issue in the Great Lakes is the accumulation via the food chain of PBT chemicals. There have been notable signs of success in reducing persistent toxic substances in the Great Lakes, including the cleanup of contaminated sediments in some Great Lakes harbors; reduced levels of PCBs, dioxins, and DDT; and improved sport fisheries (EPA 2004f).

Even with the important accomplishments in toxics reduction achieved over the past decade and the actions taken by both the United States and Canada to ban, cancel, and restrict the

use of a number of PBTs, these substances continue to be present in the Great Lakes ecosystem and affect human activities in those areas (EC and EPA 1997). For example, the presence of contaminated sediments has impeded navigational dredging of some harbors. Unacceptable levels of PCBs, methylmercury, and toxaphene have required fish consumption advisories in some areas of the Great Lakes, thus locally impacting the economic potential of the region's fisheries industries and presenting a continued human health risk (EC and EPA 1997). More recently, there has been growing concern about toxic pollutants that may produce noncancerous health effects in wildlife and in humans, including endocrine disruption and learning disabilities (EC and EPA 1997).

A variety of sources are responsible for the continued presence of PBTs within the Great Lakes Basin, including atmospheric deposition, releases from contaminated bottom sediments, releases from various industrial processes, releases from non-point-sources, and continuous cycling of naturally occurring and anthropogenic substances within the Great Lakes (EC and EPA 1997). In some cases, there may also be illegal or accidental discharge of stored substances for which production and use have previously been canceled or banned (EC and EPA 1997).

5.6.4 Issues of Concern — Ecosystem Health

The health of fish and wildlife provides a good indication of the overall condition of an ecosystem. Research over the past 25 years has shown that a variety of PBTs that are present in Great Lakes food chains are toxic to wildlife. For example, reproductive impairments have been described in a variety of bird, fish, and mammal populations. Numerous hazardous chemicals have greater health impacts on ecological communities than on humans when found at elevated levels in sediments (EPA and Government of Canada 1995). These include some metals such as lead and some organic compounds such as PAHs. Both Canadian and U.S. health agencies have concluded that the weight of evidence based on the findings of wildlife biologists, toxicologists, and epidemiologists clearly indicates that wildlife populations continue to be exposed to PCBs and other chemical contaminants, and that significant ecosystem health consequences are associated with these exposures (EPA and EC 2003).

5.7 OIL AND GAS PRODUCTION IN THE GREAT LAKES BASIN

Currently, oil and gas production occurs in each of the Great Lakes Basin states except Minnesota and Wisconsin. Oil and gas production and use vary considerably across the states of the Basin. The number of oil and gas wells that have been drilled in each of the states varies considerably — from more than 14,000 wells in New York (since 1821) to more than 292,600 wells in Pennsylvania (since 1859) (IPAA 2005) (Table 5.25). These wells are located throughout the Basin states, within and outside of the Great Lakes Basin. Much of the production that occurs in the Basin states comes from stripper wells, which produce small amounts of oil or

TABLE 5.25 Oil and Gas Well Statistics for the Great Lakes Basin States[a]

Parameter	Illinois	Indiana	Michigan	Minnesota	New York	Ohio	Pennsylvania	Wisconsin
No. counties/no. counties with oil and/or gas production	102/42	92/48	83/63	0	62/19	88/71	67/31	0
Deepest producing oil well (ft)	5,405	8,429	10,515	NA[b]	4,906	7,805	8,484	NA
Deepest producing gas well (ft)	4,832	3,355	13,513	NA	10,458	8,953	13,186	NA
Deepest well drilled (ft)	14,942	8,429	17,466	NA	13,500	11,442	21,640	NA
Number of producing oil wells (2004)	16,859	4,788	3,675	NA	3,095	28,941	16,242	NA
Number of producing gas wells (2003)	1,836	2,291	8,600	NA	5,878	33,828	41,112	NA
2003 production – Oil (million bbl)	11.4	1.8	6.4	NA	0.14	5.5	2.5	NA
2003 production – Gas (million ft^3)	174	1,464	242,651	NA	36,137	93,641	159,827	NA

[a] Statistics include wells located outside of the Great Lakes Basin but within the boundaries of the Basin states.

[b] NA = not applicable or not available.

Sources: EIA (2005a–h); IPAA (2005).

natural gas (less than 10 bbl of crude oil per day, or less than 60,000 ft^3 [1,700 m^3] of gas per day).

5.7.1 Oil and Gas Production

5.7.1.1 Illinois

Among the producing Great Lakes states, Illinois ranks 2nd and 6th in the number of producing oil and gas wells, respectively (Table 5.25). In terms of production, Illinois ranks 1st in crude oil production and last in natural gas production. Nationally, Illinois is ranked 15th (including Federal offshore areas) in oil production and also ranks near the top in consumption of some petroleum products, including 6th in gasoline and 4th in liquefied petroleum gas (LPG). Illinois leads the Midwest in petroleum refining, with a combined crude oil distillation capacity of nearly 0.9 million bbl/d (EIA 2005a). The Chicago, Illinois, area is one of the few regions in the country that uses reformulated gasoline made with ethanol. The Illinois suburbs east of St. Louis, Missouri, also use a fairly unique gasoline. Less than 1% of the homes in the state use heating oil as their primary heating fuel, compared with nearly 81% for natural gas. Because Illinois is centrally located, the state serves as a hub for the many interstate oil pipelines that traverse it.

Oil and gas production in Illinois occurs in 40% of the counties in the state (Table 5.25). Production is limited to the southern half of the state, with no production occurring in the shoreline counties along Lake Michigan (IPAA 2005). Illinois has three major crude oil pipelines, 11 petroleum product pipelines, and five pipelines for the transportation of liquefied natural gas (LNG) (EIA 2005a). There were approximately 11,900 mi (19,151 km) of natural gas pipeline in the state in 2004 (Table 5.26). This is the greatest amount of natural gas pipeline among any of the Basin states. The highest concentration of pipelines in the state occur in the northeastern counties of the state, associated with the Chicago metropolitan area.

5.7.1.2 Indiana

Among the producing Great Lakes states, Indiana ranks 4th and 5th in the number of producing oil and gas wells, respectively, and 5th in both crude oil and natural gas production (Table 5.25). Indiana ranks 24th among oil-producing states (including Federal offshore areas) in the country (EIA 2005b). The state is traversed by several major pipelines that carry crude oil, petroleum products, and LPG between the large population centers in the adjoining states of Michigan, Illinois, and Ohio. Two refineries operate in the state, the Countrymark Cooperative refinery in Mt. Vernon with a daily distillation capacity of 23,000 bbl/d, and the BP Products Whiting refinery in Whiting, which is one of the largest refineries in the country with a distillation capacity of 410,000 bbl/d. Natural gas dominates the home heating market with a nearly 65% share, with electricity accounting for the next-largest share totaling about 22%. Indiana uses conventional gasoline throughout the state except for a small portion abutting the Chicago suburbs in the extreme northwest corner of the state and the northern suburbs of

TABLE 5.26 Estimated Miles of Gas Pipelines in the Great Lakes States, 2004

State	Pipeline Mileage
Illinois	11,904
Indiana	4,679
Michigan	9,688
Minnesota	4,431
New York	4,726
Ohio	7,612
Pennsylvania	8,522
Wisconsin	3,308
Total	54,870

Source: (EIA 2005j).

Louisville, Kentucky, in the southern portion of the state. These areas are required to use either reformulated gasoline blended with ethanol or low-vapor-pressure gasoline, respectively (EIA 2005b).

In Indiana, oil and gas production occurs in about 52% of the counties in the state (Table 5.25). Production occurs largely in the southwestern and east-central portions of the state, and also in two shoreline counties along Lake Michigan (IPAA 2005). In Indiana, there are three major crude oil pipelines, seven petroleum product pipelines, and four pipelines for the transportation of LNG (EIA 2005b). There are about 4,679 mi (7,530 km) of natural gas pipeline in the state (Table 5.26). Crude oil pipelines occur primarily in the southwestern portion of the state, with a concentration of natural gas and petroleum product pipelines located in the northwestern corner of the state near Lake Michigan and associated with the Chicago, Illinois, and Gary, Indiana, metropolitan areas.

5.7.1.3 Michigan

Among the producing Great Lakes states, Michigan ranks 5th and 3rd in the number of producing oil and gas wells, respectively (Table 5.25). In production, Michigan ranks 1st in natural gas production and 2nd in crude oil production. Nationally, Michigan ranks 18th (including Federal offshore areas) in crude oil production, with volumes totaling 18,000 bbl/d, mostly from stripper wells (EIA 2005c). The state has a single petroleum refinery and a large network of product pipelines. There are no pipelines in the Upper Peninsula, which is supplied by tanker truck from a pipeline terminal in Green Bay, Wisconsin. Although Michigan ranks third in the nation for LPG consumption, due mostly to high residential and commercial propane consumption, more than 78% of the overall home heating market uses natural gas as its primary

fuel. Michigan uses conventional gasoline but requires lower-vapor-pressure gasoline in the Detroit metropolitan area (EIA 2005c).

Oil and gas production in Michigan occurs in approximately 75% of the counties in the state (Table 5.25). Production occurs throughout almost all of the Lower Peninsula, including all but two Lake Michigan shoreline counties and one Lake Huron shoreline county (IPAA 2005). No production occurs in the Upper Peninsula (IPAA 2005). Michigan has three major crude oil pipelines, five petroleum product pipelines, and three pipelines for the transportation of LNG (EIA 2005c). Michigan has about 9,688 mi (15,591 km) of gas pipeline (Table 5.26). Oil pipelines only occur in the southern portion of the Lower Peninsula, with the highest concentration in the vicinity of Lake Erie and its connecting waters (the Detroit River and Lake St. Clair). Natural gas pipelines are present in both the Upper and Lower Peninsulas of the state.

5.7.1.4 Minnesota

Currently, there are no known oil or gas reserves or production in Minnesota (EIA 2005d). It is the only state that uses oxygenated gasoline statewide. Several pipelines serve the state's two refineries, while several other pipelines traverse the state, carrying crude oil, petroleum products, and LPG from Canada to markets in other Midwest states. Nearly 68% of the homes in Minnesota use natural gas as their primary heating fuel, while 12% use electricity.

Although no oil or gas production occurs in the state, there are four major crude oil pipelines, two petroleum product pipelines, and four LNG pipelines in the state (EIA 2005d), including about 4,431 mi (7,131 km) of natural gas pipeline (Table 5.26).

5.7.1.5 New York

Among the producing Great Lakes states, New York ranks last and 4th in the number of producing oil and gas wells and also the amount of oil and natural gas production, respectively (Table 5.25). New York ranks 29th in the nation (including Federal offshore areas) in crude oil production (EIA 2005e). The state has no petroleum refineries but relies partly on nearby refineries in New Jersey for its petroleum supplies. Several pipelines carry petroleum products from refineries and ports located along the Delaware River near Philadelphia, Pennsylvania, to population centers in the northern portion of the state near Syracuse, New York. In addition, a major LPG pipeline traverses the state and terminates at Selkirk, New York. Natural gas is the dominant home heating fuel, with a market share of nearly 52%, followed by fuel oil with a 33% share. New York requires reformulated gasoline blended with ethanol in New York City and surrounding metropolitan areas and conventional gasoline in the other regions of the state.

In New York, oil and gas production occurs in about 30% of the counties in the state (Table 5.25). Production is limited to the western portion of the state, including the three shoreline counties adjacent to Lakes Ontario and Erie (and the connecting Niagara River) (IPAA 2005). New York has one major crude oil pipeline, two petroleum product pipelines, and one pipeline for the transportation of LNG (EIA 2005e). There are about 4,726 mi (7,606 km) of natural gas pipeline in the state (Table 5.26).

5.7.1.6 Ohio

Among the producing Great Lakes states, Ohio ranks 1st and 2nd in the number of producing oil and gas wells, respectively (Table 5.25). In production, Ohio ranks 3rd in both natural gas and crude oil production. Nationally, Ohio ranks 19th (including Federal offshore areas) in crude oil production (EIA 2005f). Nearly all of Ohio's crude oil production is derived from stripper wells that provide crude oil to the state's four petroleum refineries. Ohio has a combined crude distillation capacity of 534,305 barrels per calendar day, but it remains dependent on crude oil from other producing states. The state has a large network of product pipelines that connect these refineries to markets in Ohio and adjoining states. Natural gas accounts for the largest share of the home heating market, with 69%, followed by electricity with an 18% share. Ohio is one of the few states that is allowed to use conventional gasoline statewide (EIA 2005f).

Oil and gas production in Ohio occurs in approximately 80% of the counties in the state (Table 5.25). Production occurs in all but the southwestern portion of the state, and all the shoreline counties of Lake Erie (IPAA 2005). Ohio has three major crude oil pipelines, six petroleum product pipelines, and five pipelines for the transportation of LNG (EIA 2005f). Ohio has about 7,612 mi (12,250 km) of natural gas pipeline (Table 5.26).

5.7.1.7 Pennsylvania

Among the producing Great Lakes states, Pennsylvania ranks 1st and 3rd in the number of producing gas and oil wells, respectively (Table 5.25). In production, Pennsylvania ranks 2nd in natural gas production and 4th in crude oil production. Nationally, Pennsylvania ranks 23rd (including Federal offshore areas) in crude oil production, producing only 7,000 bbl/d (EIA 2005g). Like other states in the region, production is mostly from stripper wells. The state's refineries are mostly large-scale facilities located on the Delaware River near Philadelphia, although a few smaller refineries are located in the western part of the state (EIA 2005g). Pennsylvania is required to use reformulated gasoline in the heavily populated eastern section of the state, while lower-vapor-pressure gasoline is required during the summer months in the Pittsburgh metropolitan area. About 51% of the homes in Pennsylvania are heated with natural gas, compared with nearly 26% that are heated by fuel oil.

In Pennsylvania, oil and gas production occurs in nearly half (46%) of the counties of the state (Table 5.25). Production is limited to the western half of the state, including the one Pennsylvania shoreline county along Lake Erie (IPAA 2005). Pennsylvania has no major crude oil pipelines, six petroleum product pipelines, and one pipeline for the transportation of LNG (EIA 2005g). There are about 8,522 mi (13,715 km) of natural gas pipeline in the state (Table 5.26).

5.7.1.8 Wisconsin

Like Minnesota, Wisconsin has no known oil or gas reserves nor production (EIA 2005h). The state is supplied mostly by several product pipelines that originate from refineries in the Chicago, Illinois, and Minneapolis, Minnesota, areas. Wisconsin has one small refinery in the upper reaches of the state near Duluth, Minnesota. Natural gas dominates the home heating market, with a share of 66%, followed by electricity and propane with equal 11% shares (EIA 2005h).

While there is no oil or gas production in the state, there is one major crude oil pipeline, three petroleum product pipelines, and three LNG pipelines (EIA 2005h). Natural gas pipelines in the state total about 3,308 mi (5,324 km) (Table 5.26).