Department of the Army – U.S. Army Corps of Engineers
Chicago District

Known and Potential Environmental Effects of Oil and Gas Drilling Activity in the Great Lakes

Final Report
November 2005

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Known and Potential Environmental Effects of Oil and Gas Drilling Activity in the Great Lakes

A Report to Congress

Prepared by

Department of the Army
U.S. Army Corps of Engineers
Chicago District

November 2005

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NOTATION

The following is a list of the abbreviations, acronyms, chemical symbols, and units of measure used in this document. Some acronyms used only in tables may be defined only in those tables.

GENERAL ACRONYMS, ABBREVIATIONS, AND CHEMICAL SYMBOLS

AD	anno Domini
AEA	Atomic Energy Agency
amsl	above mean sea level
AOC	Area of Concern
ARCO	Atlantic Richfield Corporation
ATSDR	Agency for Toxic Substances and Disease Registry
BC	before Christ
BLM	Bureau of Land Management
CAA	Clean Air Act
CEC	Commission for Environmental Cooperation
CFR	*Code of Federal Regulations*
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CGP	Construction General Permit
CMP	Coastal Management Program
CO_2	carbon dioxide
CRCPD	Conference of Radiation Control Program Directors
CSO	combined sewage overflow
CWA	Clean Water Act
CZARA	Coastal Zone Management Act Reauthorization Amendments
CZMA	Coastal Zone Management Act
DDE	dichloro diphenyl dichloroethylene
DDT	dichloro diphenyl trichloroethane
DEC	Department of Environmental Conservation
DEP	Department of Environmental Protection
DEQ	Department of Environmental Quality
DNR	Department of Natural Resources
DNR OMM	Department of Natural Resources, Office of Minerals Management (Illinois)
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
DOT	U.S. Department of Transportation
EAF	environmental assessment form
EC	Environment Canada

EIA	Energy Information Administration
E.O.	Executive Order
EPA	U.S. Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
E&P	exploration and production
ESA	Endangered Species Act
ESI	environmental sensitivity index
EWA	Energy and Water Appropriations Act of 2002
FR	*Federal Register*
FRP	Facility Response Planning
FY	fiscal year
GLC	Great Lakes Commission
GLIN	Great Lakes Information Network
GLWMF	Great Lakes Waterways Management Forum
GLWQA	Great Lakes Water Quality Agreement
HAP	hazardous air pollutant
H_2S	hydrogen sulfide
IJC	International Joint Commission
ISDH	Indiana State Department of Health
LaMP	Lakewide Management Plan
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MDEQ	Michigan Department of Environmental Quality
MDH	Minnesota Department of Health
MESB	Michigan Environmental Science Board
MMS	Minerals Management Service
MPA	Marine Protected Area
NARM	naturally occurring/accelerator-produced radioactive material
NHPA	National Historic Preservation Act
NOAA	National Oceanic and Atmospheric Administration
NORM	naturally occurring radioactive material
NRC	U.S. Nuclear Regulatory Commission
NRHP	*National Register of Historic Places*
NYSDEC	New York State Department of Environmental Conservation
ODNR	Ohio Department of Natural Resources
OGS	Office of Geologic Survey
OPS	Office of Pipeline Safety
OSC	On-Scene Coordinator

OSHA	Occupational Safety and Health Administration
PBT	persistent bioaccumulative toxic chemicals
PCB	polychlorinated biphenyl
PCDD	polychlorinated dibenzo-p-dioxin
PCDF	polychlorinated dibenzofuran
PEIS	programmatic environmental impact statement
P.L.	Public Law
RAP	Remedial Action Plan
RCRA	Resource Conservation and Recovery Act
ROW	right-of-way
SDWA	Safe Drinking Water Act
SHPO	State Historic Preservation Office
SLSDC	St. Lawrence Seaway Development Corporation
SLSMC	St. Lawrence Seaway Management Corporation
SPCC	Spill Prevention Control and Countermeasures
SVOC	semivolatile organic compound
TENORM	technologically enhanced naturally occurring radioactive material
TRI	Toxic Release Inventory
UIC	underground injection control
U.S.	United States
USC	*United States Code*
USCG	U.S. Coast Guard
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
UST	underground storage tank
VOC	volatile organic compound
3-D	three-dimensional
4-D	four-dimensional

UNITS OF MEASURE

bbl	barrel(s)	ft	foot (feet)
		ft^3	cubic foot (feet)
Ci	curie(s)		
cm	centimeter(s)	gal	gallon(s)
cm^2	square centimeter(s)	g	gram(s)
d	day(s)	h	hour(s)
		ha	hectare(s)

in.	inch(es)
km	kilometer(s)
km^2	square kilometer(s)
km^3	cubic kilometer(s)
L	liter(s)
m	meter(s)
m^2	square meter(s)
m^3	cubic meter(s)
Mgal	millions of gallons
mi	mile(s)
mi^2	square mile(s)
mi^3	cubic mile(s)
mrem	millirem(s)
MWe	megawatt(s) electrical
pCi	picocurie(s)
ppb	part(s) per billion
ppm	part(s) per million
s	second(s)
t	metric ton(s)
μR	microroentgen(s)
yr	year(s)

ACKNOWLEDGEMENTS

The U.S. Army Corps of Engineers (Corps), Chicago District, wishes to acknowledge the assistance of Argonne National Laboratory (Argonne) in conducting this study and developing this report. Technical and project management staff from the Environmental Science (EVS) and Decision and Information Sciences (DIS) Divisions of Argonne included:

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The following Argonne staff provided internal technical review of this report:

Karen Smith (EVS) John Veil (EVS)

The following staff from the Information and Publishing Division at Argonne were critical in editing and producing this report:

Pat Hollopeter Marita Moniger Linda Graf
Louise Kickels Mary Fitzpatrick Lorenza Salinas
Michelle Nelson Suzanne Williams

The Corps would like to thank the following individuals who served as Subject Matter Experts and provided independent technical reviews of the draft and interim final reports, as well as providing information, contributing to text, or making helpful comments to this report:

Dr. James L. Coleman, Eastern Resources Energy Team, U.S Geological Survey
Dr. John R. Halsey, Office of the State Archeologist, Michigan Historical Center
Dr. Charles E. Herdendorf, the Ohio State University and EcoSphere Associates

Finally, the following Corps staff served as technical reviewers of this report:

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Executive Summary

Section 503 of the Energy and Water Appropriations Act (EWA) of 2002 directed the United States Army Corps of Engineers (USACE) to "conduct and submit to Congress a study that examines the known and potential environmental effects of oil and gas drilling activity in the Great Lakes (including effects on the shorelines and water of the Great Lakes)." The House Energy and Water Appropriations Subcommittee requested that USACE initiate the study in June 2004 and full study funding was received in March 2005. This report presents a review and synthesis of existing information pertaining to the environmental and economic setting and natural resources of the Great Lakes Basin, and the potential environmental effects that oil and gas extraction beneath the Great Lakes could have on those settings and resources. This study is restricted to U.S. water and shoreline areas. It does not address or recommend any particular Federal action and is intended for informational use.

The Great Lakes, including Lakes Superior, Michigan, Huron, Erie, and Ontario are among the largest and deepest lakes in the world. The Great Lakes Basin falls in portions of Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, New York, and Canada. The Basin is important not only because of its unique and valuable natural resources (such as wetlands, fish and wildlife, cultural and archeological resources, and drinking water supplies), but also because of its large population and industrial centers, and because it serves as a major maritime transportation link. The Basin contains a wide variety of habitats that support diverse plant and animal life including more than 130 species and natural communities that have been identified as imperiled by Federal, state, and local agencies. It supports a multibillion dollar recreation and tourism industry and contains 678 state parks, 110 of which are located on coastlines of the Great Lakes. Cultural resources in the Basin include archaeological sites and historic structures present on land and underwater. Water from the Great Lakes is used for residential, farming, industrial, and energy production purposes, which account for approximately 18% of the total daily U.S. use of fresh water.

Oil and gas production includes exploration, drilling, extraction, and treatment. During exploration, geologic formations are surveyed and mapped using seismic technology to determine the formation's potential for oil and gas production and to identify optimal drilling locations. Exploration also involves drilling exploratory wells to determine whether oil or gas production from a formation is economically feasible. During extraction, the well site is established. Well site infrastructure may include onsite disposal pits, well pads, access roads, utility corridors, and pipelines. A main borehole is drilled, its walls strengthened with metal casing, and a wellhead is installed. Wells may be vertical (drilled in a vertical line from the well pad to a deposit), slant (drilled at an angle from the well pad to a deposit), or directional (drilled vertically first and then angled to reach a deposit). Directional drilling also allows multiple deposits to be accessed from a single well pad. Potentially toxic materials may be produced during drilling that require proper containment and disposal. During treatment, naturally occurring unwanted materials or impurities (such as salt water or organic compounds) are

removed from the oil or gas. The treated oil or gas is temporarily stored at the well site before being transported offsite to a commercial refinery or a storage and distribution facility.

Oil and gas reserves under the Great Lakes have been accessed by the United States and Canada. Potential oil and gas source rocks are present beneath Lakes Michigan, Huron, Erie, and Ontario, and throughout much of the Great Lakes Basin. U.S. oil and gas production currently occurs in each of the Great Lakes Basin States except Minnesota and Wisconsin, but not under the lakes themselves. Reserves under the Great Lakes have been accessed via offshore vertical drilling and onshore directional drilling. Approximately 2,200 vertical gas extraction wells have been drilled under the Canadian portion of Lake Erie since 1913, and 13 oil and gas wells have been drilled in Michigan under Lakes Michigan and Huron from onshore locations via directional drilling since 1979. Of the three oil spill incidents reported on the Canadian side of Lake Erie since 1959, only one was directly attributed to a drilling operation. There have been no reported oil releases from subsurface formations into overlying waters during any Canadian drilling or production operations.

Potentially adverse environmental effects of oil and gas drilling under the Great Lakes may be associated with drilling and well site construction, and accidental release of oil or production wastes. Well drilling and the construction of the well site and associated infrastructure has the potential to directly impact fish and wildlife habitats by clearing land areas or disturbing lake bottoms. In some areas of the Basin, the visual intrusion of oil and gas developments could reduce the desirability of these areas for tourism and other recreational uses. Accidental releases of oil and drilling waste could incur consumption bans on fish and game, impact fish and wildlife habitats, disrupt recreation and tourism, and, depending on the proximity of water intakes, contaminate public drinking water supplies. These effects could be short or long-term in nature, depending on the location and magnitude of the release and the quality of the resource that was affected.

Some of the potential effects of oil and gas drilling may be mitigated through compliance with state and Federal regulations, restrictions, and requirements for oil and gas leases, and through the use of new technologies. State and Federal regulations require the avoidance of endangered species, recreational areas, wetlands, and unique habitats. State and Federal programs include requirements for spill prevention, reporting, and response to minimize the likelihood, magnitude, and effects of accidental spills. As drilling technology advances, it may be possible to access more gas deposits from fewer well locations than is currently possible. In addition, new advances in spill containment may further reduce the number and severity of oil and gas releases by minimizing the potential for accidental spills and by promoting rapid containment and cleanup.

1 INTRODUCTION

1.1 STUDY AUTHORITY

Section 503 of the Energy and Water Appropriations (EWA) Act of 2002 directed the U.S. Army Corps of Engineers (Corps) to "conduct and submit to Congress a study that examines the known and potential environmental effects of oil and gas drilling activity in the Great Lakes (including effects on the shorelines and water of the Great Lakes)." The guidance for the 2002 EWA, approved by the Assistant Secretary of the Army (Civil Works), was to initiate the study when specific funding was provided. In June 2004, the House Energy and Water Appropriations Subcommittee requested that the Corps initiate the study, and full study funding was received in March 2005.

Section 503 of the EWA of 2002 further established a 2-year moratorium on all Federal and state permits and leases for new oil and gas drilling in or under the Great Lakes. That moratorium was subsequently extended through fiscal year (FY) 2005 (Section 505 of the Consolidated Appropriations Resolution of 2003) and again through FY 2007 (Section 504 of the Consolidated Appropriations Act of 2005). In July, 2005, Congress issued a permanent ban on the issuance of Federal and State permits or leases for new oil and gas drilling in the Great Lakes, which the President signed into law on August 8, 2005 (the Energy Policy Act of 2005). Specifically, Section 386 of this Act bans the issuance of "Federal or State permits or leases for new oil and gas slant, directional, or offshore drilling in or under one or more of the Great Lakes."

This study was coordinated with other Federal agencies through the Regional Working Group of the Great Lakes Interagency Task Force established under Executive Order (E.O.) 13340 (U.S. President 2004). Federal departments and agencies participating in the Task Force include the U.S. Environmental Protection Agency (EPA), Council on Environmental Quality, and the Departments of the Army, Interior, Agriculture, Commerce, Transportation, State, Housing and Urban Development, and Homeland Security. The study was also coordinated with the U.S. Department of Energy (DOE).

1.2 STUDY PURPOSE

The purpose of this study was to identify the potential effects that oil and gas exploration and production (E&P) might have on the Great Lakes Basin and its resources. The study reviewed and synthesized existing information in order to characterize the potential environmental effects that could be incurred if gas and oil resources beneath the Great Lakes were to be developed. The study was not intended to be all inclusive or site-specific, but rather to provide a comprehensive review of oil and gas technology and the potential effects that could occur with the development of oil and gas resources beneath the Great Lakes. This report identifies data gaps that would need to be addressed should detailed, site-specific analyses be necessary. This environmental report does not address nor recommend any particular Federal action and is intended for informational purposes only.

1.3 LOCATION OF STUDY

The Great Lakes constitute the largest system of fresh surface water in North America, containing nearly 20% of the world's supply. The Great Lakes Basin, which includes Lakes Superior, Michigan, Huron, Erie, and Ontario and their drainage basins in the states of Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, and New York (Figure 1.1), is a major economic, population, and resource center for both the United States (U.S.) and Canada. The discussions regarding the current status of resources within the Great Lakes Basin, the past and current production of oil and gas within the Basin, and the potential environmental effects that could be associated with development of offshore oil and gas resources are limited to the U.S. portion of the Great Lakes and Basin (up to the Lake Ontario outfall to the St. Lawrence River). It should be acknowledged that many of the natural resources provided by the Great Lakes Basin are shared by the United States and Canada, and that activities within the U.S. portion of the Basin may affect Canadian resources and activities within the Basin (and visa versa). Each Great Lakes state has a portion of its boundary within a lake, and any oil or gas development of resources beneath the lakes would occur within the political boundaries of the states.

Great Lakes Demographics

- 25 U.S. cities with more than 100,000 residents are within 100 mi (160 km) of a Great Lakes port.
- 29% of the U.S. population lives in the Great Lakes Basin.
- 30% of U.S. personal income is distributed in the eight Great Lakes states.
- 31% of the U.S. population over 65 resides in the Great Lakes states.

Gas and oil resources underneath the Great Lakes have been or are currently being accessed by vertical wells in Lake Erie (e.g., 2,200 offshore wells in Ontario, Canada, since 1913) and by slant drilling underneath Lake Michigan (13 wells in Michigan since 1979). Potential gas and oil resources occur within a number of geologic formations in the Basin, primarily under Lakes Ontario, Erie, and Michigan, and southwestern Lake Huron. Currently within the Basin, active oil and gas production occurs within each of the Basin states except Wisconsin and Minnesota. This production is accessing oil and gas reserves located onshore and not beneath the lakes.

1.4 REPORT ORGANIZATION

Section 1 of this report introduces the study and report. Section 2 describes the technologies currently used for oil and gas exploration and extraction, while Section 3 provides an overview of the types of environmental effects associated with oil and gas drilling, both in the Great Lakes Basin and elsewhere. Section 4 provides an overview of the current regulatory background affecting oil and gas exploration in the Great Lakes, as well as other environmental regulations and policies that could apply if exploration and development were to occur. The current environmental setting of the Great Lakes Basin, including the distribution and status of oil and gas resources, other natural resources (such as fish and wildlife, wetlands, and water quality), and human activities (such as recreation, land and water use, shipping, and current oil and gas production within the Basin) within the region, is described in Section 5. The types of potential effects, and the resources that could be affected, if oil and gas beneath the Great Lakes

were to be developed are identified and discussed in Section 6. Section 7 summarizes the report, while Section 8 presents the references cited in the report.

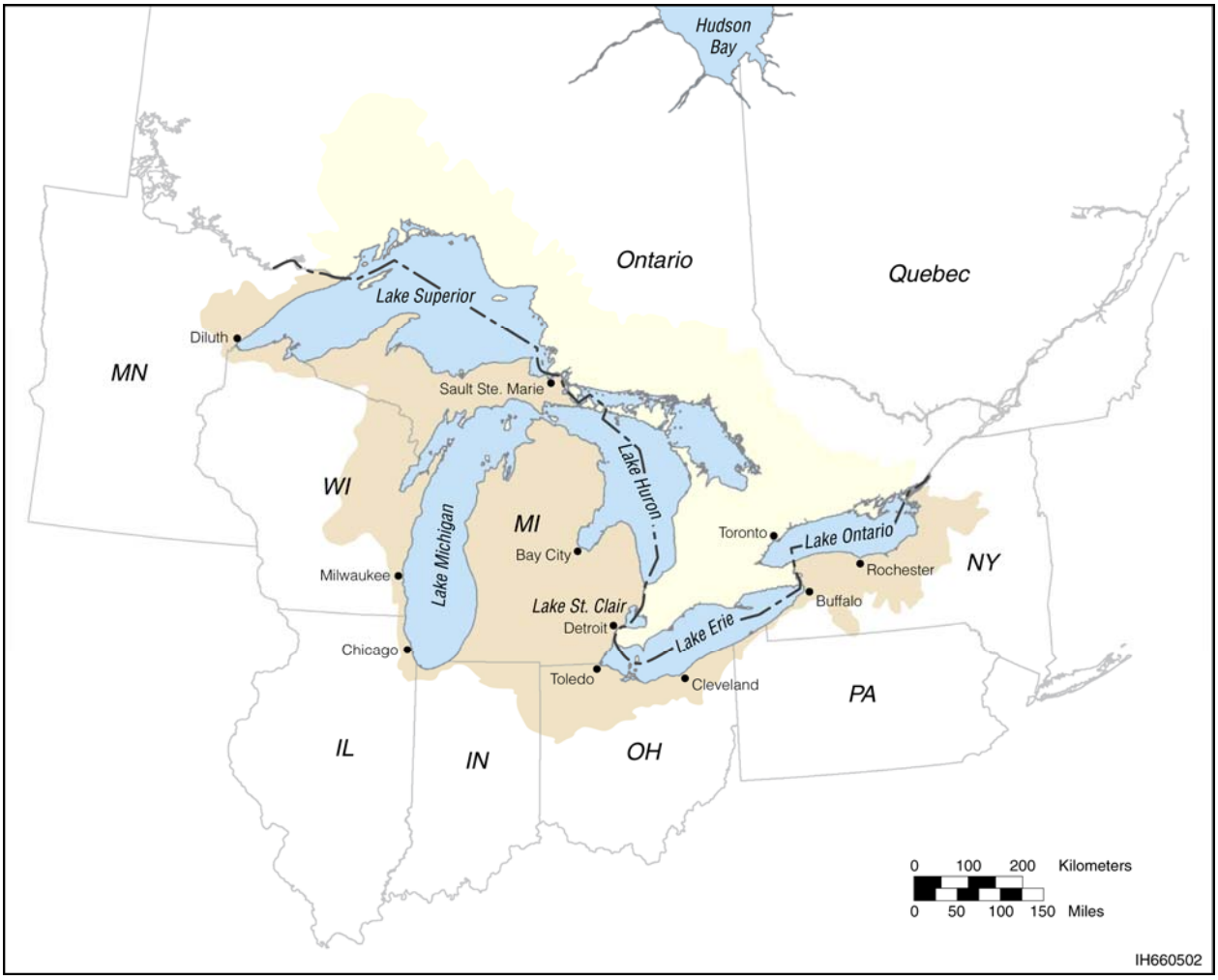

FIGURE 1.1 The Great Lakes Basin

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2 OIL AND GAS EXPLORATION AND DRILLING TECHNOLOGY

A variety of technologies are employed in the oil and gas industry to identify oil and gas reserves, to access those reserves, and to extract and deliver the products. The following subsections provide an overview of current technologies employed in oil and gas exploration and drilling.

2.1 OIL AND GAS EXPLORATION

The exploration for oil and gas, which may be quite time- and effort-intensive and rely on the collection and detailed analyses of extensive geologic information, involves a number of activities, including the following:

- Surveying and mapping surface and subsurface geologic features with techniques such as seismic reflection to identify areas (called hydrocarbon traps) where oil and gas may have accumulated;

- Determining a geologic formation's potential for containing commercial quantities of economically producible oil and/or gas;

- Identifying the best locations to drill an exploratory well to test the hydrocarbon traps;

- Drilling exploration and delineation wells to determine where hydrocarbons are present and to measure the area and thickness of the oil- and/or gas-bearing reservoir or reservoirs;

- Logging and coring wells to measure the permeability, porosity, and other properties of the geologic formation(s) encountered; and

- Completing construction of wells and site facilities deemed capable of producing commercial quantities of oil and/or gas.

While past surveying and mapping activities employed invasive techniques that included explosive seismic profiling and extensive drilling to map and locate potential reservoirs, modern exploration involves the use of non-explosive reflection seismic profiling, together with seismic imaging software and computers, to interpret geological and geophysical data more completely and to manage, visualize, and evaluate greater amounts of data more quickly and efficiently. Reflection seismic profiling transmits acoustic vibrations (seismic waves) underground. As these waves travel through different rock layers, some are reflected backward by the different subsurface layers to an array of receiving (detecting) geophones (or hydrophones, if in water). These reflections off of subsurface layers are then used to generate multidimensional representations of the subsurface.

2.1.1 Onshore Seismology

In practice, using seismology for exploring onshore areas involves artificially creating seismic waves, the reflections of which are then picked up by sensitive pieces of equipment called geophones embedded in the ground or placed on the ground surface (Figure 2.1). The data picked up by these geophones are then transmitted to a seismic recording truck that records the data for further interpretation by geophysicists and petroleum reservoir engineers.

In the past, seismic waves were created using dynamite. Today, most seismic crews use nonexplosive seismic technology to generate the required data. This nonexplosive technology usually consists of wheeled or tracked vehicles carrying special equipment (a vibrator) designed to create a series of vibrations, which in turn creates seismic waves. Other seismic sources include dropped weights and air guns.

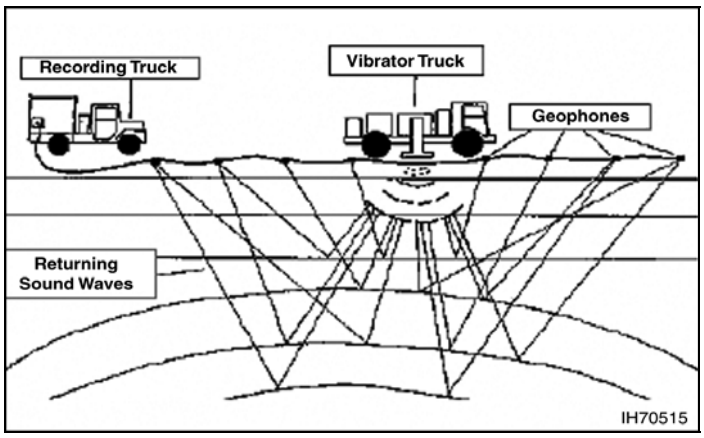

FIGURE 2. 1 Onshore Seismology Using a Vibration Truck as a Seismic Energy Source (Source: modified from DOE 2005a)

2.1.2 Offshore Seismology

Offshore seismic exploration is similar to onshore exploration, but rather than trucks and geophones, a ship is used to convey equipment needed to generate the seismic waves and gather the seismic data, and hydrophones are used to pick up seismic waves underwater (Figure 2.2) (Natural Gas Supply Association 2004a). The hydrophones are towed behind a ship in various configurations, depending on the needs of the geophysicist. Rather than using dynamite or impacts on the seabed floor, the seismic ship uses a large air gun that releases bursts of compressed air under water to create seismic waves that travel through the earth's crust and generate the necessary seismic reflections.

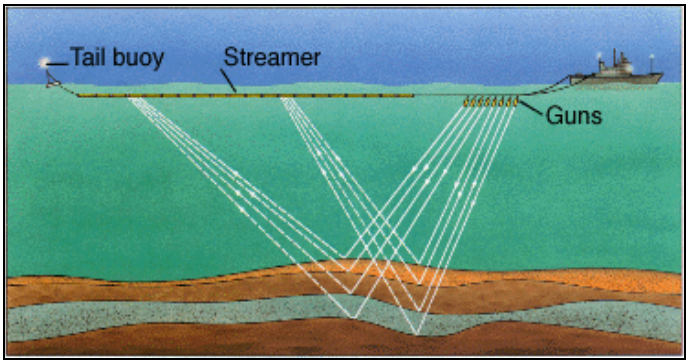

FIGURE 2. 2 Offshore Seismic Exploration (Source: Schlumberger Limited 2005)

2.1.3 Exploratory Wells and Logging

Once a specific location has been identified as potentially containing oil and/or gas deposits, one or more exploratory wells are drilled to provide information on the composition of the underground rock layers and their geological and geophysical properties.

Well logging refers to performing tests during or after the drilling process to allow geologists and drill operators to monitor the progress of the well drilling, to gain a clearer picture of subsurface formations, and to identify specific rock layers, in particular those that represent target zones for further exploration. There are many different types of logging; more than 100 different logging tests can be performed to help characterize the composition and characteristics of the different layers of rock through which the well passes. Following interpretation of the logging data, a determination can be made as to whether or not to proceed with the installation of production wells. Logging is also used to monitor the drilling process and to ensure that the correct drilling equipment, materials, and supplies (such as drilling muds), are being used and that drilling is not continued if unfavorable surface or subsurface conditions develop.

Two of the most common types of logging are sample and wireline. Sample logging consists of examining and recording the physical aspects of the rock penetrated by a well. Drill cuttings (rock that is displaced by the drilling of the well) and core samples (intact underground rock samples) may be collected from the exploratory well and physically examined to describe the subsurface rock, determine the position and thickness of the various layers of rock, and estimate (with cuttings) or determine (with cores) the porosity and fluid content of the subsurface rock. Wireline logging consists of lowering a device used to measure the electrical, acoustic, or radiological properties of the rock layers into the downhole portion of the well to provide an estimate of the fluid content and characteristics of the various rock layers through which the well passes.

2.2 OIL AND GAS WELL DRILLING

Today, almost all oil and gas wells are drilled using rotary drilling. In rotary drilling, a length of steel pipe (the drillpipe) with a drill bit on the end is rotated to cut a hole called the well bore. As the well goes deeper, additional sections of drillpipe are added to the top of the rotating drill string. Rotary drilling uses a steel tower to support the drillpipe. If the tower is part of a tractor-trailer and is jacked up as a unit, it is called a mast. If it is constructed on site, it is called a derrick. Both towers are constructed of structural steel and sit on a flat steel surface called the drill or derrick floor; this is where most of the drilling activity occurs. Four major systems comprise an operational rotary drilling rig: the power supply, the hoisting system, the rotating system, and the circulating system.

An operational rig requires a dependable power supply in order for the other rig systems to operate. Power to these systems may be supplied through one or more diesel engines used alone or in conjunction with an electrical power supply.

The hoisting system raises, lowers, and suspends equipment in the well and typically consists of a drilling or hoisting line composed of wound steel cable spooled over a revolving reel. The cable passes through a number of pulleys, including one suspended from the top of the derrick or mast. The hoisting system is used to move drillpipe into or out of the well.

The rotating system includes the turning drillpipe, the drill bit, and related equipment. It cuts the well bore, which may have an initial diameter of 20 in. (51 cm) or more but is usually less. The drill bit is located at the bottom end of the first drillpipe within the rotating system. The drillpipe is rotated by a rotary table located on the derrick floor. The drillpipe consists of heat-treated alloy steel and may range in length from 18 to 45 ft (5 to 14 m); drillpipe length is typically uniform at each individual drilling rig. Before the drillpipe is fully inserted into the well bore, another section of drillpipe is added.

During drilling, the circulating system pumps drilling mud or fluids into the well bore to cool the drill bit, remove rock chips, and control subsurface fluids. Typically, mud is circulated down through the hollow drillpipe. The mud exits the pipe through holes or nozzles in the drill bit, and returns to the surface through the space between the drillpipe and the well bore wall.

2.2.1 Drilling Muds

Drilling muds (also termed fluids) are used during the drilling process to transport rock chips (cuttings) from the bottom of the well up and out of the well bore, where the cuttings are screened and removed, and the separated mud is reused. Drilling muds also act to cool the drill bit, to stabilize the well walls during drilling, and to control formation fluids that may flow into the well.

The most common drilling mud is a liquid-based mud typically composed of a base fluid (such as water, diesel oil, mineral oil, or a synthetic compound), with optional additives such as weighting agents (most commonly barium sulfate), bentonite clay (to help remove cuttings and to form a filler cake on the well bore walls), and lignosulfates and lignites (to keep the mud in a fluid state) (DOE 2005c). Water-based muds and cuttings can be readily disposed of at most onshore locations, and in many U.S. offshore waters offshore disposal occurs as long as applicable regulatory effluent guidelines are met. In contrast, oil-based muds from onshore wells have more stringent land disposal requirements and are prohibited from discharge from offshore well platforms. Synthetic-based muds use nonaqueous chemicals (other than oils) as their base fluid, such as internal olefins, esters, linear alpha-olefins, or linear paraffins. While these fluids have a lower toxicity, undergo more rapid biodegradation, and have a lower bioaccumulation potential than oil-based fluids, they are also prohibited from offshore discharge.

2.2.2 Blowout Preventer

All drilling sites include a blowout preventer. The blowout preventer, which is routinely used in onshore and offshore drilling, is intended to prevent oil, gas, and/or other subsurface liquids (i.e., salt water) from leaving the well and escaping into the atmosphere, onto the ground,

into adjacent water bodies, or overlying waters. At the bottom of a well, there are two fluid pressures. Pressure on fluids in the formation tries to force the fluids to flow from the formation into the well. Pressure exerted by the weight of the drilling mud filling the well tries to force the drilling mud into the surrounding rocks. Under normal operations, the effective weight of the drilling mud is adjusted to exert a slightly greater pressure on the bottom of the well than the effective pressure on the fluid in the rocks, causing the mud to enter the rock and cover the sides of the well and thus stabilize the well. If the pressure on the fluid in the rocks is greater than the pressure of the drilling mud, water, gas, or oil will flow out of the rock into the well. In extreme cases, a blowout occurs where the fluids flow uncontrolled into the well and on occasion violently to the surface. A blowout preventer is a device that is used to close off a well if there is a loss of control of the fluids in the formation. There are a variety of types of blowout preventers. Some close over the top of the well bore, some are designed to seal around the tubular components in the well (such as the drillpipe, casing, or tubing), and some have hardened steel shearing surfaces that actually cut through the drillpipe to seal off the opening.

2.2.3 Offshore Drilling

A major difference between onshore and offshore drilling is the nature of the drilling platform. In addition, in offshore drilling the drillpipe must pass through the water column before entering the lake or seafloor. Offshore wells have been drilled in waters as deep as 10,000 ft (305 m). The following text provides an overview of drilling in offshore environments.

2.2.3.1 Drilling Template

Offshore drilling requires the construction of an artificial drilling platform, the form of which depends on the characteristics of the well to be drilled. Offshore drilling also involves the use of a drilling template that helps to connect the underwater drilling site to the drilling platform located at the water's surface. This template typically consists of an open steel box with multiple holes, depending on the number of wells to be drilled. The template is installed in the floor of the water body by first excavating a shallow hole and then cementing the template into the hole. The template provides a stable guide for accurate drilling while allowing for movement in the overhead platform due to wave and wind action.

2.2.3.2 Drilling Platforms

There are two types of basic offshore drilling platforms, the movable drilling rig and the permanent drilling rig. The former is typically used for exploration purposes, while the latter is used for the extraction and production of oil and/or gas.

A variety of movable rigs are used for offshore drilling. Drilling barges are used in shallow (<20 ft [<6 m] water depth), quiet waters such as lakes, wetlands, and large rivers. As implied by the name, drilling barges consist of a floating barge that must be towed from location to location, with the working platform floating on the water surface. In very shallow waters,

these may be sunk to rest on the bottom. They are not suitable for locations with strong currents or winds and strong wave action. Like barges, jack-up rigs are also towed, but once on location three or four legs are extended to the lake bottom while the working platform is raised above the water surface; thus, they are much less affected by wind and water current than drilling barges. Submersible rigs are also employed in shallow waters and, like jack-up rigs, are in contact with the lake bottom. These rigs include platforms with two hulls positioned above one another, with the lower hull acting like a submarine. When being towed to a new location, the lower hull is filled with air and serves to float the entire platform. Once on location, the lower hull is filled with water, and the rig sinks until the legs make contact with the lake bottom. As with the previous movable rigs, use of this type is limited to shallow water areas. Because of their size and relative ease of transport to drill sites, shallow water rigs would be the most likely type of rig that could be employed in the Great Lakes.

The most common movable offshore drilling rig is the semi-submersible rig. It functions in a similar manner to the submersible rig, with a lower hull that can be filled or emptied of water. However, this type of rig does not contact the lake floor but floats partially submerged and is held in place through a number of anchors. This type of rig provides a stable and safe working platform in deeper and more turbulent offshore environments, and when high reservoir pressures are expected. The final type of movable drilling rig is the drillship. These are ships designed to carry drilling platforms great distances offshore and in very deep waters. A drilling platform and derrick are located in the middle of a large, open area of the ship, and the drill is extended through the ship to the drilling template.

When exploratory drilling locates commercially viable oil or gas deposits, a more permanent drilling platform is required to support well completion and oil and/or gas extraction. A variety of such production platforms are used for offshore drilling. Fixed platforms are typically used in areas with water depths less than 1,500 ft (457 m) and would be the most likely type of production platform that would be used in the Great Lakes. These platforms contact the bottom using concrete or steel legs and are either directly attached to, or simply rest on, the bottom. A variety of other production platforms are available for deeper water conditions and would probably not be applicable for use in the Great Lakes.

2.2.4 Drilling Techniques

Several types of drilling techniques are currently employed in oil and gas drilling: straight hole drilling, directional drilling, horizontal drilling, air drilling, and foam drilling. Regardless of the drilling technique, a well is typically drilled in a series of progressively smaller-diameter intervals. Thus, wells typically exhibit their largest diameter at the surface and smallest diameter at the end of the well.

2.2.4.1 Straight Hole Drilling

In straight hole drilling, the well bore is vertical and deviates by no more than 3 degrees anywhere along the well bore, and the bottom of the well deviates by no more than 5 degrees

from the starting point of the well bore at the drilling platform. With straight hole drilling, the drill bit may be deflected if it contacts fault zones or dipping beds of hard rock layers.

2.2.4.2 Directional and Horizontal Drilling

Directional drilling (also termed slant drilling) involves the drilling of a curved well to reach a target formation (Figure 2.3). Directional drilling is employed when it is not possible, practicable, or environmentally sound to place the drilling rig directly over the target area. Directional drilling is especially useful for offshore locations. With directional drilling, it may take several thousand feet for the well to bend from drilling vertically to horizontally.

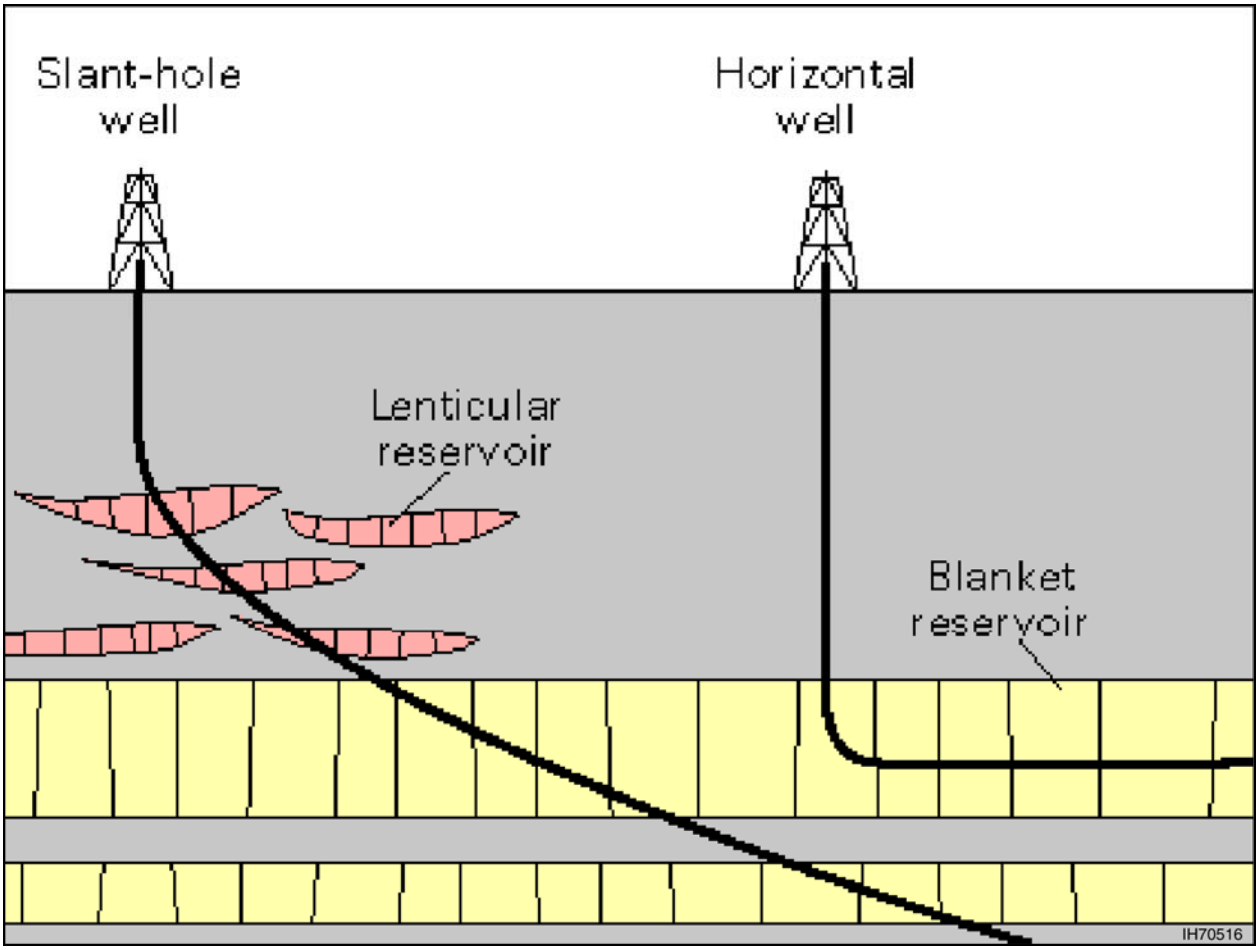

FIGURE 2.3 Directional (Slant) and Horizontal Drilling (Natural Gas Supply Association 2004b)

Horizontal drilling is a form of directional drilling in which a 90-degree turn in the well may be made within a few feet (Figure 2.3). There are three main types of horizontal wells. Short-radius wells have a curvature radius of 20 to 45 ft (6 to 14 m) and can be easily dug out from existing vertical wells. This allows for the development of several wells accessing multiple

reservoirs from a single drilling platform. Medium-radius wells have typical curvatures of 300 to 700 ft (91 to 213 m), with a horizontal extension up to 3,500 ft (1,067 m). Long-radius wells typically have curvatures of 1,000 to 4,500 ft (305 to 1,372 m) and can extend horizontally out to about 15,000 ft (457 m). Long-radius wells are typically used to access offshore deposits (Natural Gas Supply Association 2004).

Horizontal drilling is especially effective in accessing productive formations that are not thick but extend over a large lateral area. Prior to the advent of directional drilling, such formations were either uneconomical or required multiple wells to recover the hydrocarbons. A single horizontal well can contact more of the reservoir and therefore takes the place of several traditional vertical wells. Because the well bore from the surface to the producing formation is drilled only once, a horizontal well generates less waste than several vertical wells (DOE 2005b).

2.2.4.3 Air and Foam Drilling

Air drilling employs a rotary drilling rig that uses air rather than drilling mud to remove drill cuttings. The drilling rig and operations would be identical to those for a rotary drilling rig, except that there would be no drilling mud circulating system. Instead of a mud, air would be pumped down the drill string and out the drill bit, forcing cuttings up and out of the well bore. While air drilling has a faster penetration rate than mud-based drilling, it does not build up a filler cake and stabilize the walls of the well bore, nor can it control formation fluids. In addition, natural gas flowing into the well can form a flammable mixture with the injected air. Air drilling is typically used in low permeability and porosity reservoir intervals where oil or water are not expected to be encountered during drilling. If (or when) natural gas is encountered during drilling, the gas may be safely combusted at the drill site using a flaring device over a waste containment pit. Foam drilling is similar to air drilling but mixes detergents with the air and a small volume of water to form a foam that is better at removing cuttings and water from the well.

2.2.5 Well Completion

Once a well has been drilled and verified to be commercially viable, it must be completed to allow for the flow of oil or gas. The completion process involves the strengthening of the well walls with casing and installing the appropriate equipment to control the flow of oil or gas from the well. Casing consists of a stacked series of metal pipes installed into the new well in order to strengthen the walls of the well hole, to prevent fluids and gases from seeping out of the well as it is brought to the surface, and to prevent other fluids or gases from entering the rock formations through which the well was drilled.

Casing extends from the surface to the bottom of the well and is typically steel pipe with a diameter that may range from 4.5 to 36 in. (11 to 91 cm). Casing with a diameter slightly smaller than that of the well hole is inserted into the well, and a wet cement slurry is pumped between the casing and the sides of the well. Casing is installed as the well is progressively drilled deeper. The top interval of the well, extending from the surface to a depth below the lowermost drinking water zone, is the first to be completed, being cemented from the surface to

below the drinking water zone. Next, a smaller diameter hole is drilled to a lower depth, and then that segment is completed. This process may be repeated several times until the final drilling depth is reached.

Another aspect of well completion is the selection of an appropriate intake configuration for the well. Intake configurations are designed to permit the flow of oil or gas into the well, and the selection of a particular intake type will depend on the nature of the formation surrounding the intake portion of the well. Well completion also involves the installation of an appropriate wellhead. A wellhead is the permanent equipment mounted at the opening of the well that is used to regulate and monitor oil or gas extraction from the well. The wellhead also prevents oil or gas leakage from the well and blowouts due to high-pressure formations associated with the well. For wells with sufficient pressure for the oil or gas to reach the surface without assistance, the wellhead will include a series of valves and fittings to control the flow. Gas wellheads in the Canadian waters by Lake Erie are located on the lake bottom because of winter ice and navigational concerns. Such wellheads would likely be used for any offshore wells in U.S. waters of the Great Lakes.

Most modern (or recently drilled) onshore U.S. oil wells do not have enough internal pressure for the oil to flow to the surface. For such oil wells, lifting equipment or well treatment is used to bring the oil to the surface. Lifting equipment typically involves the use of some type of mechanical surface or downhole pump. Well treatment involves the injection of acid, water, or gases into the well to open the formation and allow oil to flow more freely through it and into the well. For some oil wells, a compressed gas (often natural gas collected from the oil well) is injected into the well. This gas dissolves into the oil, forming bubbles that lighten the oil and bring it to the surface. For wells in limestone or carbonate formations, acid may be injected under pressure to dissolve portions of the rock and thus create spaces that enhance the flow of oil. Fracturing involves the injection of a fluid that cracks or opens up fractures in the oil-bearing formation. In some cases, propping agents may be added during the injection. Propping agents are materials that act to prop open newly widened fractures; these agents can consist of sand or glass beads. While well treatment has been used more often for oil wells, it has also been used to increase extraction rates in gas wells.

2.2.6 Drilling and Production Site Size

The oil and gas industry is addressing the issue of habitat loss by reducing the footprint of drilling and production facilities (DOE 1999; Arscott 2004). Facility footprints have been reduced through the use of laterals drilled from individual wells. Laterals are short, horizontal branches drilled from a single well bore. With current technology, several laterals may be drilled off the main vertical well bore to reach individual reservoirs. In these cases, the main well bore is drilled once, followed by the drilling of several smaller-diameter lateral well bores (Figure 2.4). With this type of drilling, only a single surface drilling location may be needed to access multiple reservoirs, and/or a greater portion of a single reservoir, thus greatly reducing the amount of surface disturbance and the total volume of drilling wastes that would be generated if multiple surface wells were drilled. For example, BP's Alaska Kuparuk field uses a 55-acre (22-ha) facility as an operations base compared with a 1,000-acre (405-ha) site providing

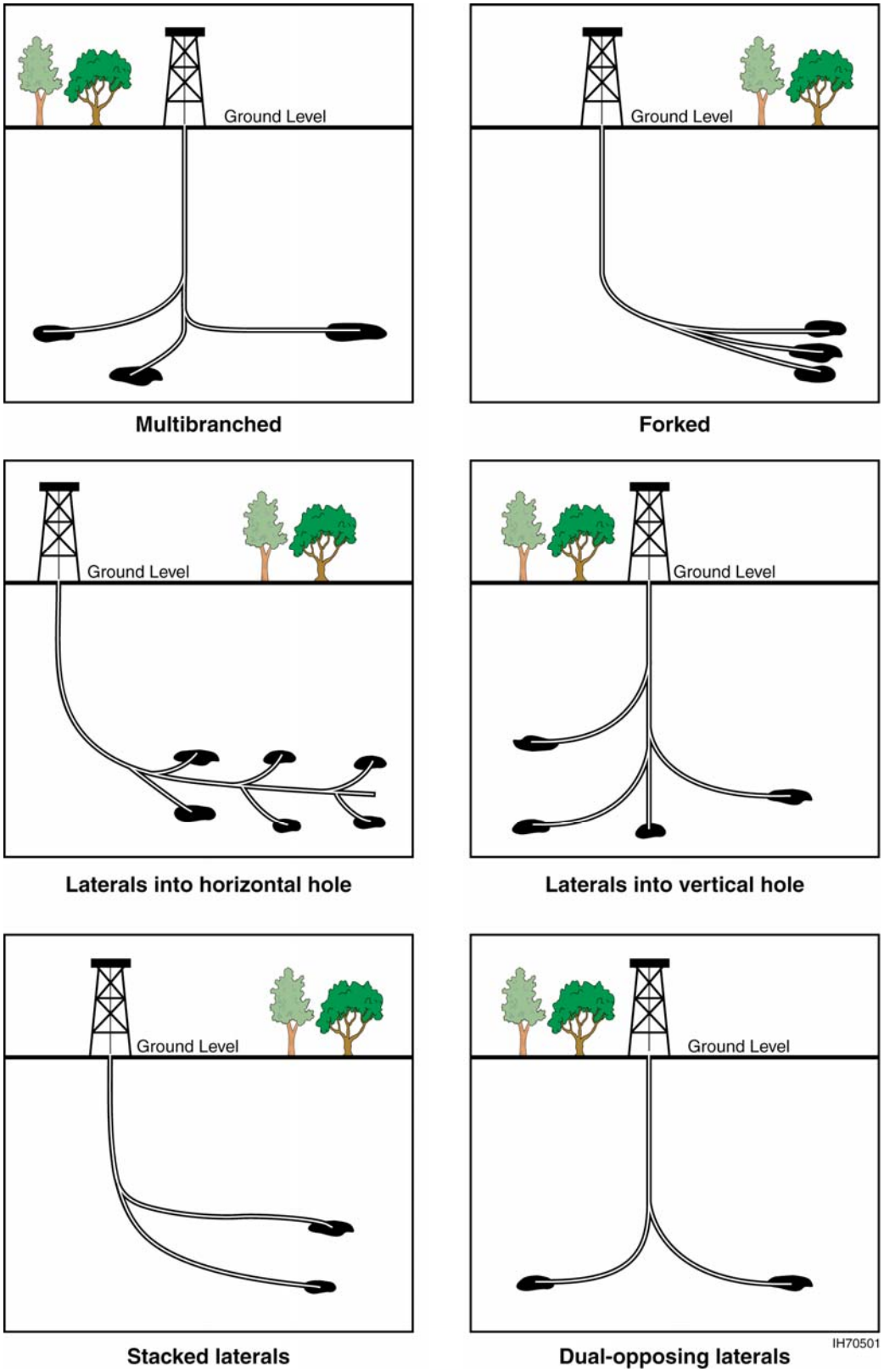

FIGURE 2.4 Examples of the Types of Lateral Well Bores That May Be Drilled from a Single Location to Access Multiple Reservoirs

similar facilities in the original Prudhoe Bay field. If the entire Prudhoe Bay oil field were built with today's technology, its footprint would be 64% smaller than its current size. The area impacted by drilling pads would be 74% smaller; roads would cover 58% less surface area; and oil and gas separating facilities would take up 50% less space. Today, new production pads are up to 70% smaller than the original Prudhoe pads, and spacing between wellheads has been reduced dramatically.

2.2.7 Post-Production Treatment and Storage

Once the oil or gas reaches the wellhead, it enters into a steel, plastic, or fiberglass flowline and is directed to separation and storage equipment. For multiple wellheads, separation and storage may occur at each well or at a central processing unit. Oil wells often produce natural gas and water as well as oil. If there is natural gas and water vapor flowing through the flowline, a hydrate may form that blocks the flowline. To prevent this, heaters can be installed on the flowlines, or chemicals such as glycol or methanol can be added to the produced fluids to prevent hydrate formation. Natural gas produced at a well often needs to be processed prior to its sale. Impurities in the gas are removed by using any of a variety of gas conditioning processes in the field. Gas conditioning often involves the use of a dehydration system to boil off water and the gaseous impurities. In such systems, triethylene glycol is circulated through a boiler unit that boils off the water and gas impurities, producing methane and other volatile and semivolatile organic compounds (VOCs and SVOCs, respectively) such as benzene, toluene, ethyl benzene, and xylenes, which may then be vented to the atmosphere (DOE 1999).

Most oil wells produce saltwater along with gas bubbling out of the oil. These materials are separated in a metal tank (separator) that has an inlet for fluids from the flowline and separate outflows at different levels for each of the separated fluids. Separators may be horizontal or vertical (Figure 2.5) and may be either two-phase (separates gas from liquid) or three-phase (separates gas, oil, and water).

FIGURE 2.5 Horizontal and Vertical Gas and Oil Separators (Source: JL Bryan Equipment 2005)

Oil from the separator goes through another flowline and into a stock tank for storage until the oil is transferred to a tanker truck or into a pipeline system and leaves the site. Stock tanks are made of bolted or welded carbon steel and range in size from 90 to several thousand barrels of oil. A minimum of two and usually three or four stock tanks are connected by pipe in a tank battery for sequential filling (Figure 2.6).

FIGURE 2.6 Tank Battery (Source: Eastern Energy Corporation 2003)

2.3 WASTE MANAGEMENT

Wastes generated during oil and gas exploration and production fall into four general categories: used drilling muds and drill cuttings, produced water, low-volume "associated wastes," and other wastes.

2.3.1 Drilling Muds and Cuttings

Drilling rigs that use drilling mud will generate a large volume of used drilling mud. Drilling muds that are oil- or synthetic-based are typically recycled, although over time the oil or synthetic materials may degrade and render the mud unusable for further drilling. Most water-based muds are disposed of after the completion of drilling although they can be managed to allow the water to be recycled.

Drill cuttings are bits of rock that are ground up during the drilling process and brought to the surface with the drilling mud as the well is being drilled. Most drill cuttings are managed through disposal, although some are treated and beneficially reused. In some circumstances, drill cuttings can be beneficially reused for stabilizing road surfaces, as landfill cover material, or as a construction material. For example, oily cuttings have been used to provide the same service as tar-and-chip road surfacing, although not all regulatory agencies allow for such a reuse (DOE 2005d). For reuse, the hydrocarbon content, moisture content, salinity, and clay content of the cuttings are evaluated to determine suitability of the cuttings for a specified reuse. Some cuttings may undergo washing to remove dissolved salts prior to reuse, with the wash water being handled in the same manner as produced water.

Most U.S. offshore platforms discharge cuttings from water-based and synthetic-based systems, as well as water-based muds. Cuttings from oil-based muds, as well as oil-based and synthetic-based muds, must be transported to shore for disposal at an onshore commercial facility.

At most onshore well sites in the United States (with the exception of Alaska), drilling wastes are managed on site by burial in pits or landfills, or through land application or other biological treatment. For some types of wastes, or at particularly sensitive locations, these

disposal methods are not permitted, requiring the drilling wastes to be transported off site for disposal at a commercial disposal facility or municipal landfill.

2.3.2 Produced Water

In subsurface formations, naturally occurring rocks are generally permeated with fluids such as water, oil, or gas (or some combination of these fluids). Reservoir rocks normally contain both petroleum hydrocarbons (liquid and gas) and water. Extraction of oil or natural gas from reservoirs also generates produced water. Produced water is any water that is present in a reservoir with the hydrocarbons and is brought to the surface with the crude oil or natural gas. When hydrocarbons are extracted, they are brought to the surface as a produced fluid mixture. The composition of this mixture is dependent on whether crude oil or natural gas is being produced and generally includes a mixture of either liquid or gaseous hydrocarbons, produced water, dissolved or suspended solids, and any injected fluids and additives that may have been placed into the formation as a result of E&P.

As reservoir pressure declines over time, additional water is often injected into the reservoirs to help force the oil to the wells. This process is known as enhanced oil recovery. Both formation and injected water are brought to the surface along with the hydrocarbons and as the reservoir becomes depleted, the amount of produced water increases as the reservoir fills with the injected water. Produced water is usually very salty and may contain residual hydrocarbons, heavy metals, naturally occurring radionuclides, numerous inorganic species, suspended solids, and chemicals used in hydrocarbon extraction.

At the surface, produced water is separated from the hydrocarbons and treated to remove as much oil as possible (see Section 2.2.6). At offshore facilities, this treated water is generally discharged into the sea under the authority of a permit issued by the EPA. At most onshore locations, produced water cannot be discharged and is therefore injected underground either for enhanced oil recovery or for disposal. In some parts of the western United States, produced water can be discharged if it is not too salty and it can be beneficially reused. In recent years, researchers have been exploring ways to treat salty produced water for potable or agricultural uses.

2.3.3 Associated Waste

The process of producing, treating, storing, and transporting crude oil and natural gas generates low volumes of a variety of wastes, such as sludges, scales, produced sand, and other process-related wastes. These wastes, referred to as “associated wastes,” make up less than 1% of the total volume of waste generated by oil and gas exploration and production (EPA 1987). These wastes are managed in much the same way as other operational wastes.

2.3.4 Other Wastes

Waste soils may also be generated as a result of oil and gas activities. These would include soils contaminated by releases of crude oil, produced water, or other materials. Contaminated soils are frequently managed along with other operational wastes.

As previously described (Section 2.2.6), oil and gas separators are used to separate produced water and gases from the extracted oil. Disposal of the produced water is conducted in the manner described previously. The methane, VOCs, and SVOCs removed from extracted natural gas are vented directly into the atmosphere. These air emissions are often reduced through the use of additional separators and condensers to capture the methane, VOCs, and SVOCs, thereby reducing the amounts of these materials that are vented to the atmosphere. In addition, adjusting the glycol circulation during dehydration optimizes the extraction of water and other impurities (DOE 1999).

2.3.5 Disposal Alternatives

2.3.5.1 Disposal in On-Site Pits and Landfills

Waste management using on-site disposal involves the burial of the drilling muds in man-made or natural pits or landfills. Burial is the most common onshore disposal approach for disposing of drilling muds and cuttings (DOE 2005e). In most U.S. onshore drilling operations, cuttings are separated from the drilling muds and sent to a pit called the reserve pit located near the drilling rig (Figure 2.7). Such pits are typically open to the atmosphere and also receive wash water from the drilling rig as well as storm water. Liners are almost always required, and their siting and construction require careful consideration of a variety of factors, including surface topography, underlying geology, nearby surface waters, and underlying aquifers. After completion of drilling activities, any hydrocarbon products floating on top of the pits as well as any water or other liquids are removed for disposal. The remaining materials are evaluated to ensure that they do not exceed regulatory limits for pit disposal. The materials that do not exceed regulatory limits are covered in place with clean soil, the surface is graded to prevent water accumulation, and the area is revegetated to control erosion and runoff. Drilling wastes are also disposed of in engineered landfills. Depending on the applicable regulatory requirements, these landfills will typically have either clay or synthetic liners, and wastes placed into the landfill are covered with clean soil or other cover material on a regular interval (e.g., daily or weekly).

FIGURE 2.7 Oil Field Waste Pits (Source: USFWS 2001)

2.3.5.2 Disposal Using Land Application

Land application uses the soil's natural microbial population to metabolize, transform, and assimilate waste constituents in place. Land spreading and land treatment are often used interchangeably to describe the one-time application of wastes to the soil surface (DOE 2005i). Land spreading involves only a one-time application of the drilling wastes, thus limiting the potential for buildup of salt, hydrocarbons, and other waste-related materials. Land farming refers to the repeated application of wastes to the soil surface. It often includes tilling the drilling wastes into the soil and adding nutrients (fertilizer) to enhance microbial action (DOE 2005i). Many states regulate the salt, hydrocarbon, and metals content of wastes that can be disposed of by land application.

2.3.5.3 Disposal Using Bioremediation

Bioremediation is similar to land application in that it also relies on microorganisms to degrade hydrocarbon-contaminated drilling muds and cuttings (DOE 2005j). Bioremediation, as used here, accelerates the microbial degradation process through active manipulation of temperature, oxygen, moisture, and nutrients within the materials undergoing bioremediation. Common forms of bioremediation include composting and the use of bioreactors. Composting involves the addition of bulking agents (such as straw) to increase porosity, enhance aeration, and increase water-holding-capacity of the materials being composted, and the addition of fertilizer (such as manure) to provide nutrients for increased microbial activity. Bioreactors work in the same manner as composting or land application, but use open or closed vessels or impoundments that allow for increased control of temperature, moisture, and oxygen, thus enhancing microbial activity.

2.3.5.4 Off-Site Disposal

In contrast to on-site waste disposal, drilling wastes are also managed through disposal at licensed off-site commercial facilities or at municipal landfills if the landfill acceptance requirements are met. Commercial facilities use a variety of approaches for disposing of the oil and gas wastes, including pits and landfills, some form of on-site treatment (e.g., biological, chemical, or thermal), subsurface disposal, and landfarming (DOE 2005f). Examples of inappropriate wastes for on-site disposal may include saltwater muds or very oily cuttings. Examples of locations that are not appropriate for on-site burial or land application include areas with high seasonal water tables, wetlands, or tundra (DOE 2005f). At least nine oil- and gas-producing states (Figure 2.8) (Veil 1997) have commercial disposal companies that exclusively handle oil field wastes. Many more oil- and gas-producing states have few or no disposal companies dedicated to oil and gas industry waste. In those states, oil field wastes must be sent to other off-site commercial landfills or out of state. As recently as 1997, only Pennsylvania among the Great Lakes states had commercial off-site disposal facilities for oil and gas wastes.

2.3.5.5 Underground Injection

In areas lacking local waste management infrastructure (such as Alaska), drilling wastes are often disposed of through injection into underground formations. Underground injection involves the grinding or processing of the drilling waste solids into small particles, then mixing them with water or some other liquid to make a slurry and injecting the slurry into an underground formation at pressures high enough to fracture the rock. The process referred to here as slurry injection has been termed fracture slurry injection, drilled cuttings injection, cuttings reinjection, and grind and inject (DOE 2005g).

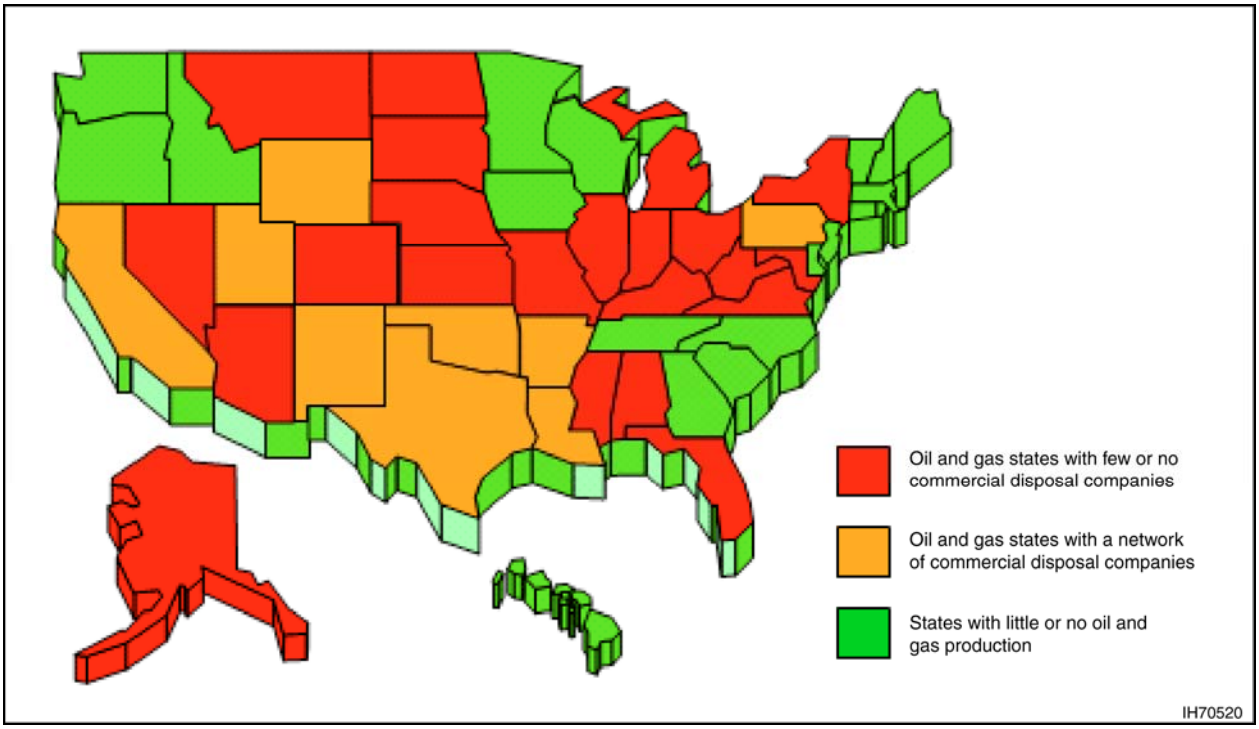

FIGURE 2.8 Off-Site Commercial Dedicated Oil and Gas Waste Disposal Facilities, 1997 (Source: Veil 1997)

The two common forms of slurry injection are annular injection and injection into a disposal well (Figure 2.9). With annular injection, the waste slurry is injected through the space between two sections (strings) of casing (this space is known as the annulus), with the slurry entering the formation at the lower end of the outermost casing string. Injection into a disposal well involves injection into either a section of the drilled hole that is below all casing, or to a section of the casing that has been perforated with a series of holes at the depth of an injection formation.

When the slurry is ready for injection, the underground formation is prepared to receive the slurry. First, clear water is rapidly injected to pressurize the system and initiate fracturing of the formation (DOE 2005g). When the water is flowing freely at the fracture pressure, the slurry

is introduced into the well. Slurry injection continues until an entire batch of material has been injected. Additional water is then injected to flush solids from the well bore, and pumping is discontinued. The pressure in the formation gradually declines as the liquid portion of the slurry bleeds off over the next few hours, and the solids become trapped in place in the formation. Slurry injection can be conducted as a single continuous process or as a series of smaller-volume intermittent cycles. On some offshore platforms, where drilling occurs continually and storage space is inadequate to operate in a daily batch manner, injection occurs continuously as new wells are drilled. However, most injections occur intermittently (DOE 2005g).

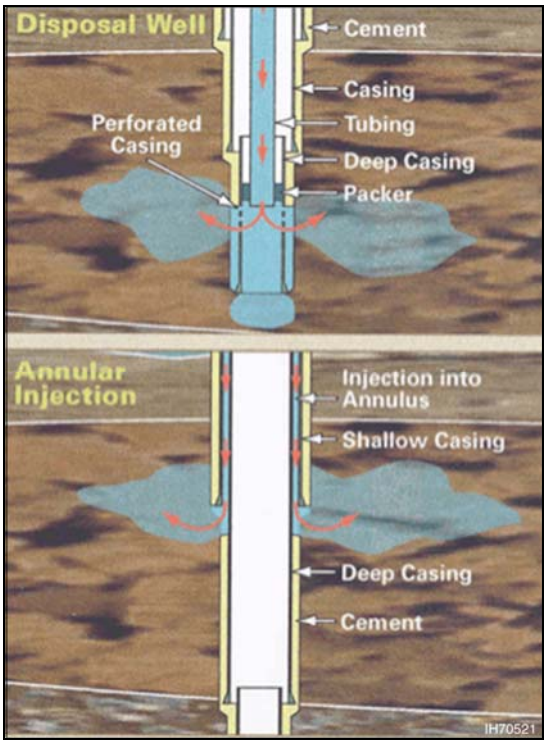

FIGURE 2.9 Annular and Disposal Well Slurry Injection (Source: DOE 2005f)

The most common problems with slurry injection are operations related. These problems may include the plugging of the casing or piping by solids that have settled out during or following injection; and the excessive erosion of casing, tubing, and other system components caused by pumping solids-laden slurry at high pressure. Environmental problems associated with slurry injection include unanticipated leakage to the environment (the surface of the seafloor in the case of offshore wells). Such leakage events are most likely due to a fracture that has moved up and away from the injection point and intersected a natural geologic fault or fracture, or a different well that had not been properly cemented. Because they are under high pressure, the injected fluids seek out the pathway of least resistance. Thus, if a crack in a well's cement job or geological fault is present, the fluids may preferentially migrate upward and reach a shallower formation (e.g., a drinking water aquifer),the land surface, or the seafloor.

Two commercial injection facilities manage a large portion of oil and gas industry wastes in the U.S. Both are located in Texas in areas with favorable geologic settings. One facility injects wastes into fractured limestone beds flanking salt dome deposits, and the other injects wastes into solution mined salt caverns. The viability of underground injection in other areas will depend upon local geologic conditions.

2.3.5.6 Disposal in Salt Caverns

Underground salt deposits, occurring as salt domes or bedded salt formations, are found throughout the continental United States (DOE 2005h). Salt domes are large, finger-like projections of nearly pure salt that have risen to near the surface, while bedded salt formations consist of multiple layers of salt separated by layers of other rocks. Salt deposits may occur at

depths of 500 ft (152 m) to more than 6,000 ft (829 ft) below the surface. Large salt caverns have been used for decades to store natural gas, crude oil, and other hydrocarbon products. During the 1990s, several companies in Texas received permits to dispose of drilling waste and other oil-field wastes in salt caverns (DOE 2005h).

Drilling wastes are brought to the cavern site where they are blended with water or brine to make a slurry. Drilling wastes suitable for disposal in caverns include drilling muds, drill cuttings, produced sands, tank bottom sediment, contaminated soil, and completion wastes. Grinding equipment may be used to reduce particle size. The waste slurry is then pumped into the caverns. Inside the cavern, the solids, oils, and other liquids separate into distinct layers: solids sink to the bottom, the oily and other hydrocarbons float to the top, and brine and other watery fluids remain in the middle (DOE 2005h).

Salt formations are found beneath portions of the Great Lakes Basin, but no disposal of wastes has occurred in these formations within the Basin. As of 2005, in the United States, only Texas had issued permits for the disposal of oil field wastes in salt caverns. Louisiana adopted cavern disposal regulations in May 2003 but has not yet permitted any disposal caverns. Several disposal caverns are operated in Canada, while in early 2004, Mexico announced that it was developing regulations for disposal of oil-based muds and cuttings in salt caverns (DOE 2005h).

2.4 WELL ABANDONMENT

If well logs determine that there is insufficient hydrocarbon potential to complete an exploratory well, or after production operations have drained a reservoir, the well must be plugged and abandoned. Following removal of production equipment, onshore and offshore wells are plugged and abandoned in a similar manner, although different regulatory bodies have their own requirements for plugging operations. Typically, cement plugs are placed and tested across any open hydrocarbon-bearing formations, across all casing shoes, across freshwater aquifers, and possibly several other areas near the surface, including the top 20 to 50 ft (6 to 15 m) of the well bore. This is accomplished by pumping a cement slurry to the desired location within the well bore. For plugging at locations above the well bottom hole (such as at aquifer locations), bridge plugs are used to prevent the cement from falling into the well bore. The bridge plug is set below the well section to be plugged, and cement is pumped on top of the plug..

At onshore locations, after the well has been plugged the casing is cut below the ground surface and a steel plate is welded to the top of the casing. The area around the sealed well is then backfilled with clean fill and a marker is installed indicating the presence of an abandoned well. For abandoned offshore wells, after the well has been plugged and abandoned the casing and production platform supports are cut at or below the bottom surface and the production rig is often toppled where appropriate and permissible to provide an artificial reef.

2.5 PIPELINE CONSTRUCTION

Pipelines are typically used to transport oil and natural gas to storage, processing, or distribution facilities. The construction of pipelines differs considerably between offshore and onshore.

Offshore pipelines are typically constructed by assembling pipeline sections on a barge (the lay barge) and lowering the pipeline string to the lake or sea bottom as the barge follows the pipeline route. Pipelines that are greater than about 8 in. (20 cm) in diameter and are installed in water depths less than 200 ft (61 m) are typically buried to a depth of at least 3 ft (1 m) below the mudline. Burial reduces the potential for pipeline movement due to high currents or storms and protects the pipelines from damage from anchors, fishing gear, and boat traffic.

Offshore pipeline burial typically involves the use of a jetting sled to dig a trench for the pipeline. Jetting sleds have high-pressure water jets that are directed downward and as the sled is pulled along the seafloor by the lay barge the water jets dig the trench while the sled guides the pipeline into the trench. In areas where solid bedrock is present at the bottom of the surface water body, some type of rock-cutting tool may be required to augment trenching capabilities of the high-pressure water jets.

Onshore pipeline construction requires the removal of vegetation and other surface features (such as large boulders) that may interfere with construction equipment. As the surface is cleared, sections of pipe are laid along the route in a process called stringing. Individual pipe sections may be up to 80 ft (24 m) in length and configured (pipe thickness and coating materials) specifically to that portion of the route. Next, a trench is dug alongside the laid out pipe. Trench depths are typically 5 to 6 ft (1.5 to 2 m) below the ground surface, but must provide a depth sufficient to ensure that the buried pipeline is at least 30 in. (76 cm) below the surface of the ground.

Next, the pipeline sections are welded together, and if needed, bent slightly to fit the contours of the trench. The pipeline is then lowered into the trench. Then water under high pressure (hydrostatic testing) is run through the pipeline to identify any leaks that may be present. Additional tests, such as x-ray examination of welds, are also conducted. If no leaks are found, the pipeline is ready for use; otherwise, those sections with leaks are repaired or replaced, and hydrostatic testing is repeated. Finally, the trench is backfilled with soil.

Two approaches are typically used if the pipeline must cross a river or stream. In one approach, a trench is dug into the stream bottom to receive the pipeline. That portion of pipe located in the crossing is fitted with a concrete casing that serves to maintain the position of the pipeline on the stream bottom and to provide added protection. The other approach involves the excavation of a tunnel beneath the river through which the pipe would pass. This latter approach is also typically used for crossing roads.

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3 INCIDENCE AND ENVIRONMENTAL EFFECTS OF OIL AND GAS RELEASES

Oil and gas development typically involves three phases: exploration, well completion and site construction, and operation of extraction and processing facilities. Related activities include the transport of extracted oil and gas to large storage and distribution facilities and transportation to refineries. Much of the available information regarding environmental effects is related to effects from the accidental releases of oil or gas from a variety of sources (i.e., pipelines, tanker trucks and ships, and wellheads) and a variety of causes (i.e., pipeline ruptures, truck accidents, tanker ship groundings, and well blowouts). Environmental effects associated with the large-scale storage, transportation, and processing of oil and natural gas (e.g., refineries) are outside the scope of this study and are not addressed in this report. Current levels of oil and gas production in the Great Lakes Basin states are discussed in Section 5.7.

3.1 OIL AND GAS RELEASE INCIDENTS

A number of sources account for oil spills. Tanker accidents have accounted for most of the world's largest individual spills, but are much less frequent than spills from other sources such as pipeline breaks, leaking storage tanks, offloading accidents, refinery accidents, and truck and train accidents (NOAA 2005a). For example, in 2001, spills from fixed platforms and onshore and offshore pipelines accounted for about 8.7% of the total number of spills and 8.9% of the total spill volume reported by the Coast Guard for U.S. waters under Coast Guard jurisdiction (including the Great Lakes) (USCG 2003). In inland waters under EPA jurisdiction (excluding the Great Lakes, there were approximately 43,000 spills, totaling more than 300 million gal (1,135 L), reported between 1980 and 2000 (Etkin 2004). About 80% of the total volume of these spills was due to releases from pipelines and other facilities. Nearly 40% of the spills had no reported causes, while structural failure accounted for the greatest percentage of number (24%) and volume (42%) of the known causes, and operational errors accounted for 22% of the spills.

More than 2,000 land-based oil and gas wells have been directionally drilled in Michigan since the 1970s (MESB 1997). According to insurance industry data, there have been no reported incidents at the more than 3,800 directional well bores drilled in Michigan, including 13 beneath the Great Lakes (LaFaive 2002). Approximately 2,200 wells have been drilled to date on the Canadian side of Lake Erie, and there are currently about 594 commercial wells in the lake. Only gas production, not oil production, is allowed in the lake on the Canadian side potentially because of greater concerns for oil spills than for accidental gas releases. Gas production is prohibited if hydrocarbon liquids are encountered with the gas production (Borawski 2005).

Since 1959, there have been three oil spill incidents on the Canadian side of Lake Erie, of which only one was directly attributed to a drilling operation (Borawski 2005). In that incident, about 210 gal (795 L) of fuel oil were accidentally released from a drill rig into the lake. There have been no reported oil releases from subsurface formations into overlying waters during any Canadian drilling or production operations.

Between 1969 and 2001, the number of oil spills from all sources (such as tanker spills, platform releases, pipeline leaks, refinery accidents, tanker truck accidents) reported from the Great Lakes by the U.S. Coast Guard (USCG 2003) has ranged from as few as 2 spills in 1983 to as many as 282 spills in 1995, with an annual average of 135 spills over that time period (Table 3.1). In comparison, spills reported during this same time period for East and West Coast harbors ranged from a low of 692 spills in 1987 to a high of 4,015 spills in 1974, with an annual average of 1,712 spills. The volumes of the spills reported from the Great Lakes ranged from 11 gal (42 L) in 1983 to 179,912 gal (681,041 L) in 1976, with an annual average volume of 41,121 gal (155,660 L) (Table 3.1). The volumes of the spills in coastal harbors during this same time period ranged from 45,932 gal (173,872 L) in 1997 to more than 7.6 million gal (28.8 million L) in 1984. A total of 239,053 spills were reported by the Coast Guard from 1973 to 2001 in all U.S. waters (e.g., Atlantic and Pacific Oceans, Gulf of Mexico, Great Lakes, lakes, rivers, channels, harbors, and other). Spills in the Great Lakes represent 1.6% of this total (USCG 2003); this low contribution is due to the much greater amount of oil and gas transportation that occurs on the East and West Coasts than in the inland waters of the Great Lakes. Spills from pipelines accounted for approximately 3.4% (8,076 spills) of the total spills reported from 1973 through 2001, while spills from facilities (i.e., oil platforms, refineries, factories, and industrial facilities) accounted for about 27% of the total spills reported during that time.

TABLE 3.1 Oil Spills in the U.S. Great Lakes and Coastal Harbors, 1973–2001

Location	Annual Number of Spills – Range	Annual Number of Spills – Average	Annual Volume of Spills – Range (gal)	Annual Volume of Spills – Average (gal)
Great Lakes	2–282	135	11–179,912	41,121
Harbors[a]	692–4,015	1,712	45,932–7,604,388	1,180,719

[a] Harbors along the East and West Coasts.

Source: USCG (2003).

In an evaluation of the characteristics of inland freshwater and coastal marine oil spills, Yoshioka and Carpenter (2002) reported that for 1995 and 1996, 77% of all spills greater than 1,000 gal (3,785 L) and 88% of spills greater than 10,000 gal (37,854 L) occurred at inland freshwater locations. More than half of all inland spills (56%) were attributed to pipelines, while vessels accounted for the majority of coastal spills. Yoshioka and Carpenter (2002) also found inland spills to be more likely than coastal spills to occur near populated areas or biologically sensitive areas.

The U.S. Department of Transportation Office of Pipeline Safety (OPS) reports a total of 2,580 pipeline incidents occurring in the United States between 1986 and 2004 (OPS 2005). These incident summaries do not identify the type or volume of the release; they do, however, identify the causes of the incidents, which include construction defects, accidental excavation,

weld failure, lightning, and earth movement. The total number of incidents reported from 1986 through 2004 was 2,580, ranging from a low of 97 incidents in 1995 to a high of 201 incidents in1988 (OPS 2005). These incidents resulted in 318 fatalities and 1,404 injuries, as well as more than $350 million in property damage.

3.2 ENVIRONMENTAL EFFECTS OF HISTORIC RELEASES

Between 1967 and 1991, there were 53 major spills (>10,000 barrels) in U.S. waters (NOAA 1992). The majority of these spills occurred in coastal areas, although one such large release occurred within the Great Lakes Basin in the Saginaw River in Michigan. That spill occurred on September 16, 1990, when a tanker caught fire and exploded while offloading about 20,000 barrels of unleaded gasoline at a refinery on the Saginaw River near Bay City, Michigan. The wake from a passing bulk carrier is believed to have caused the parting of the tanker's transfer hose, grounding cable, and all but one mooring line. Residual gasoline from the broken transfer hose was believed to have then ignited, and the ship swung into the river and grounded perpendicular to the direction of stream flow, cracking its hull. The fire was finally extinguished on September 18.

As a result of the release, area marinas were evacuated, and vessel traffic in the river halted. A 3-in.-(8-cm)-thick layer of gasoline was observed around the hull of the tanker. With the use of a containment boom and vacuum trucks, approximately 262 gal (992 L) of gasoline/water mixture were recovered, and small amounts of carbon residue were manually removed from beaches in the area. Little environmental damage was reported; a small number of fish were killed by the shock waves of the explosion rather than exposure to the gasoline.

While very limited environmental effects were reported for this spill, most of the other spills discussed in the case studies report produced a range of environmental effects. These include the fouling of beaches (Figure 3.1) and wetlands, mortality of ducks and diving birds such as cormorants and gulls from oiling (Figure 3.2), mortality of fish embryos, increased contaminant concentrations in fish, shellfish, ichthyoplankton (larval fish), and zooplankton (microcrustaceans), although relatively few long-lasting impacts were identified for many of the spills (NOAA 1992).

In contrast to the relatively limited environmental impacts identified for many of the spills described in the NOAA report (NOAA 1992), the Exxon Valdez spill resulted in a variety of environmental affects, some of which have lasted for more than 10 years following the initial spill Rice 2002). The Exxon Valdez ran aground on March 24, 1989, spilling approximately 10.9 million gal (41.2 million L) of Prudhoe Bay crude oil; this is the largest oil spill to date in U.S. waters. The spill soiled shorelines for up to 500 mi (805 km) of Alaskan coastline. The grounding

FIGURE 3.1 Example of a Very Large Oil Spill Washing Ashore (Source: EPA 2005f)

occurred at the beginning of the bird migration season, and the U.S. Fish and Wildlife Service (USFWS) estimated that between 350,000 and 390,000 bird mortalities could be directly attributed to the spill; birds especially affected included common and thick-billed murres (small diving birds related to puffins). An estimated 3,500 to 5,500 sea otter and 200 harbor seal mortalities were also attributed directly to the spill. These wildlife mortalities were directly related to extensive oiling rather than to acute toxicity. Concerns regarding contamination of fish and shellfish resulted in the cancellation of the 1989 black cod season in Prince William Sound, banned fishing for Pacific herring, and a reduced shrimp season.

FIGURE 3.2 Example of an Avian Mortality from Extreme Oiling (Source: EPA 2005f)

Although a massive cleanup effort was initiated that lasted several years, long-term effects have resulted from residual oil that remained in the environment. Population impacts to pink salmon from reduced egg survival and increased larval deformities, lasted for more than 4 years in some areas, while populations of sea otter and sea ducks had not recovered to prespill levels 10 years following the spill. Elevated concentrations of oil components have been detected in a variety of vertebrate and invertebrate biota (Rice 2002).

3.3 FATE OF SPILLED OIL

Once released into the environment, oil may undergo a variety of natural processes that may act to reduce the severity of a spill, or accelerate the decomposition of the spilled oil into forms that are less environmentally hazardous. Five natural processes have been identified as particularly important to the fate of oil in the environment: (1) weathering, (2) evaporation, (3) oxidation, (4) biodegradation, and (5) emulsification.

3.3.1 Weathering

Weathering represents a series of physical and chemical changes that cause the spilled oil to break down and become heavier than water. Wind, waves, and currents may result in the natural dispersion of an oil slick, breaking it into droplets that become suspended within the water column (EPA 2004a).

3.3.2 Evaporation

Oil is a complex mixture of hundreds of organic substances dominated by hydrocarbons. Evaporation occurs when the lighter substances within the oil mixture become vapors and enter

the atmosphere. This process leaves behind the heavier components of the oil, which may undergo further weathering and, when in a water body, sink (EPA 2004a). Spills of lighter refined products, such as kerosene and gasoline, contain a high proportion of flammable components and may evaporate within a few hours. Heavier oils are also likely to evaporate. The heavier oils that remain may leave a thicker, more viscous residue that is difficult to remove from beaches.

3.3.3 Oxidation

In water, oil may combine with oxygen to produce water-soluble compounds. This process affects oil slicks mostly around their edges (EPA 2004a). Thick oil slicks may only partially oxidize, resulting in the formation of tar balls — dense, sticky black spheres that may remain in the environment for a long time — which can collect in sediments, or wash up on beaches long after a spill.

3.3.4 Biodegradation

Biodegradation refers to the breakdown of oil by microorganisms such as bacteria. For biodegradation to proceed, nutrients such as nitrogen and phosphorus must be present. These are sometimes added to the water during cleanup response actions at oil spill sites. Biodegradation seems to work best in warmer waters (EPA 2004a).

3.3.5 Emulsification

Emulsification is a process that forms emulsions, that is, mixtures of small droplets of oil and water. These are formed by wave action and act to hamper weathering and cleanup processes (EPA 2004a). Oil and water emulsions cause oil to sink, and thus the oil may linger in the environment for months or years.

3.4 EFFECTS OF OIL RELEASES

Crude oil (oil that has not been refined) is classified into four categories (Table 3.2) that differ in how the oil may react (e.g., how quickly it weathers, whether it forms tar balls) when released to the environment and also its toxicity and potential for adversely impacting the environment.

In addition to the oil itself, some hazardous, toxic, and carcinogenic materials may be present at many oil production sites. These materials (such as hydrogen sulfide [H_2S], benzene, radium, heavy metals, toluene, and xylenes) are associated with the construction, operation, or maintenance of pipelines, storage tanks, and processing facilities, as well as by-products of the drilling process (see Section 2.3.1). For example, some of these chemicals may be added to

drilling muds, which are used to lubricate the drill bit as it grinds through the rock layer. As a result of this addition the drilling muds may contain heavy metals and other toxic substances.

TABLE 3.2 Types of Crude Oil

Oil Type	Characteristics
Class A: Light, Volatile Oils	Highly fluid, often clear, spread rapidly on solid and water surfaces, have a strong odor and high evaporation rate, are usually flammable, penetrate porous surfaces (such as sand and dirt), and may be persistent in such matrixes. Class A oils do not tend to adhere to surfaces and are flushed readily with water. Class A oils are highly toxic to humans and biota. Because they are highly fluid, they have the potential to move through the soil and impact groundwater.
Class B: Nonsticky Oils	Have a waxy or oily feel, are less toxic but adhere more than Class A oils. They can be removed from surfaces with rigorous scrubbing. At warmer temperatures, they become less viscous and may more easily penetrate porous surfaces. Evaporation of volatiles may lead to a Class C or D residue. May be persistent in the environment.
Class C: Heavy, Sticky Oils	Characteristically viscous, sticky, or tarry, and black or brown. Flushing with water has little effect on their removal from surfaces, but because of their thickness, these oils do not readily penetrate porous surfaces. The density of Class C oils is near that of water, and thus they often sink when released into a water body. Weathering or evaporation may produce solid or tar-like Class D residues. Toxicity is low, but wildlife may be smothered or drowned when contaminated (see Figure 3.2).
Class D: Nonfluid Oils	These oils are relatively nontoxic, do not penetrate porous surfaces, and are usually black or brown in color. When heated, these oils may melt and coat surfaces making cleanup very difficult.

Source: EPA (2004b).

Depending on its form (Table 3.2) and chemistry, oil can cause an array of physiological and toxic effects. For example, benzene is a known carcinogen and is toxic to humans and wildlife. Some petroleum hydrocarbons are toxic to organisms but less persistent in the environment, while others tend to be less toxic, but more persistent and more likely to result in long-term environment effects. As previously discussed, a number of factors govern the behavior and fate of an oil spill, including the particular chemistry of the crude oil and refined petroleum products and wind and water conditions, any of which may interact to determine the nature and magnitude of any environmental effects.

Freshwater areas are important to human health and the environment and are sensitive to oil spills. They are often used for drinking water and frequently serve as nesting grounds and food sources for various freshwater organisms. All types of freshwater organisms are susceptible to the effects of spilled oil, including fish, insects, microorganisms, vegetation, birds, and mammals. Because many of the organisms that would be affected by an oil spill in a freshwater environment are important components of food chains, impacts to these biota may very likely

affect species not directly exposed to the release but that are higher on the food chain and rely on the exposed biota for their food (EPA 2004c).

The nature and magnitude of the effects of an oil spill on freshwater habitats depend on the rate of water flow and the habitat's specific characteristics. Standing water such as wetlands with little water movement are likely to incur more severe impacts than flowing water because spilled oil will tend to collect in the habitat and can remain there for long periods of time. With calm water conditions, the affected habitat may take years to recover (EPA 2004c).

Lake and stream bottoms may support a diverse flora and fauna, including worms, insects, and shellfish. Lake and stream bottoms also serve as breeding grounds and feeding areas for these organisms and higher organisms. Oil in sediments may be very harmful because sediment traps the oil and affects the organisms that live in or feed off the sediments.

In aquatic habitats, oil can be toxic to the frogs, reptiles, fish, waterfowl, and other animals that live in or otherwise use the water (EPA 2004c). Oiling may affect not only wildlife but also plants that are rooted or float in the water, harming both the plants and the animals that depend on them for food and shelter. Freshwater fisheries are also subject to the toxic effects of oil. Aquatic insects that skim the surface and floating plants such as water lilies are threatened by oil slicks that spread across the water surface.

Terrestrial, emergent, and submerged vegetation in shoreline habitats provides many important functions for fish and wildlife. It serves as a food source and provides nesting grounds and shelter for fish and wildlife. Oil spills can coat these areas, thereby affecting the plants and the organisms that depend on them (EPA 2004c). Wetlands are among the most sensitive freshwater habitats to oil spills because of their minimal water flow. Impacts to these habitats may adversely affect a wide variety of biota that use the wetlands as nurseries, feeding areas, and shelter.

Oil spills impact flowing water less severely than standing water because the currents provide a natural cleaning mechanism. Although the effects of oil spills on river habitats may be less severe or last for a shorter amount of time than those on standing waters, the sensitivity of river and stream habitats is similar to that of standing water, and riverine systems may distribute exposure over a wider area (EPA 2004c).

An oil spill may affect biota by (1) direct physical contact, (2) toxicity, and (3) impacts to food sources (EPA 2004d). With physical contact, the body of the exposed organism comes in contact with and is covered by the spilled oil. In birds and mammals, this oiling mats the feathers or fur, causing these to loose their insulating properties, and placing animals at risk of freezing to death. With aquatic mammals and especially birds, this loss of insulation also reduces the buoyancy of the exposed organism, thus increasing the risk of drowning.

Many species will experience toxic effects when exposed to oil (EPA 2004d). Oil exposure has been shown to affect the central nervous system, organ function, reproduction, and development. Species not directly exposed to the oil spill may nonetheless be affected if the spill has affected their prey. In some cases, the abundance of prey may be reduced or even completely

lost. In other cases, higher organisms may be secondarily exposed to the oil spill by eating prey that have been contaminated and subsequently incur toxicological effects.

3.5 EFFECTS OF NATURAL GAS RELEASES

As with oil, the composition of natural gas varies, depending on its origin, type, genesis, the location of the deposit, the geological structure of the region, and other factors. Natural gas chiefly consists of a mixture of hydrocarbons (i.e., methane and its related compounds) and carbon dioxide. In addition, H_2S may account for as much as 30% of natural gas by weight. Natural gas containing H_2S is termed sour gas, and before it can be safely used the H_2S must be removed at a processing plant. Hydrogen sulfide is a colorless gas with a characteristic odor of rotten eggs. It naturally occurs in the gases from volcanoes, sulfur springs, undersea vents, swamps, and stagnant bodies of water, and in some crude petroleum and natural gas accumulations. In addition, bacteria, fungi, and other microorganisms may release H_2S during the decomposition of organic materials. Hydrogen sulfide is frequently encountered in various industries and may be released to the environment as a result of their operations. Some of these industries include natural gas production, municipal sewage pumping and treatment plants, landfilling, swine containment and manure handling, pulp and paper production, construction in wetlands, asphalt roofing, pelt processing, petroleum refining, petrochemical synthesis, coke production plants, viscose rayon manufacture, sulfur production, iron smelting, and food processing (ATSDR 2004).

Natural gas exhibits negligible solubility in water, and thus has little affect on water quality in the event of an underwater leak. For terrestrial releases, exposure to an accidental natural gas leak may result in asphyxiation as a result of oxygen displacement, and the greatest threat from a natural gas leak is explosion and fire. In contrast, the greatest concern from an accidental release of H_2S is asphyxiation (also as a result of oxygen displacement) and, to a lesser degree, toxic effects from inhalation. Currently, the Occupational Safety and Health Administration (OSHA) has established an acceptable ceiling concentration of 20 parts per million (ppm) for H_2S in the workplace, with a maximum level of 50 ppm allowed for 10 minutes maximum duration if no other measurable exposure occurs. The National Institute for Occupational Safety and Health (NIOSH) has set a maximum Recommended Exposure Limit ceiling value of 10 ppm for 10 minutes maximum duration (ATSDR 2004). Concentrations in ambient air from natural sources have been reported to range between 0.11 and 0.33 parts per billion (ppb), with no visible adverse effects on indigenous biota at concentrations of 3.9 ppm, while concentrations at landfills and sewage treatment plants have been reported to reach peaks of 100 ppm (ATSDR 2004).

Exposure to low concentrations of H_2S may cause irritation of the eyes, nose, or throat, as well as difficulty in breathing in asthmatic individuals (ATSDR 2004). Brief exposures to high concentrations (greater than 500 ppm) can cause respiratory irritation, fluid buildup in the lungs, convulsions, loss of consciousness, and possibly death. Similar effects (to similar exposure levels) have been observed in laboratory animals (ATSDR 2004), and may be expected for wildlife exposed at similar levels.

While many individuals have been reported to recover from high exposures with no apparent lasting effects, others may experience long-term effects such as headaches, poor attention span, reduced memory, and poor motor function (ATSDR 2004). Wildlife may be expected to exhibit similar variability in recovery from H_2S exposure.

3.6 OIL SPILL RESPONSE

Oil spills may occur in a variety of settings, and the specific steps taken to respond to the spill will depend on the type and amount of oil discharged, the location of the release, the proximity of the spill to a sensitive environment or resource (e.g., unique habitat, drinking water supply), and other environmental factors (such as weather conditions).

There are two major steps in the control and cleanup of an oil spill: containment and recovery (EPA 1999, 2004e). These two steps may be conducted using mechanical equipment, chemical or biological agents, or a combination of mechanical, chemical, and biological methods. In addition, in-situ (in-place) burning of the spilled oil may also be used to clean up an oil spill.

3.6.1 Mechanical Containment and Recovery

With mechanical containment, specialized equipment may be used to minimize the spread of the spilled oil, prevent its transport to sensitive areas, and to concentrate the spilled material into a thicker layer which makes its removal easier.

Booms are the primary tool used for containing oil spills in aquatic systems. While booms may vary in their design and construction, they all generally share the following four basic elements:

- An above-water “freeboard” to contain the oil and prevent waves from splashing oil over the top of the boom;
- A flotation device;
- A below-water “skirt” that contains the oil and helps prevent oil from moving under the boom; and
- A “longitudinal support,” usually a chain or cable running along the bottom of the skirt, that strengthens the boom against wind and wave action, and that may serve as a weight or ballast to add stability and help keep the boom upright.

All booms are affected by water conditions, and their effectiveness decreases with increasing wave or swell heights.

Booms can be fixed to a structure, such as a pier or a buoy, or towed behind or alongside one or more vessels. When stationary or moored, the boom is anchored below the water surface. It is necessary for stationary booms to be monitored or tended because of changes produced by shifting tides, currents, winds, or other factors that influence water depth, direction, and force of motion. Boom tending requires round-the-clock personnel to monitor and adjust the equipment. The forces exerted by currents, waves, and wind may significantly impair the ability of a boom to hold oil. Currents may wash oil beneath a boom's skirt. Wind and waves can force oil over the top of the boom's freeboard or even flatten the boom into the water, causing it to release the contained oil. Mechanical problems and improper mooring can also cause a boom to fail.

When a spill occurs and no containment equipment is available, barriers can be improvised from such materials as wood, plastic pipe, inflated fire hoses, automobile tires, and empty oil drums. They can be as simple as a board placed across the surface of a slow-moving stream, or a berm built by bulldozers pushing a wall of sand out from the beach to divert oil from a sensitive section of shoreline. Although they are most often used as temporary measures to hold or divert oil until more sophisticated equipment arrives, improvised booms can be an effective way to deal with oil spills, particularly in calm water such as streams, slow-moving rivers, or sheltered bays and inlets.

Once a spill has been contained, oil removal is typically initiated using one of three different types of equipment: booms, skimmers, and sorbents. Booms and skimmers are suitable for spills on surface waters, while sorbents may be used for spills on water and on land.

A recovery boom is suspended from a horizontal arm that extends off one or both sides of a vessel. The recovery vessel sails through the heaviest sections of the spill at low speeds, scooping and trapping the oil between the angle of the boom and the vessel's hull. Alternately, a recovery boom may be moored at the end points of a rigid arm extended from the recovery vessel, forming a "U"- or "J"-shaped pocket that collects the oil. In either case, the trapped oil is then pumped to a holding tank and returned to shore for proper disposal or recycling.

A skimmer is a device that recovers oil from the water's surface. Skimmers may be self-propelled and may be used from shore or operated from vessels. The efficiency of skimmers depends on weather conditions. There are different types of skimmers, each offering advantages and drawbacks, depending on the type of oil being cleaned up, the conditions of the sea during cleanup efforts, and the presence of ice or debris in the water.

Weir skimmers use a dam or enclosure positioned at the oil/water interface to contain the trapped oil and water mixture, which can then be pumped out through a pipe or hose to a storage tank for recycling or disposal. Oleophilic (oil-attracting) skimmers use belts, disks, or continuous mop chains of oleophilic materials to blot the oil from the water surface, which is then squeezed out or scraped off into a recovery tank. Oleophilic skimmers have the advantage of flexibility, allowing them to be used effectively on spills of any thickness. Suction skimmers operate like a vacuum cleaner, sucking the oil up through wide floating heads and pumping it into storage tanks. Suction skimmers operate best on smooth water where oil has collected against a boom or barrier.

Sorbents recover oil by absorbing and/or adsorbing the spill. Absorbents allow oil to penetrate into pore spaces in the material they are made of, while adsorbents attract oil to their surfaces but do not allow it to penetrate into the material. Although they may be used as the sole cleanup method in small spills, sorbents are most often used to remove final traces of oil, or in areas that cannot be reached by skimmers. Sorbents may be made of natural organic, natural inorganic, or synthetic materials.

Natural organic sorbents include peat moss, straw, hay, sawdust, ground corncobs, feathers, and other carbon-based products. Organic sorbents can soak up from 3 to 15 times their weight in oil, but they do present some disadvantages. Some organic sorbents tend to soak up water as well as oil, causing them to sink. Many organic sorbents are loose particles, such as sawdust, and are difficult to collect after they have been applied onto the water. Natural inorganic sorbents include clay, perlite, vermiculite, glass, wool, sand, and volcanic ash. They can absorb from 4 to 20 times their weight in oil. Synthetic sorbents are man-made materials similar to plastics, such as polyurethane, polyethylene, and nylon fibers, and can absorb as much as 70 times their weight in oil.

For spills in shoreline and terrestrial environments, spill cleanup may include wiping with sorbents, pressure washing, raking, and bulldozing. Sorbents in the form of towels and mops may be used to wipe oily rocks and soils. Pressure washing involves rinsing oiled shorelines and rocks with low- or high-pressure, hot or cold water to flush the oil into plastic-lined trenches for collection with sorbents. Low-pressure water may be used to clean oiled vegetation. Raking and bulldozing involves the disturbance or removal of sand, gravel, pebbles, cobble, or soil into which oil has moved. If the oil is limited to the shallow subsurface, tilling or raking the substrate exposes the oil to air and sunlight, potentially speeding evaporation and natural degradation. For oil in deeper soils, bulldozers are used to bring the contaminated soils to the surface for removal, pressure washing, or biodegradation.

3.6.2 Chemical and Biological Containment and Recovery

Chemical and biological treatment of oil can be used in place of mechanical methods to contain and recover spills, especially in areas where untreated oil may reach shorelines and sensitive habitats where a cleanup becomes difficult and environmentally damaging (EPA 1999, 2004e). Such treatment typically uses dispersing agents and/or biological agents.

Dispersing agents, also called dispersants, are chemicals that contain compounds (surfactants) that act to break the oil into small droplets. The small oil droplets then disperse into the water column where they are subjected to natural processes such as wind, waves, and currents that help to break them down further. Dispersing agents thus hasten the removal of oil from the water surface, making it less likely that the oil slick will reach a shoreline. The effectiveness of a dispersant is determined by the type of the oil that is being treated and the method and rate at which the dispersant is applied. Heavy crude oils do not disperse as well as light- to medium-weight oils. Dispersants are most effective when applied immediately following a spill, before the lightest components in the oil have evaporated.

Environmental factors such as water salinity and temperature, as well as surface water conditions impact effectiveness; many dispersants work best at salinity levels close to that of normal seawater and in warm water (EPA 1999). Some countries rely almost exclusively on dispersants to combat oil spills because frequently rough or choppy conditions at sea make mechanical containment and cleanup difficult. However, dispersants have not been used extensively in the United States because of difficulties with application, disagreement among scientists about their effectiveness, and concerns about the toxicity of the dispersed mixtures. Dispersants used today are much less toxic than those used in the past, but few long-term environmental effects tests have been conducted after a dispersant application.

Biological agents are nutrients, enzymes, or microorganisms that increase the rate at which natural biodegradation occurs. Biodegradation of oil is a natural process that may take weeks, months, or years to remove oil from the environment. However, rapid removal of spilled oil from shorelines and wetlands may be necessary in order to minimize potential environmental damage to these sensitive habitats. By speeding up the rate of biodegradation, biological agents speed up the breakdown of the spilled oil and its conversion to less harmful compounds.

The addition of biological agents such as fertilizers or microorganisms to increase the rate at which natural biodegradation occurs is termed bioremediation. This approach is often used after all mechanical oil recovery methods have been used. Two bioremediation approaches have been used in the United States for oil spill cleanups: biostimulation and bioaugmentation. Biostimulation involves the addition of nutrients such as phosphorus and nitrogen to a contaminated environment (beaches, shorelines, and inland soils) to stimulate the growth of the naturally occurring microorganisms that break down oil. Bioaugmentation is the addition of microorganisms to the existing native oil-degrading biota to increase the population of microorganisms that can biodegrade the spilled oil. Bioaugmentation is seldom used, however, because hydrocarbon-degrading bacteria exist almost everywhere and nonindigenous species are often unable to compete successfully with native microorganisms.

3.6.3 In-Situ Burning

In-situ burning involves the ignition and controlled combustion of the spilled oil. It can be used when oil is spilled on a water body or on land. The National Oil and Hazardous Substances Contingency Plan authorizes in-situ burning as a cleanup method but requires EPA approval before it can be used. In-situ burning is typically used in conjunction with mechanical recovery on open water. Fire-resistant booms are used to collect and concentrate the oil into a slick that is thick enough to burn. Factors influencing the decision to use in-situ burning on inland or coastal waters include water temperature, wind direction and speed, wave amplitude, slick thickness, oil type, and the amount of oil weathering and emulsification that has occurred (EPA 1999). Oil layer thickness, weathering, and emulsification are usually dependent upon the time period between the actual spill and the start of burn operations.

The major issues for in-situ burning of inland spills are proximity to human populations, soil type, water level, erosion potential, vegetation species and condition, and wildlife species presence. Burning may actually allow oil to penetrate farther into some soils and shoreline

sediments, and it releases pollutants into the air. Although it can be effective in some situations, in-situ burning is rarely used on marine spills because of concerns over atmospheric emissions and uncertainty about its impacts on human and environmental health. However, burning of inland spills is frequently used in a number of states (EPA 1999).

Despite its drawbacks, in-situ burning may be an efficient cleanup method under certain conditions. These conditions include remote areas away from human use, areas with herbaceous or dormant vegetation, and water or land covered with snow or ice. Under these circumstances, burning can quickly prevent the movement of oil to other areas, eliminate the generation of oily wastes, provide a cleanup means for affected areas with limited access for mechanical or physical removal methods, or provide an additional level of cleanup when other methods become ineffective. When oil is spilled into water containing a layer or chunks of ice, burning can often remove much more oil than conventional means. Burning can also help to eliminate some volatile compounds that might otherwise evaporate off a slick.

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4 INTERNATIONAL, FEDERAL, REGIONAL, AND STATE LEGISLATION, POLICIES, AND AGREEMENTS AFFECTING OIL AND GAS DEVELOPMENT IN THE GREAT LAKES

This section discusses the Federal and state policy and regulatory settings that currently control oil and gas development in the U.S. portion of the Great Lakes.

4.1 INTERNATIONAL POLICIES AND AGREEMENTS

Under the Boundary Waters Treaty of 1909,[1] Canada and the United States established the International Joint Commission (IJC) to prevent and resolve disputes over water use and provide independent advice on such other transboundary environmental issues as air and water pollution. Under the auspices of the IJC, in 1972 the two governments entered into the Great Lakes Water Quality Agreement (GLWQA) to "restore and maintain the chemical, physical, and biological integrity of the waters of the Great Lakes basin ecosystem." The focus of the IJC and the cooperating federal, state, and provincial agencies for nearly 30 years has been to develop and implement pollution-abatement measures that will restore and maintain beneficial uses of the lakes. In the IJC Eleventh Biennial Report (IJC 2002), the section entitled "further matter of importance" discussed the principles, as well as programs and measures, to prevent discharges of oil and other substances into the Great Lakes system from drill rigs, pipelines, wells, and other onshore or offshore facilities. The Twelfth Biennial Report (IJC 2004) however, did not mention the issue of drilling in the Great Lakes.

The International Association of Great Lakes and St. Lawrence Mayors has passed a resolution calling for a moratorium on Great Lakes oil and gas exploration, development, and extraction. The Chippewa Ottawa Resources Authority has also passed a resolution stating its unqualified opposition to any oil drilling activities to exploit oil deposits under the Great Lakes.[2]

The Great Lakes Commission was established by joint legislative action of the Great Lakes states in 1955 (the Great Lakes Basin Compact) and was granted Congressional consent in 1968. A Declaration of Partnership established associate membership for the provinces in 1999. The Great Lakes Commission is a binational public agency dedicated to the use, management, and protection of the water, land, and other natural resources of the Great Lakes-St. Lawrence system. In partnership with the eight Great Lakes states (Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin) and provinces of Ontario and Québec, the Commission applies sustainable development principles in addressing issues of resource management, environmental protection, transportation, and sustainable development.

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1 Treaty between the United States and Great Britain Relating to Boundary Waters and Questions Arising between the United States and Canada, Jan. 11, 1909 (36 Stat. 2448) (1909).

2 See http://www.glc.org/mayors.

4.2 FEDERAL REGULATION OF OIL AND NATURAL GAS DRILLING

The Energy and Water Development Appropriations Act of 2002[3] banned directional drilling underneath any of the Great Lakes for 2 years. This Act was approved on November 12, 2001. Section 503 of the bill states "That during the fiscal years (FY) 2002 and 2003, no Federal or State permit or lease shall be issued for new oil and gas slant, directional, or offshore drilling in or under one or more of the Great Lakes." Section 503 also imposes on the Secretary of the Army the duty to conduct a study examining the "known and potential environmental effects of oil and gas drilling in the Great Lakes." The moratorium on drilling was subsequently extended through FY 2005 in the Omnibus Appropriations Act of 2003,[4] and again through FY 2007 by the Omnibus Appropriations Act of 2005.[5] On August 8, 2005, the President signed into law the Energy Policy Act of 2005. Under Section 386 of this act, no Federal or State permit or lease shall be issued for new oil and gas slant, directional, or offshore drilling in or under one or more of the Great Lakes.

The Corps has responsibility for regulating activities for offshore drilling through its permit programs authorized under Section 10 of the Rivers and Harbors Act of 1899[6] and Section 404 of the Clean Water Act (CWA).[7] The geographic jurisdiction of the Rivers and Harbors Act of 1899 includes all navigable waters of the United States that are defined as "those waters that are subject to the ebb and flow of the tide and/or are presently used, or have been used in the past, or may be susceptible to use to transport interstate or foreign commerce."[8] The CWA uses the term "navigable waters," which is defined as "waters of the U.S., including the territorial seas."[9] Thus, Section 404 jurisdiction is defined as encompassing Section 10 waters, plus their tributaries and adjacent wetlands and isolated waters where the use, degradation, or destruction of such waters could affect interstate or foreign commerce. Offshore drilling activities, including construction of drilling platforms in the lake and pipelines along the lakebed, clearly come within the Corps permitting jurisdiction.

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3 Energy and Water Development Appropriations Act, Public Law (P.L.) No. 107-66, 115 Stat. 486 (2002).

4 P.L. 108-7, signed into law February 20, 2003.

5 P.L 108-447, signed into law November 20, 2004.

6 *United States Code*, Title 33, Section 403 (33 USC § 403). "That the creation of any obstruction not affirmatively authorized by Congress, to the navigable capacity of any of the waters of the United States is hereby prohibited; and it shall not be lawful to build or commence the building of any wharf, pier, dolphin, boom, weir, breakwater, bulkhead, jetty, or other structures in any port, roadstead, haven, harbor, canal, navigable river, or other water of the United States, outside established harbor lines, or where no harbor lines have been established, except on plans recommended by the Chief of Engineers and authorized by the Secretary of War; and it shall not be lawful to excavate or fill, or in any manner to alter or modify the course, location, condition, or capacity of, any port, roadstead, haven, harbor, canal, lake, harbor of refuge, or enclosure within the limits of any breakwater, or of the channel of any navigable water of the United States, unless the work has been recommended by the Chief of Engineers and authorized by the Secretary of War prior to beginning the same."

7 33 USC § 1344.

8 Title 33, Part 329 of the *Code of Federal Regulations* (CFR Part 329).

9 33 USC § 1362 [502(7)].

The Submerged Lands Act of 1953,[10] granted title to and ownership of the lands beneath navigable waters (i.e., submerged lands or bottomlands) within the boundaries of the respective states, and the natural resources within such lands and waters to the states along with the right and power to manage, administer, lease, develop, and use the said lands and natural resources all in accordance with applicable state law. Under this Act, the Federal government released and relinquished all right, title, and interest in and to all said lands, improvements, and natural resources with certain exceptions, including powers of regulation and control of said lands and navigable waters for the constitutional purposes of commerce, navigation, national defense, and international affairs. In addition, the Federal government still has authority over the use, development, improvement, or control of lands and waters for the purposes of navigation, flood control, or the production of power. The Federal government continues to maintain authority over lands beneath navigable waters off land owned by the Federal government, lands held by the Federal government for the benefit of any Tribe, band, or group of Indians or for individual Indians, as well as all structures and improvements constructed by the United States in the exercise of its navigational servitude. The actual water of the Great Lakes remains under Federal authority as navigable waters.

Under the Submerged Lands Act, "lands beneath navigable waters" are defined as (1) all lands within the boundaries of each of the respective states which are covered by nontidal waters that were navigable under the laws of the United States at the time such state became a member of the Union up to the ordinary high water mark as heretofore or hereafter modified by accretion, erosion, and reliction;[11] (2) all lands permanently or periodically covered by tidal waters up to but not above the line of mean high tide and seaward to a line three geographical miles distant from the coast line of each such state and to the boundary line of each such state where in any case such boundary as it existed at the time such state became a member of the Union;[12] and (3) all filled in, made, or reclaimed lands which formerly were lands beneath navigable waters, as hereinabove defined.

Under E.O. 13158 (U.S. President 2000), each Federal agency whose authorities provide for the establishment or management of Marine Protected Areas (MPAs) must take action to enhance or expand protection of existing MPAs and establish or recommend, as appropriate, new MPAs. The definition of "marine environment" under this E.O. includes the Great Lakes. This E.O. is in furtherance of the purposes of the National Marine Sanctuaries Act (16 USC § 1431 et seq.); National Wildlife Refuge System Administration Act of 1966 (16 USC § 668dd-ee), National Park Service Organic Act (16 USC § 1 et seq.), National Historic Preservation Act (16 USC § 470 et seq.), Wilderness Act (16 USC § 11331 et seq.) Magnuson-Stevens Fishery Conservation and Management Act (16 USC § 1801 et seq.), Coastal Zone Management Act (16 USC § 1451 et seq.), Endangered Species Act of 1973 (16 USC § 1531 et seq.), Marine Mammal Protection Act (16 USC § 1362 et seq.), Clean Water Act of 1977 (33 USC § 1251

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[10] 43 USC §§ 1301–1315.

[11] Reliction is defined as a slow change of water line on real property that results in the owner obtaining additional dry land.

[12] The seaward boundary of each Great Lakes state is approved and confirmed as a line to the international boundary.

et seq.), National Environmental Policy Act, as amended (42 USC § 4321 et seq.), Outer Continental Shelf Lands Act (42 USC § 1331 et seq.), and other pertinent statutes.

The Department of Commerce and the Department of the Interior, in consultation with the Department of Defense, the Department of State, the United States Agency for International Development, the Department of Transportation, the EPA, the National Science Foundation, and other pertinent Federal agencies is developing a national system of MPAs. The Department of Commerce's National Oceanic and Atmospheric Administration (NOAA), in cooperation with the Department of the Interior, is establishing a marine Protected Area Center; creating a Web site (http://mpa.gov/); and conducting necessary research, analysis, and exploration. Although the list of MPAs affected by this order has not yet been published, it may include water bodies currently protected under the National Estuaries Program, wildlife refuges, and other significant natural and cultural resources in marine environments. In addition, the EPA must use the CWA authorities to expeditiously propose new science-based regulations, as necessary, to ensure appropriate levels of protection for the marine environment, including identification of areas that warrant additional pollution protections and the enhancement of marine water quality standards. The EPA evaluates new regulations under the CWA to determine the impact on MPAs. No regulations specific to the Great Lakes have been promulgated in response to this E.O.

4.3 STATE LEGISLATION, POLICIES, AND AGREEMENTS

In 1985, the eight governors of the Great Lakes states signed a nonbinding statement of principle entitled "A Statement of Principle Against Oil Drilling in the Great Lakes," agreeing to ban oil drilling in the waters of the Great Lakes.[13] This statement, however, did not specifically address directional drilling or drilling for natural gas.

At present, Michigan is the only state in the United States that has leased directionally drilled wells under the Great Lakes. The other Great Lakes states either do not permit drilling or do not have the necessary geologic conditions for petroleum generation, expulsion, or entrapment. The states that have since reconsidered the issue of drilling have taken the position that the governor's compact applies only to offshore drilling and not to directional drilling from land.

In 2002, the Michigan Senate approved a permanent ban on Great Lakes drilling and dropped the House provision to reopen development in the event of an energy emergency. The permanent ban automatically took effect after Michigan Governor John Engler refused to sign the legislation. On April 5, 2002, Gov. Engler sent a letter to the legislature indicating he thought the ban was based on flawed policy rather than sound science, would reduce future revenues that would otherwise be available to protect Michigan's environment, and was directly contrary to

[13] A "Statement of Principle Against Oil Drilling in the Great Lakes" was signed by the governors of Michigan (James J. Blanchard), Wisconsin (Anthony S. Earl), Pennsylvania (Dick Thornburgh), Minnesota (Rudy Perpich), Indiana (Robert D. Orr), Ohio (Richard F. Celeste), Illinois (James R. Thompson), and New York (Mario M. Cuomo) and states, "We collectively state our opposition to oil drilling in the waters of the Great Lakes or their connecting channels."

our nation's goal of achieving energy independence. He also stated that the ban on directional drilling instituted by the Federal government was Congressional interference in state powers. The Michigan state constitution allows a new law to take effect if it has not been signed or vetoed within 14 days of final passage.[14] The permanent ban automatically took effect 14 days after final passage since it was neither signed nor vetoed by the governor.

On July 14, 2003, Ohio Governor Bob Taft signed an E.O. banning all gas and oil drilling in Lake Erie for the remainder of his term (2006). Ohio Representative Chris Redfern has recently (March 8, 2005) introduced a bill to permanently ban drilling for oil and gas beneath Lake Erie (House Bill 119, a bill to amend Section 1505.07 of the Revised Code to ban the taking or removal of oil or natural gas from and under the bed of Lake Erie).

In New York, an act to amend the Environmental Conservation Law, in relation to oil or natural gas drilling operations or pipelines under certain water bodies has been proposed by New York Assemblyman Sam Hoyt.[15] This act would prohibit oil or natural gas drilling operations or pipelines on or beneath the lands under the waters of Lakes Ontario and Erie, the connecting bays and harbors of such lakes, the connecting waterways of such lakes, or along their shorelines. It would apply to all contracts, includes leases entered into or renewed, but would not apply to contracts, including leases, in force at the effective date and those entered into before such date. This act would amend the Environmental Conservation Law to create a statutory ban.

Wisconsin has instituted a statutory ban on drilling operations for the exploration or production of oil or gas if the drilling extends beneath the beds of the Great Lakes or bays or harbors that are adjacent to the Great Lakes.[16]

4.4 STATE REGULATION OF OIL AND NATURAL GAS DRILLING

Most states have regulations pertaining to the technical act of drilling of oil and gas wells (e.g., spacing, casings, and depths), environmental protection (e.g., waste management), plugging/abandonment of wells, and emergency response. In addition, as discussed in Section 4.2, the Submerged Lands Act of 1953 gave each of the eight states bordering the Great Lakes title to and ownership of the lands beneath navigable waters within the Great Lakes within their respective boundaries. The state can use, lease, or sell the rights to these Great Lakes

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[14] Act 148, Imd. Eff. Apr. 5, 2002, amended Section 324.61505a of the Michigan Natural Resources and Environmental Protection Act 451 of 1994 to read: "Notwithstanding any other provision of this part or the rules promulgated under this part, beginning on the effective date of this section, the supervisor shall not issue a permit for drilling, or authorize the drilling of, a well beneath the lake bottomlands of the Great Lakes, the connected bays or harbors of the Great Lakes, or the connecting waterways as defined in Section 32301, for the exploration or production of oil or gas unless the applicant holds a lease that was in effect prior to the effective date of the amendatory act that added this section that allows the well to be drilled.

[15] Assembly Bill A06907.

[16] Wisconsin Statutes, Chapter 295, Subchapter II, Oil and Gas, Section 295.3(4).

bottomlands within their jurisdiction. However, under the public trust doctrine, the state is expected to protect the public's interest in waters and submerged bottomlands of the Great Lakes that are deemed fundamental to the well-being of everyone.[17] This section provides a high-level summary of the regulation of oil and gas E&P activities and resource ownership within the eight states bordering the Great Lakes.

4.4.1 Illinois

In Illinois, no person may drill, deepen, or convert any well to an oil or gas production well without a permit from the Illinois Department of Natural Resources, Office of Mines and Minerals (DNR OMM).[18] The application must contain the name of the well, the surveyed location of the well, a map showing the boundaries of the leasehold, the exact location of the well, the depth of the well and the name of the lowest geologic formation to be tested, the locations of all producing wells previously drilled on the drilling unit, and the locations of all offset wells on adjacent drilling units. In addition, if the applicant intends to deviate from the vertical, the application must include a map showing the proposed direction of the deviation and proposed horizontal distance between the end of the well bore and the surface location of the well. Within 60 days after the completion of drilling a certified directional survey of the well must be filed with the DNR OMM showing the surface location of the well, the location of the top and bottom of the producing interval, and the location of the end of the well bore. If the applicant intends to drill one or more horizontal drain holes using a short radius from a vertical well bore, the well bore must be spaced according to the regulations concerning well spacing and construction.[19] In addition, the applicant must file a copy of the directional drilling survey for each horizontal drain hole within 60 days after the completion of the drilling. The application for a permit requires a nonrefundable fee and a bond.

Illinois holds certain lands for the benefit of the People, including lands now submerged and lands that were formerly submerged, but that have been illegally filled in, reclaimed, and occupied.[20] The Illinois DNR has the authority to grant permits and leases, with the approval of the Governor in writing, for the extraction of oil, gas, and other petroleum deposits, except that no surface extraction activities shall be performed nor production equipment located on lands owned by the DNR if the state owns 100% of the underlying mineral interests of those lands. Extraction activities underlying lands owned by the DNR that utilize directional drilling techniques may be permitted at the discretion of the Department. However, the Department shall not grant permits on leases for the extraction of oil, gas, and other petroleum deposits from the following classifications of lands if the state owns 100% of the underlying mineral interests: (1) lands where threatened or endangered species occur, as determined pursuant to the Federal

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17 *Illinois Central Railroad Company v. Illinois*, 146 U.S. 387 (1892).

18 Illinois Oil and Gas Act (225 Illinois Consolidated Statutes 725); 62 Illinois Administrative Code (Ill. Adm. Code) 240.200 et seq.

19 62 Ill. Admin. Code 240.400 et seq. and 62 Ill. Admin. Code 240.600 et seq.

20 5 ILCS 605, Submerged Lands Act.

Endangered Species Act or the Illinois Endangered Species Protection Act, (2) Illinois Natural Area Inventory sites, (3) nature preserves dedicated under the Illinois Natural Areas Preservation Act, (4) lands containing a wild and scenic river as designated under the Wild and Scenic River Area Act, (5) lands registered under the Register of Land and Water Reserves under Part 4010 of Title 17 of the Illinois Administrative Code, and (6) lands on which Federal or state laws or regulations prohibit the surface extraction or production facility activity.[21]

4.4.2 Indiana

In Indiana, no person may drill, deepen, operate, or convert a well for oil and gas purposes without a permit issued by the Indiana Natural Resource Commission, Division of Oil and Gas.[22] The permit application must include a fee; a survey showing the location of the proposed well; and a schematic diagram showing depths, geological zones, distance from underground drinking water zones, and construction.[23] In addition to an annual well fee, the applicant must file a bond. Indiana has established regulations on well spacing and drilling unit sizes, as well as construction, operations, and abandonment of wells.[24] In addition, it has established spill reporting and mitigation/reclamation requirements.[25]

Indiana requires a permit from the Indiana Natural Resources Commission for the right to prospect and explore on public land for the occurrence of petroleum.[26] Then, at any time during the life of the permit or upon expiration of the exploration permit, the permittee can enter into a lease for the extraction of petroleum.

4.4.3 Michigan

In the State of Michigan, no person may drill or begin the drilling of any well for oil or gas until a permit to drill and operate the well is issued by the Supervisor of Wells.[27] When an application to drill an oil and gas well is received by the Department of Environmental Quality (DEQ), Offices of Geological Survey, it must include the permit fee, bond, and all relevant forms and notifications identified on the Permit Application Instructions (Form EQP 7200-1, including lease or well name and number; surface location; bottom hole location; location of endpoint, if directionally drilled; if it is an area where sour (containing H_2S) oil and gas are likely to be encountered; any freshwater aquifers; total depth; formation at total depth; and the proposed

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21 5 ILCS 615 Oil and Gas Wells on Public Land Act.

22 312 Indiana Administrative Code (IAC) 16-3-1.

23 312 IAC 16-3-2.

24 312 IAC Rule 5, Performance Standards and Enforcement, 16-5-1 et seq.

25 312 IAC 16-5-22 through 16-5-29.

26 Indiana Code (IC) 14-38-1, et seq. and IC 17-1-1 et seq.

27 Mich. Comp. Laws, Section 342.61252.

drilling, casing, cementing, and sealing program. It must also have a survey showing the approximate distances and directions from the well to special hazards or conditions, including surface waters and other environmentally sensitive areas; floodplains; wetlands; natural rivers; dune areas; threatened or endangered species; buildings; freshwater wells; all public water supply wells; public roads; pipelines; and power lines. When the proposed well is located in or adjacent to these types of areas, the person must obtain all environmental permits and approvals and, if so instructed by the Supervisor of Wells, file an environmental impact assessment. The applicant must also have the necessary mineral and surface rights at the time of the application to allow a well to be drilled at the proposed location. If the well site is located on state-owned land, near threatened or endangered species, or within a state-managed area, staffs from the Department of Natural Resources (DNR) may also review the application to conduct a resource evaluation and recommend possible mitigation of impacts.

In addition, under Act 9 of Public Acts of 1929,[28] the Michigan Public Service Commission has the authority to regulate production rates of natural gas from gas wells through the issuance of Well Connection Permits, Allowable Withdrawal Orders, and Proration Orders.

In Michigan, the authority to lease state-owned minerals vests with the DNR, Real Estate Division. Application to drill an oil or gas well on state-owned land, near threatened or endangered species, or within a state-managed area, may be reviewed by the DNR to conduct a resource evaluation and recommend possible mitigation of impact. Under Michigan's Great Lakes Submerged Lands Act, the state may lease public trust lands to private parties when it is in the "public interest."[29] The lands covered and affected by this part are all of the unpatented lake bottomlands and unpatented made lands in the Great Lakes, including the bays and harbors of the Great Lakes, belonging to the state or held in trust by it, including those lands that have been artificially filled in. The waters covered and affected by this part are all of the waters of the Great Lakes within the boundaries of the state. This part shall be construed so as to preserve and protect the interests of the general public in the lands and waters described in this section, to provide for the sale, lease, exchange, or other disposition of unpatented lands and the private or public use of waters over patented and unpatented lands, and to permit the filling in of patented submerged lands whenever it is determined by the Department that the private or public use of those lands and waters will not substantially affect the public use of those lands and waters for hunting, fishing, swimming, pleasure boating, or navigation or that the public trust in the state will not be impaired by those agreements for use, sales, lease, or other disposition.

4.4.4 Minnesota

In Minnesota, a person needs a license from the Commissioner of Natural Resources to conduct exploratory boring.[30] Thirty days before making an exploratory boring, a licensee must

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[28] Michigan Compiled Laws 483.151–483.162.

[29] Mich. Comp. Laws, Section 324.32502.

[30] Minnesota Statutes, Section 103I.601.

register with the Commissioner of Natural Resources and provide a copy of the registration to the Commissioner of Health. Ten days before beginning exploratory boring, a licensee must submit to the Commissioners of Health and Natural Resources a map showing the location of each proposed exploratory boring to the nearest estimated 40-acre (16-ha) parcel.

In Minnesota, the Commissioner of Natural Resources may issue leases to prospect for, mine, and remove minerals other than iron ore upon any lands owned by the state, including trust fund lands. All leases for nonferrous metallic minerals or petroleum must be approved by the Executive Council.[31]

4.4.5 New York

In New York, the Bureau of Oil and Gas Regulation in the New York Department of Environmental Protection (DEP), Division of Mineral Resources, oversees permitting, compliance, and enforcement of all regulated wells in New York.[32]

A permit application must be filed, along with a plat, proposed drilling program, including the proposed casing, cementing, completion testing and stimulation procedures fee, and an environmental assessment form (EAF). The EAF includes information about the physical setting of the proposed project, the general character of the land and land use, the projected size of the area that will be disturbed, and the length of time the drilling rig will be on the site. The applicant must also describe on the EAF the procedures that will be used to construct the access road, supply water for drilling, contain and dispose of wastes, and reclaim the site. Information provided on the EAF allows the Division of Mineral Resources to evaluate the environmental impacts and site-specific concerns associated with the proposed drilling activity and determine whether special permit conditions, a Supplemental Environmental Impact Statement, or any additional Department permits are required.

The New York Department of Environmental Conservation (DEC), Division of Mineral Resources, Bureau of Oil and Gas Regulation, is authorized under the Environmental Conservation Law Article 23, Title 11, to lease state lands for oil and gas exploration and development and for underground gas storage. However, the DEC is not authorized to lease lands under the waters of Lake Ontario or lands under Lake Erie for oil development. Under the New York Public Lands Law,[33] the Commission of General Services may grant leases, easements, and lesser interests, including permits, for the use of state-owned land underwater. Such grants must be consistent with the public interest in the use of state-owned lands underwater, for purposes of navigation, commerce, fishing, bathing, and recreation; environmental protection; access to the navigable waters of the state; and with due regard for the need of affected owners of private property to safeguard their property. The Commissioner of

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[31] Minn. Statutes, Section 93.25.

[32] Environmental Conservation Law, §§ 23-0305[8] [9]; 6 New York Code Rules and Regulations (NYCRR) 550-559.

[33] Public Lands, Chapter 46, Article 6, Section 75.

Environmental Conservation and the Secretary of State shall review any proposed lease, easement, permit, or other interest and can recommend conditions to protect the environment and natural resources for incorporation into the lease. The Secretary of State also has input with respect to coastal issues, or shall deny the proposal if the Commissioner of Environmental Conservation, upon administrative findings, determines that the environment or natural resources cannot be adequately protected.

4.4.6 Ohio

Ohio law requires a permit to drill a new well, deepen an existing well, reopen an existing well, convert a well to any use other than its original purpose, or to plug back a well to a different source of supply.[34] The Division of Mineral Resources Management in the Ohio DNR has sole authority for permitting and siting oil and gas wells and production facilities. The application must include the designation of the well by name and number; the plan for disposal of water and other waste substances resulting from, obtained, or produced in connection with exploration, drilling, or production of oil or gas; an affidavit that the applicant is the owner; a map showing the subject tract of land or drilling unit upon which the well is to be drilled; the location of the proposed well; and the locations of all buildings, public roads, railroads, and streams within one 150 ft (46 m) of the proposed well site.

In addition, the maximum point at which a well penetrates the producing formation shall not vary unreasonably from the vertical drawn from the center of the hole at the surface, with the exception of approved directional drilling. The Division of Mineral Resources Management will not issue a permit for the drilling of a new well, the reopening of an existing well, or the deepening or plugging back of an existing well to a different pool for the production of oil and gas unless the proposed well location and spacing substantially conform to the requirements of its rules. All persons engaged in any phase of operation of any well or wells must conduct such operation or operations in a manner that will not contaminate or pollute the surface of the land, or water on the surface or in the subsurface.

The Ohio General Assembly designated the DNR as the state agency in all matters pertaining to the care, protection, and enforcement of the state's rights in Lake Erie.[35] The DNR is to control, manage, and direct an upland owner's use and occupation of Lake Erie public trust lands through the medium of leasing those lands.[36] The DNR recognizes no boundary higher or lower than the ordinary high-water mark of Lake Erie as the landward boundary of the lands held in trust for the people of the state. Upon application of any person who wants to develop or improve part of the territory, and after the director determines that any part of this land can be developed and improved without impairment of the public right of navigation, water commerce, and fishery, a lease of all or any part of the land may be entered into or a permit may be issued.

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[34] Ohio Revised Code, Chapter 1509, Section 1509.22.1; Ohio Administrative Code 1501:9, et seq.

[35] Ohio Revised Code, Section 1506.10.

[36] Ohio Revised Code, Section 1506.11.

4.4.7 Pennsylvania

In Pennsylvania, the Bureau of Oil and Gas Management is responsible for the statewide oil and gas conservation and environmental programs to facilitate the safe exploration, development, and recovery of Pennsylvania's oil and gas in a manner that will protect the Commonwealth's natural resources and the environment. The Bureau develops policies and programs for the regulation of oil and gas development and production pursuant to the Oil and Gas Act, the Coal and Gas Resource Coordination Act, and the Oil and Gas Conservation Law;[37] oversees the oil and gas permitting and inspection programs; develops statewide regulation and standards; conducts training programs for industry; and works with the Interstate Oil and Gas Compact Commission and the Technical Advisory Board.

The Pennsylvania DEP enforces Pennsylvania's oil and gas laws relating to resource management, well construction activities, and waste management practices. An operator must secure a bond before applying for a well permit. The DEP approves bonds and well permits, inspects wells and environmental controls, and permits and inspects waste disposal facilities and waste management activities. Operators must submit reports on well completion, waste management, annual production, and well plugging. The DEP has the authority to take action to enforce compliance with applicable laws and to seek civil penalties for violations of these laws.

In Pennsylvania, through various state agencies the Commonwealth owns property that is available under lease for oil and gas development — for example, state forests, parks, and state game lands. There are even a few gas wells on the campuses and lands of state universities. The leasing of oil and gas rights on land owned by the Commonwealth is administered by the Department of Conservation and Natural Resources, Bureau of Forestry, Minerals Section.

4.4.8 Wisconsin

In Wisconsin, no person may engage in the exploration for or production of oil or gas without a license from the Wisconsin DNR.[38] However, there is a ban on drilling beneath the beds of the Great Lakes or bays or harbors that are adjacent to the Great Lakes.[39] The Wisconsin DNR has issued regulations concerning oil and gas exploration.[40] An application for an exploration license must be filed with the Wisconsin DNR and must include a fee and a bond payable to the Department in the amount of $50,000 conditioned on the faithful performance of the regulatory requirements. In addition, prior to constructing any drill holes, the licensee must receive written approval from the Wisconsin DNR. An application for drill hole construction approval must contain the location and date of commencement of drilling; proposed method of drilling; proposed drill hole construction, proposed method of containing any oil and gas that

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[37] 25 Pa. Code § 78.1, et seq. and § 79.1 et seq.

[38] Wisconsin Statutes, Chapter 295, Subchapter II, Oil and Gas.

[39] Wisconsin Statutes, Section 295.33(4).

[40] Wisconsin Administrative Code, Chapter on Natural Resources (NR) 134.

might be encountered; proposed method of containment and eventual disposal of any groundwater that may flow to or is otherwise brought to the ground surface; and the proposed method of drill hole abandonment and drilling site reclamation. If the Wisconsin DNR finds that the proposed drill hole location, construction, abandonment, and site reclamation will adequately protect the waters of the state, it will grant the approval. Such approval can be conditioned to provide such protection.

The Wisconsin Board of Commissioners of Public Lands may grant leases of parts or parcels of any public lands except state park lands and state forest lands; grant easements, leases to enter upon the lands to flow the same or to prospect for and to dig and remove ore, minerals and other deposits, and sell such timber as the board shall find necessary to prevent future loss or damage.[41]

4.5 ENVIRONMENTAL REGULATIONS APPLICABLE TO OIL AND GAS EXPLORATION AND PRODUCTION

The onshore and offshore segments of the oil and gas extraction industry are subject to different sets of regulations. Onshore, activities primarily are under the authority of the EPA or the authorized state authority. Although certain wastes from oil and gas exploration are partially exempt from Federal regulation under the Resource Conservation and Recovery Act (RCRA), states may impose regulations or requirements over and above the Federal requirements discussed below on oil and gas exploration activities taking place within their borders. The eight states involved have primary authority for the enforcement of Federal environmental laws within their state borders. Each state may have slightly different regulatory requirements governing impacts to the environment from oil and gas E&P.

The following discussion is based on information from the EPA's industry sector notebook entitled *Profile of the Oil and Gas Extraction Industry* (EPA 2000), and it outlines the type of environmental regulations that may apply to emissions, waste management, and discharges from oil and gas E&P activities.

Produced water is the largest volume waste generated in oil and gas extraction operations. The concentration of contaminants in produced water varies from region to region and depends on the geology of the production zone and the age of the well, among other factors. Since most contaminants found in produced water are naturally occurring, they will vary based on what is present in the subsurface at a particular location.

Associated wastes are a relatively small but significant category of waste from the oil and gas extraction industry. The term "associated wastes" encompasses a wide range of small-volume waste streams essential to oil and gas extraction. Because of their nature, these waste streams are the most likely to contain constituents of concern.

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[41] Wisconsin Statutes, Section 24.39.

Well maintenance, including work over, treatment, and completion, requires the use of fluids similar to drilling fluid and is the largest miscellaneous source of waste. These fluids may contain a range of chemicals (depending on the maintenance activity undertaken) and naturally occurring materials (i.e., trace metals). Because of the presence of these constituents, the wastes require proper disposal. Onshore, most of these wastes are disposed of through Class II injection wells.

Table 4.1 lists the major Federal laws, E.Os., and other compliance instruments that establish permits, approvals, or consultations that may be applicable to the extraction of oil and gas from drilling under the Great Lakes. The table is divided into general environmental resource categories. The citations in the table are those of the general statutory authority that governs the indicated category of activities to be undertaken under the proposed action and alternatives. Under such Federal statutory authority, the lead Federal or state agency may have promulgated implementing regulations that set forth the detailed procedures for permitting and compliance. The sections following the table provide more detail on the application of some of these laws or regulations.

TABLE 4.1 Major Federal Laws, Executive Orders, and Other Compliance Instruments That Establish Permits, Approvals, or Consultations That May Be Applicable to the Extraction of Oil and Gas from under the Great Lakes.

Air Quality and Noise
Clean Air Act (CAA) (42 USC § 7401 et seq.)
Noise Control Act as Amended by the Quiet Communities Act (42 USC § 4901 et seq.)

Water Bodies, Floodplains, and Wetlands
Clean Water Act (33 USC § 1344)
Rivers and Harbors Act of 1899 (33 USC § 401 et seq.)
Water Bodies, Floodplains and Wetlands
E.O. 11988, “Floodplain Management” (May 21, 1977)
E.O. 11990, “Protection of Wetlands” (May 24, 1977)
E.O. 13158, “Marine Protected Area” (May 26, 2000)

Wastewater and Storm Water
Clean Water Act (CWA) (33 USC § 1251 et seq.)
Oil Pollution Control Act (33 USC § 2701 et seq.)
Pollution Prevention Act (PPA) of 1990 (42 USC § 13101 et seq.)

Hazardous Materials and Waste
Solid Waste Disposal Act (SWDA) (42 USC § 6901 et seq.)
Hazardous Waste and Polychlorinated Biphenyls (PCBs)
Toxic Substances Control Act (TSCA) [15 USC § 2605(e)]
Solid Waste Disposal Act (SWDA), as amended by the Resource Conservation and Recovery Act (RCRA) (42 USC § 6901 et seq.) and the Hazardous Solid Waste Amendments of 1984 (HSWA)
Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (42 USC § 9601 et seq.)
Emergency Planning and Community Right-to-Know Act (EPCRA) (42 USC § 11001 et seq.)

TABLE 4.1 (Cont.)

Source Water Protection, Groundwater, and Drinking Water
Safe Drinking Water Act (SDWA) [42 USC § 300(f) et seq.]

Wildlife
Bald and Golden Eagle Protection Act (16 USC 668)
Migratory Bird Treaty Act (16 USC § 703)
Endangered Species Act (16 USC § 1531 et seq.)
Wild Free-Roaming Horse and Burro Act of 1971 (P.L. 92-195)
E.O. 13112, "Invasive Species" (February 3, 1999)

Land Use
Coastal Zone Management Act (16 USC § 1451 et seq.); Coastal Zone Act Reauthorization Amendments of 1990 [16 USC § 1456 (c)(3)(A)]
Wild and Scenic Rivers Act (16 USC §1271 et seq.)
Submerged Lands Act of 1953 (43 USC § 1301–1315)
Farmland Protection and Policy Act (7 USC § 4201 et seq.)
Soil and Water Conservation Act of 1977 (16 USC § 2001 et seq.)
E.O. 12898, "Environmental Justice" (February 11, 1994)
E.O. 13045, "Protection of Children from Environmental Health Risks and Safety Risks" (April 21, 1997)

Archaeology, Paleontology, and Historic Preservation
E.O. 13007, "Indian Sacred Sites" (May 24, 1996)
E.O. 13084, "Consultation and Coordination with Indian Tribal Governments" (May 14, 1998)
Native American Graves Protection and Repatriation Act (NAGPRA) (25 USC § 3001)
American Indian Religious Freedom Act (AIRFA) (42 USC § 1996)
Archeological Resources Protection Act [16 USC § 470(aa) et seq.]
Archaeological and Historic Preservation Act (AHPA) (16 USC § 469a et seq.)
Antiquities Act (16 USC § 431 et seq.)
National Historic Preservation Act (NHPA) (16 USC § 470 et seq.)
E.O. 11593, "Protection and Enhancement of the Cultural Environment" (May 15, 1971)

4.5.1 Clean Air Act (CAA)

The oil and gas production industry is subject to National Emission Standards for Hazardous Air Pollutants (NESHAPs). The regulation calls for the application of maximum achievable control technology in order to reduce the emissions of hazardous air pollutants (HAPs) at facilities classified as major sources. The primary HAPs released by the industry are benzene, toluene, ethyl benzene, and mixed xylenes (BTEX), and *n*-heptane. The technology requirements involve the following emission points: process vents on glycol dehydration units, storage vessels with flash emissions, and equipment leaks at natural gas processing plants. Additional requirements include the installation of air emission control devices, and adherence to test methods and procedures, monitoring and inspection requirements, and record keeping and reporting requirements. Another air pollutant of concern at oil and gas production sites is H_2S. Although this pollutant was originally listed as a potential HAP and studies were conducted by

the EPA in accordance with the direction in the Clean Air Act Amendment of 1990, it was removed from the list [Section 112(b)] by Congressional action in 1991. However, H_2S is included in Section 112(r) and is subject to the accidental release provisions. A study was required under Section 112(n)(5) (EPA 2005d). This pollutant may be regulated at the state or local level.[42]

In addition, New Source Performance Standards may affect E&P facilities. The standards apply to devices used at these facilities, including gas turbines, steam generators, storage vessels for petroleum liquids, volatile organic liquid storage vessels, and gas processing plants. Requirements will depend on whether the region in which the particular facility is located is in compliance with National Ambient Air Quality Standards and whether Prevention of Significant Deterioration requirements apply.

4.5.2 Clean Water Act (CWA)

Onshore E&P facilities may be subject to four aspects of the CWA: (1) national effluent limitation guidelines, (2) storm water regulations, (3) wetlands regulations, and (4) Spill Prevention Control and Countermeasure (SPCC) requirements.

National effluent limitation guidelines have been issued for two subcategories of onshore nonstripper wells.[43] The Onshore Subcategory guidelines prohibit the discharge of water pollutants from any source associated with production, field exploration, drilling, well completion, or well treatment (40 CFR 435.30).

Oil and gas E&P facilities are exempt from CWA storm water Phase I regulations for industrial activities under most conditions, with two exceptions: (1) if the facility has a reportable quantity spill that could be carried to waters of the United States via a storm event, or (2) if the storm water runoff contributes to a violation of a water quality standard. (See 40 CFR Parts 117 and/or 302 for reportable quantities of hazardous substances or Part 110 for the reportable quantity of spilled oil.) If either of these two scenarios should happen, the facility would be required to apply for a Multisector General Permit and develop a pollution prevention plan. However, if a reportable quantity spill was to be cleaned up quickly or containment was so total that there would be no threat of a product release as a result of a storm water event, no permit would be required. Coverage under the Phase I regulations and the Construction General Permit for earth-disturbing activities of 5 acres (2 ha) or more was always applicable to oil and gas E&P facility construction activities. However, the Phase II regulations would have extended coverage for earth-disturbing activities of between 1 and 5 acres (0.4 to 2 ha), to oil and gas E&P facilities. In March 2003, the EPA issued a ruling that delayed the start date of the Phase II rule

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[42] In Michigan, permits are reviewed for the probability of encountering H_2S gas based on knowledge of the rock formations from other wells. Activities that do or could produce H_2S as a result of oil and gas production or exploration are regulated by the Michigan DEQ, Air Quality Division, which issues permits on some of the equipment associated with wells and processing facilities such as storage tanks, flares, and other fuel-burning equipment, depending on the amount of emissions expected to be discharged.

[43] A nonstripper well is one that produces more than 20 bbl/day of crude oil.

for permitting discharges associated with small construction activities at oil and gas E&P sites to March 10, 2005. Oil and gas industry groups have asked the 5th Circuit U.S. Court of Appeals to vacate the March 2003 rule to the extent that it requires small oil and gas construction activities to obtain any permit coverage under the Phase II rule. On March 7, 2005, the EPA postponed the requirement for permitting discharges from small construction activities at oil and gas E&P sites until June 12, 2006.[44]

During the course of petroleum exploration and development, wetlands may be encountered. Under the CWA, wetlands are defined by the frequency and length of time they are saturated with water, by the type of vegetation they support, and by soil characteristics. Also, by definition, most wetlands are part of the "waters of the United States" and, as such, all discharges of pollutants to wetlands require a CWA permit. However, the CWA regulates not only the discharges of dissolved/suspended pollutants but also the discharge of solids, dredge and fill materials, or dirt to waters of the United States. Permits issued by the Corps are required for discharges of fill and/or dredge into waters of the United States, including wetlands. All work, including dredging, excavation, and construction activities in navigable waters of the United States requires Corps authorization under Section 10 of the Rivers and Harbor Act of 1899. Permits fall under either of two categories (1) general, previously issued permit for certain classes of activities that have been determined to have minimal adverse environmental impacts, individually or cumulatively, and (2) individual, a project-specific permit undergoing individual public interest review prior to issuance. Broadly speaking, individual permits are for projects presumed to have more than minimal adverse environmental impacts. Individual permits involve more intensive regulatory review (33 CFR Parts 320–330), including project-specific public notices and environmental assessments.

The Corps, the EPA, and in some cases, the states oversee enforcement of the CWA provisions for wetlands. Most of the day-to-day administration of the program is implemented by the Corps. The Corps issues and enforces permits and is also responsible for delineating wetlands. States are provided the opportunity to comment on wetland permit applications prior to permit issuance. The EPA regions comment on permit applications and can also enforce these provisions of the CWA. The EPA also helps to develop environmental criteria for wetlands (EPA 1990, 2002b). The Corps can approve a state to administer the CWA Section 404 Wetlands Program; only Michigan and New Jersey are currently approved. If a state is authorized to administer the CWA Wetlands Program, it has sole authority to issue a permit in lieu of a Corps-issued Section 404 Permit on inland waters and joint permit authority with the Corps on traditionally navigable waters and adjacent wetlands. However, the Corps retains administrative authority for Section 10 permitting.

An oil and gas production, drilling, or work-over facility is subject to the EPA's SPCC requirements if it meets the following specifications: the facility could reasonably be expected to discharge oil into or upon the navigable waters of the United States or adjoining shorelines and has (1) a total underground buried storage capacity of more than 42,000 gal (158,987 L), and/or (2) a total aboveground oil storage capacity of more than 1,320 gal (4,997 L). SPCC applicability

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[44] *Federal Register*, Volume 70, page 11560 (70 FR 11560) (March 9, 2005).

is dependent on the tank's maximum design storage volume and not "safe" operating or other lesser operational volumes. For purposes of the regulation, an onshore production facility may include all wells, flowlines, separation equipment, storage facilities, gathering lines, and auxiliary non-transportation-related equipment and facilities in a single geographical oil or gas field operated by a single operator.

All facilities subject to SPCC requirements must prepare a site-specific spill prevention plan that incorporates requirements specified in 40 CFR 112.7. In addition, the plan must discuss spill history and spill prediction (i.e., the anticipated direction of flow). The SPCC plan must be approved by a Registered Professional Engineer who is familiar with SPCC requirements, be fully implemented, and be modified when changes are made to the facility (e.g., installation of a new tank). Regardless of whether changes have been made to the facility, the plan must be reviewed at least once every 3 years and amended if new, field-proven technology may reduce the likelihood of a spill.

A portion of SPCC-regulated facilities may also be subject to Facility Response Planning (FRP) requirements if they pose a threat of "substantial harm" to navigable waters. The determination of a "substantial harm" facility is made on the basis of meeting either of two sets of criteria — one involving transfer over water, and the other involving oil storage capacity or other factors. If the facility was subject to FRP requirements, it would be required to develop a facility response plan that would involve, among other requirements, identification of small, medium, and worst-case discharge scenarios and response actions; a description of discharge detection procedures and equipment; detailed implementation plans for containment and disposal; diagrams of the facility and the surrounding layout, topography, and evacuation paths; and employee training, exercises, and drills.

4.5.3 Safe Drinking Water Act (SDWA)

The Underground Injection Control (UIC) program of the SDWA regulates injection wells used in the oil and gas production process for produced water disposal or for enhanced recovery. Wells used in this industry for produced water are classified as Class II. Minimum UIC Class II well requirements, as outlined in 40 CFR Part 144, involve specific construction, operation, and closure standards, as well as provisions for ensuring that the owner, operator, and/or transferor of the well maintains the financial responsibility and resources to plug and abandon the well. Operational standards involve regular (at least once every 5 years) mechanical integrity tests; monitoring of injection pressure, flow rate, and volume; monitoring of the nature of injected fluid as needed; and annual reporting of monitoring results. Finally, closure procedures must be performed in accordance with an approved plugging and abandonment plan, which includes the placement and composition of cement plugs, the amount of casing to be left in the hole, the estimated cost of plugging, and any proposed tests or measurements. Additional requirements may be imposed in states that have been delegated to implement the UIC program.

The EPA has authorized delegation of the UIC for all wells in 35 states, implements the program in 10 states and on all Indian lands, and shares responsibility with 5 states.[45]

4.5.4 Resource Conservation and Recovery Act (RCRA)

Under the 1980 Amendments to RCRA, Congress conditionally exempted certain categories of solid waste from regulation as hazardous wastes under RCRA Subtitle C, including drilling fluids, drill cuttings, produced waters, and other low-volume wastes associated with the exploration, development, or production of crude oil or natural gas. The Amendments required the EPA to study these wastes to determine whether their regulation as hazardous wastes was warranted and to submit a report to Congress. In its report to Congress (EPA 1987) and in a July 1988 regulatory determination (53 FR 25446, July 6, 1988), the Agency stated that regulation as hazardous wastes under Subtitle C was not warranted and that these wastes could be controlled under other Federal and state regulatory programs, including a tailored RCRA Subtitle D (solid waste) program.

Specifically, the EPA's regulatory determination for E&P wastes exempted a variety of wastes from RCRA hazardous waste management requirements, regardless of their potential to contain constituents that are listed as hazardous or may exhibit hazardous characteristics. Table 4.2 identifies many, but not all, exempt wastes. In general, E&P exempt wastes are generated in "primary field operations" and not as a result of maintenance or transportation activities. Exempt wastes are typically limited to those that are intrinsically related to the exploration, development, and production of oil or natural gas.

On March 22, 1993, the EPA provided "clarification" regarding the scope of the E&P waste exemption for waste streams generated by crude oil and tank bottom reclaimers, oil and gas service companies, crude oil pipelines, and gas-processing plants and their associated field gathering lines (see 58 FR 15284–15287). The EPA stated that certain waste streams from these operations are "uniquely associated" with primary field operations and as such are within the scope of the RCRA Subtitle C exemption. The EPA's clarification cautioned, however, that these wastes may not be exempt if they are mixed with nonexempt materials or wastes.

The EPA's 1988 regulatory determination also lists the wastes that are nonexempt. Table 4.3 identifies many, but not all nonexempt wastes, as well as transportation (pipeline and trucking) activities. While these wastes are nonexempt, their regulatory status as "hazardous wastes" is dependent upon a determination of their characteristics or whether they are specifically listed as RCRA hazardous waste.

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[45] States have the option of applying for primary responsibility, or primacy, for the UIC program for all classes of wells, only oil- and gas-related wells (Class II wells), or all wells except oil- and gas-related wells (Classes I, III, IV, and V). If a state does not obtain primacy for all or some of the well classes, then the EPA implements the program directly through one of its regional offices. The EPA administers the UIC programs in Michigan, Minnesota, New York, and Pennsylvania. Illinois, Ohio, and Wisconsin have full primacy for administering their UIC programs. Indiana has authorization to administer the UIC program for Class II wells.

TABLE 4.2 RCRA Exempt Waste Types

- Produced water
- Drilling fluids
- Drill cuttings
- Rig wash
- Drilling fluids and cuttings from offshore operations disposed of onshore
- Well completion, treatment, and stimulation fluids
- Basic sediment and water, and other tank bottoms from storage facilities that hold product and exempt waste
- Accumulated materials such as hydrocarbons, solids, sand, and emulsion from production separators, fluid treating vessels, and production impoundments
- Pit sludges and contaminated bottoms from storage or disposal of exempt wastes
- Work-over wastes
- Gas plant sweetening wastes for sulfur removal, including amine, amine filters, amine filter media, backwash, precipitated amine sludge, iron sponge, and H_2S scrubber liquid and sludge
- Cooling tower blowdown
- Spent filters, filter media, and backwash (assuming the filter itself is not hazardous and the residue in it is from an exempt waste stream)
- Packing fluids
- Produced sand
- Pipe scale, hydrocarbon solids, hydrates, and other deposits removed from piping and equipment prior to transportation
- Hydrocarbon-bearing soil
- Pigging wastes from gathering lines (liquids or solids generated from cleaning oil pipelines)
- Wastes from subsurface gas storage and retrieval, except for the listed nonexempt wastes
- Constituents removed from produced water before it is injected or otherwise disposed of
- Liquid hydrocarbons removed from the production stream but not from oil refining
- Gases removed from the production stream, such as H_2S and CO_2, and volatilized hydrocarbons
- Materials ejected from a producing well during the process known as blowdown
- Waste crude oil from primary field operations and production
- Light organics volatilized from exempt wastes in reserve pits or impoundments or production equipment

Source: EPA (2000).

The EPA also determined that produced water injected for enhanced recovery is not a waste for purposes of RCRA regulation, and therefore, is not subject to control under RCRA Subtitle C or Subtitle D. Produced water used in this manner is considered beneficially recycled and is an integral part of some crude oil and natural gas production processes. Produced water injected in this manner is already regulated by the UIC Program under the SDWA. However, if produced water is stored in surface impoundments prior to injection, it may be subject to RCRA Subtitle D regulations.

It is important to note that some states have adopted hazardous waste regulations that differ from those promulgated by the EPA. While different in many specific areas, those state programs, by law, still must be at least as stringent as the Federal programs.

TABLE 4.3 RCRA Nonexempt Waste Types

- Unused fracturing fluids or acids
- Gas plant cooling tower cleaning wastes
- Painting wastes
- Oil and gas service company wastes, such as empty drums, drum rinsate,[a] vacuum truck rinsate, sandblast media, painting wastes, spent solvents, spilled chemicals, and waste acids
- Vacuum truck and drum rinsate from trucks and drums transporting or containing nonexempt waste
- Refinery wastes
- Liquid and solid wastes generated by crude oil and tank bottom reclaimers
- Used equipment lubrication oils
- Waste compressor oil, filters, and blowdown
- Used hydraulic fluids
- Waste solvents
- Waste in transportation pipeline-related pits
- Caustic or acid cleaners
- Boiler cleaning wastes
- Boiler refractory bricks
- Incinerator ash
- Laboratory wastes
- Sanitary wastes
- Pesticide wastes
- Radioactive tracer wastes
- Drums, insulation, and miscellaneous solids

[a] Rinsate is the contaminated solution resulting from rinsing activities.

Source: EPA (2000).

4.5.5 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)

Under CERCLA, "petroleum, including crude oil or any fraction thereof," "natural gas," and "natural gas liquids" are exempted from the definition of "hazardous substance," unless specifically listed or designated under CERCLA.[46] Subsequent interpretation has concluded that listed hazardous substances normally found in crude oil, such as benzene, do not invalidate the exemption unless the concentration of these substances is increased by contamination or by addition after refining. Therefore, the notification, response, abatement, remediation, and financial responsibilities established under CERCLA[47] do not apply to releases of petroleum or natural gas. However, the National Contingency Plan, Subpart D, establishes the requirements for notification, response, and remediation of discharges of oil. Upon the discovery of a release over the reportable quantity, the person making the discovery must notify the National Response Center. The National Response Center maintains predesignated On-Scene Coordinators (OSCs). For oil releases to the Great Lakes, the predesignated OSC would be the U.S. Coast Guard.

[46] 42 USC § 9601 (14).

[47] See 40 CFR 300, Subpart E.

4.5.6 Endangered Species Act (ESA)

The ESA provides a means of protecting threatened or endangered species and the ecosystems (critical habitats) that support them. It requires Federal agencies to ensure through consultation that activities undertaken on either Federal or non-Federal property do not adversely impact threatened or endangered species or their habitat. In a 1995 ruling, the U.S. Supreme Court upheld interpretations of the Act that allow agencies to consider impacts on habitat as a potential form of prohibited "harm" to endangered species.[48] Agencies undertaking a Federal action (such as the Bureau of Land Management or Minerals Management Service review of proposed oil and gas extraction and production operations) must consult with the USFWS, and biological assessment must be prepared by the agency undertaking the action if "any major part of a new source will have significant adverse effect on the habitat" of a federally listed threatened or endangered species. On the basis of the biological assessment, the USFWS will render a biological opinion regarding the proposed action and necessary mitigation measures.

4.5.7 Coastal Zone Management Act (CZMA)

The CZMA encourages states and Tribes to preserve, protect, develop, and where possible, restore or enhance valuable natural coastal resources such as wetlands, floodplains, estuaries, beaches, dunes, barrier islands, and coral reefs, as well as the fish and wildlife using those habitats. It includes areas bordering the Atlantic, Pacific, and Arctic Oceans, Gulf of Mexico, Long Island Sound, and Great Lakes. A unique feature of this law is that participation by states and Tribes is voluntary.

In the Coastal Zone Management Act Reauthorization Amendments (CZARA) of 1990, Congress identified non-point-source pollution as a major factor in the continuing degradation of coastal waters. Congress also recognized that effective solutions to non-point-source pollution could be implemented at the state, Tribal, and local levels. In CZARA, Congress added Section 6217,[49] which calls upon states and Tribes with federally approved coastal zone management programs to develop and implement coastal non-point-source pollution control programs. The Section 6217 Program is administered at the Federal level jointly by the EPA and the NOAA. Section 6217(g) called for the EPA, in consultation with other agencies, to develop guidance on "management measures" for sources of non-point-source pollution in coastal waters. Under Section 6217, the EPA is responsible for developing technical guidance to assist states and Ttribes in designing coastal non-point-source pollution control programs. On January 19, 1993, the EPA issued its *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*, which addresses five major source categories of non-point-source pollution: (1) urban runoff, (2) agriculture runoff, (3) forestry runoff, (4) marinas and recreational boating, and (5) hydromodification (EPA 1993).

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[48] *Babbitt vs. Sweet Home Chapter of Communities for a Greater Oregon*, 515 U.S. 687 (1995).

[49] 16 USC § 1455b.

Section 307 of the CZMA (16 USC § 1456), called the Federal Consistency provision, requires that Federal agency activities that have reasonably foreseeable effects on any land or water use or natural resource of the coastal zone (also referred to as coastal uses or resources and coastal effects) must be consistent to the maximum extent practicable with the enforceable policies of a coastal state's federally approved Coastal Management Program (CMP). (Federal agency activities are activities and development projects performed by a Federal agency, or a contractor for the benefit of a Federal agency.)

Federal license or permit activities and Federal financial assistance activities that have reasonably foreseeable coastal effects must be fully consistent with the enforceable policies of State CMPs. (Federal license or permit activities are activities proposed by a non-Federal applicant requiring Federal authorization, and Federal financial assistance activities are proposed by state agencies or local governments applying for Federal funds for activities with coastal effects.)

Federal Consistency reviews are the responsibility of the lead state agency that implements or coordinates the state's federally approved CMP. At the Federal level, the Office of Ocean and Coastal Resource Management, within the NOAA's National Ocean Service, among other duties and services, interprets the CZMA and oversees the application of Federal Consistency; provides management and legal assistance to coastal states, Federal agencies, Tribes, and others; and mediates CZMA-related disputes.

4.5.8 Emergency Planning and Community Right-to-Know Act (EPCRA)

The EPA's Toxics Release Inventory (TRI) Program was established by Congress under Section 313 of EPCRA and was expanded by the Pollution Prevention Act of 1990. It requires certain facilities in covered industry sectors to file reports of their environmental releases and other waste management quantities of chemicals listed on the EPCRA Section 313 list of toxic chemicals if they manufacture, process, or otherwise use more than established threshold quantities of these chemicals. However, only facilities that are included in specified Standard Industrial Classification Codes are required to comply with the TRI program. Although petroleum bulk terminals and plants are so listed, oil and gas E&P facilities are not. Therefore, the oil and gas E&P facilities are currently not required to report or file a TRI or an annual report of toxic chemical releases under EPCRA Sections 312 and 313.[50]

4.5.9 Naturally Occurring Radioactive Materials

Material containing radionuclides that are present naturally in soil, rocks, water, and minerals and whose radioactivity has been concentrated and/or exposed to the accessible environment as a result of human activities is referred to as technologically enhanced naturally occurring radioactive material or TENORM. In the U.S, by definition, TENORM that does not

[50] 42 USC §§ 1102–11023.

contain more than 0.05% uranium or thorium by weight, or any combination thereof, is not subject to regulatory control under the Atomic Energy Act of 1954 because it does not meet the definitions for a source material, special nuclear material, or byproduct material (42 U.S.C. Section 2011-2259). TENORM, also by definition, is not subject to regulatory control under the Low Level Radioactive Waste Policy Act. Under that Act, low level radioactive waste (LLW) is defined as material that (i) is not a high-level radioactive waste, spent nuclear fuel, or byproduct material and (ii) has been classified by the Nuclear Regulatory Commission (NRC) as a LLW (42 U.S.C. Section 2021b-2021j). At this time, the NRC has not classified NORM as a LLW.

The primary radionuclides of concern in petroleum industry TENORM are radium-226 and radium-228 and their decay progeny, including radon. Oil and gas E&P results in the extraction of underground water that may naturally contain radium. The radium (if present in the produced water) as a result of changes in pressure, temperature, and chemistry at surface conditions may form a mineral scale on production piping, tanks, and separators at the field site. It may also be found in sludges and evaporite deposits in tanks, wastewater, and mud pits on the site. Typically, radium is not found in the produced oil; however small amounts of radon may be present in produced gas. Pipe yards where mineral scale has been removed during maintenance activities may have radium contamination of soils. TENORM generated by the petroleum industry may be divided into two general categories: (1) wastes containing radium isotopes and their progeny, and (2) wastes containing only lead-210 (Pb-210) and its progeny. Not all oil and gas fields have TENORM accumulations, however.

Currently no EPA regulations exist that specifically control the management and disposal of elevated levels of TENORM wastes associated with the production of oil and natural gas. Because TENORM waste is generated in primary oil field operations intrinsic to exploration, development, or production activities, it is an exempt waste under RCRA Subtitle C. There are EPA regulations related to some TENORM, including control of radionuclides in water, guidance for radon control in buildings, and cleanup of radioactively contaminated soils, but they are not specific to petroleum industry TENORM.

The U.S. Department of Labor’s OSHA has set occupational dose limits (29 CFR 1910.1096) of 500 mrem/yr for a workers classified as radiation workers. In most states, however, oilfield personnel have not been classified as radiation workers. Instead, workers are subject to dose limits established for the general public (i.e., 100 mrem/yr from all sources combined). OSHA standards contained in 29 CFR Part 1910.1096, "Ionizing Radiation,” may be applicable to petroleum industry workers who handle TENORM.

In the absence of specific Federal regulations, some states have issued general regulations for TENORM or for specific TENORM materials, while other states include TENORM in their controls for all radioactive substances. A few states have developed regulations specific to oil and gas industry TENORM; however, the remaining states address TENORM in more general terms, including establishing minimum radiation limits for any wastes to be disposed of to hazardous waste or solid waste landfills, injected into wells, or disposed of to the soil. The existing state regulatory programs establish standards for (1) TENORM exemption or action levels; (2) the licensure of parties possessing, handling, or disposing of TENORM; (3) the release of (NORM)-contaminated equipment and land; (4) worker protection; and (5) TENORM

disposal. Most state NORM programs address the disposal of TENORM wastes associated with oil and gas E&P, including (1) burial at a licensed NORM or low-level radioactive waste disposal facility, (2) encapsulation down hole inside the casing of a well about to be plugged and abandoned, and (3) underground injection into a subsurface formation. The action levels defining when wastes must be managed as TENORM wastes vary from state to state. These levels typically are expressed in terms of radionuclide activity concentrations (i.e., pCi/g), exposure levels (i.e., μR/h), surface contamination levels (in disintegrations per minute per 100 cm^2), and radon flux (i.e., $pCi/m^2/s$). Materials exceeding any one of these state-prescribed levels become regulated TENORM materials within that state. The Conference of Radiation Control Program Directors (CRCPD) is the organization through which state radiation protection programs coordinate their efforts. CRCPD's Commission on TENORM, has developed a model regulation for TENORM (CRCPD 2004). Some of the current state regulations follow this model.

The Illinois regulations for control of radiation apply to all ionizing radiation, whether emitted from radionuclides or devices.[51] The Illinois Emergency Management Agency issues licenses for possession and use of radioactive materials, including naturally occurring and accelerator-produced radionuclides. In addition, sections of the oil and gas regulations issued by the Illinois Department of Natural Resources, Division of Oil and Gas, address TENORM with respect to storage structure and pit closures.[52]

In Indiana, users of radioactive materials are required by statute[53] to register the materials with the Indiana State Department of Health (ISDH). Radioactive materials include by-product, source, and special nuclear materials, all licensed by the NRC; and naturally occurring/accelerator-produced radioactive material (NARM), which is regulated by the ISDH. In accordance with the Indiana Rule for Radiation Control,[54] each person who receives, possesses, uses, transfers, owns, or acquires radioactive material shall register such materials with the ISDH. However, only registrants utilizing NORM over the regulatory quantity are subject to inspection and enforcement by the ISDH. Indiana is a non-Agreement State (i.e., has not received NRC approval to license and regulate NRC-regulated radioactive materials).

The Michigan Department of Environmental Quality (MDEQ) has similar regulation of all radionuclides and has issued guidelines allowing the disposal of materials contaminated with average concentrations of up to 50 picoCuries per gram of radium-226 in landfills that are designed and permitted to receive nonhazardous municipal wastes (MDEQ 2005). These guidelines are applicable to radium-bearing NORM wastes generated by the petroleum industry. In addition, the MDEQ, Oil and Gas Division, has issued a special order regarding the plugging of wells where NORM may be present (MDEQ 1992).

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[51] 32 Illinois Administrative Code.

[52] 62 Illinois Administrative Code, Chapter I, Section 240, Subpart H.

[53] Radiation Control Act of Indiana (IC 16-41-35), specifically, IC 16-41-35-26(d).

[54] 410 IAC Chapter 5, specifically, 410 IAC 5-2-1.

Radioactive materials in Minnesota are currently regulated by both the NRC and the Minnesota Department of Health (MDH). The NRC regulates nuclear by-product material, which in simple terms is any radioactive material yielded in, or made radioactive by, a nuclear reactor. The MDH currently regulates NARM.[55] The MDH has developed a regular and an abbreviated license application for NARM.

The NY DEC regulates environmental releases and the disposal of radioactive material. DEC requires a permit for release of radioactive material to the environment, including the disposal of radioactive material (NORM, such as radium) and accelerator-produced radionuclides.[56] However, the NY DEC has concluded that New York State oil and gas production equipment and wastes are not significantly contaminated by NORM. The concentrations of NORM found on oil and gas production equipment and wastes pose no threat to the public health and the environment. The research and analysis supporting this conclusion were performed in 1996. Direct measurements of the radioactivity at well sites were performed. Samples of scales, sludges, sediments, soils, water, rock, brines, waxes, and oils were taken and analyzed by gamma spectrometry (NYSDEC 1999).

The Ohio Regulations for Control of Radiation[57] apply to all ionizing radiation, whether emitted from radionuclides or produced by machines. The Ohio Department of Health issues licenses for the possession and use of all radioactive material, including naturally occurring materials, such as certain isotopes of radium, and accelerator-produced radionuclides. Specific requirements regarding TENORM-bearing materials are found in Section 3701-39, §021 of the Ohio Administrative Code.

The State of Pennsylvania regulates all ionizing radiation, specifically including naturally occurring or accelerator produced materials. The Bureau of Radiation Protection, Department of Environmental Protection, requires a license for the possession and use of such sources over certain limits and waste disposal requirements.[58]

Wisconsin requires that any person who possesses, uses, manufactures, transports, stores or transfers radioactive materials in Wisconsin must have a radioactive materials license.[59] Effective August 11, 2003, the Department of Health and Family Services licenses and inspects by-product, source, special nuclear, and NARM in Wisconsin (unless it is below the regulatory quantity).

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[55] Minnesota Rules, Chapter 4731.

[56] Title 6, Parts 380, 381, 382, and 383 of the New York Codes, Rules, and Regulations.

[57] Section 3701 Ohio Administrative Code.

[58] Pennsylvania Code, Title 25, Subpart D, Article V, Radiological Health.

[59] Section 254.365 of the Wisconsin Statutes.

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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).

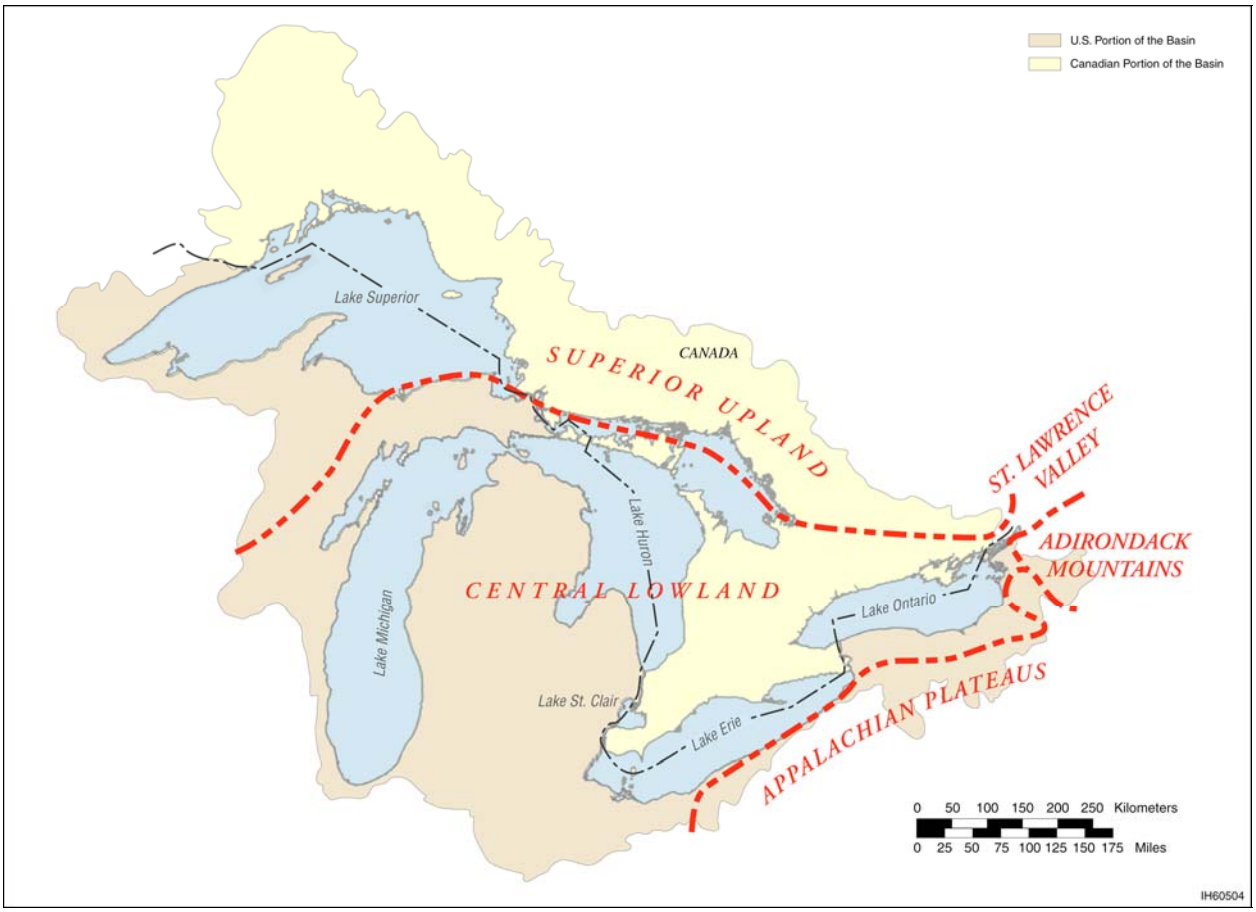

FIGURE 5.1 Physiographic Provinces of the Great Lakes Basin (Source: Fenneman 1946)

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,

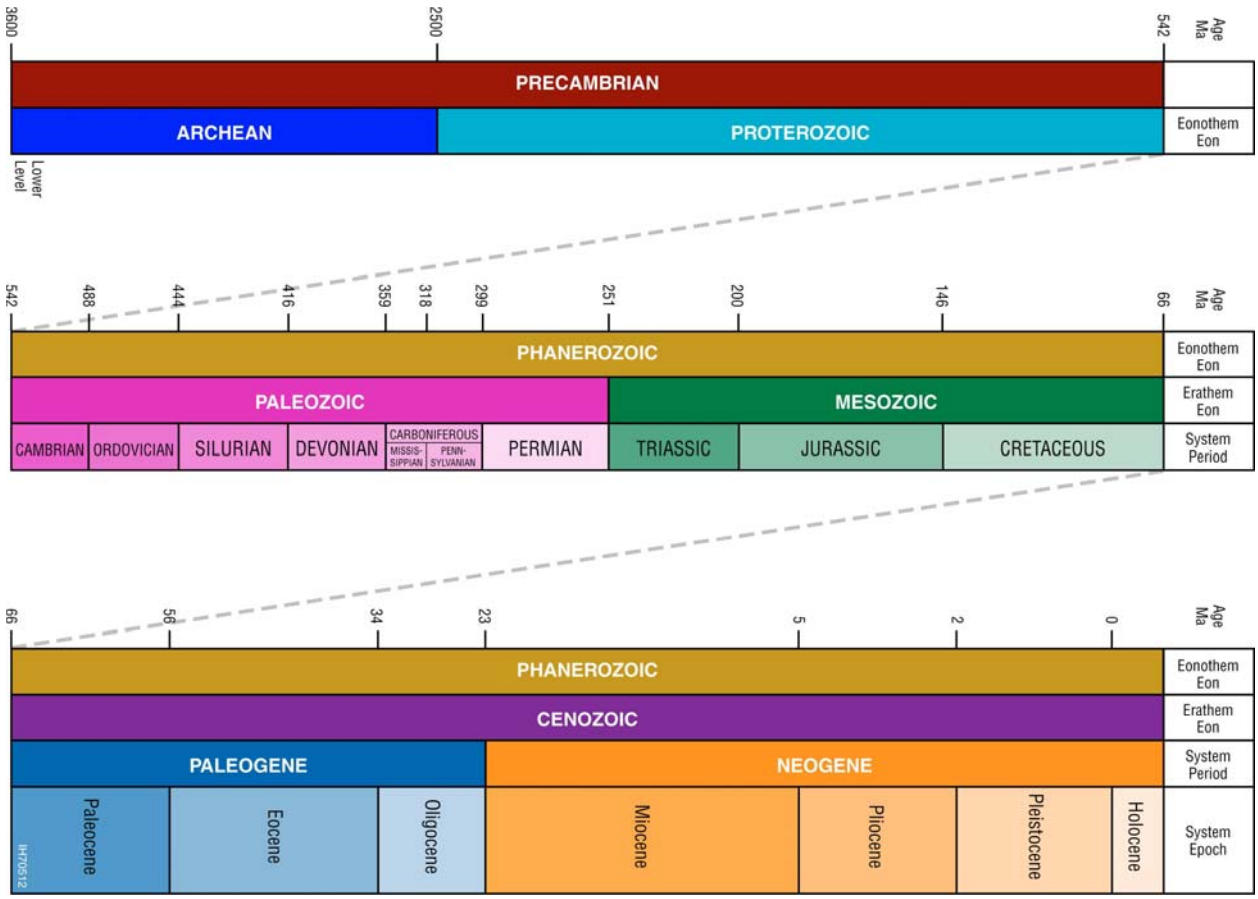

FIGURE 5.2 Geologic Time Scale (Source: Gradstein et al. 2004)

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

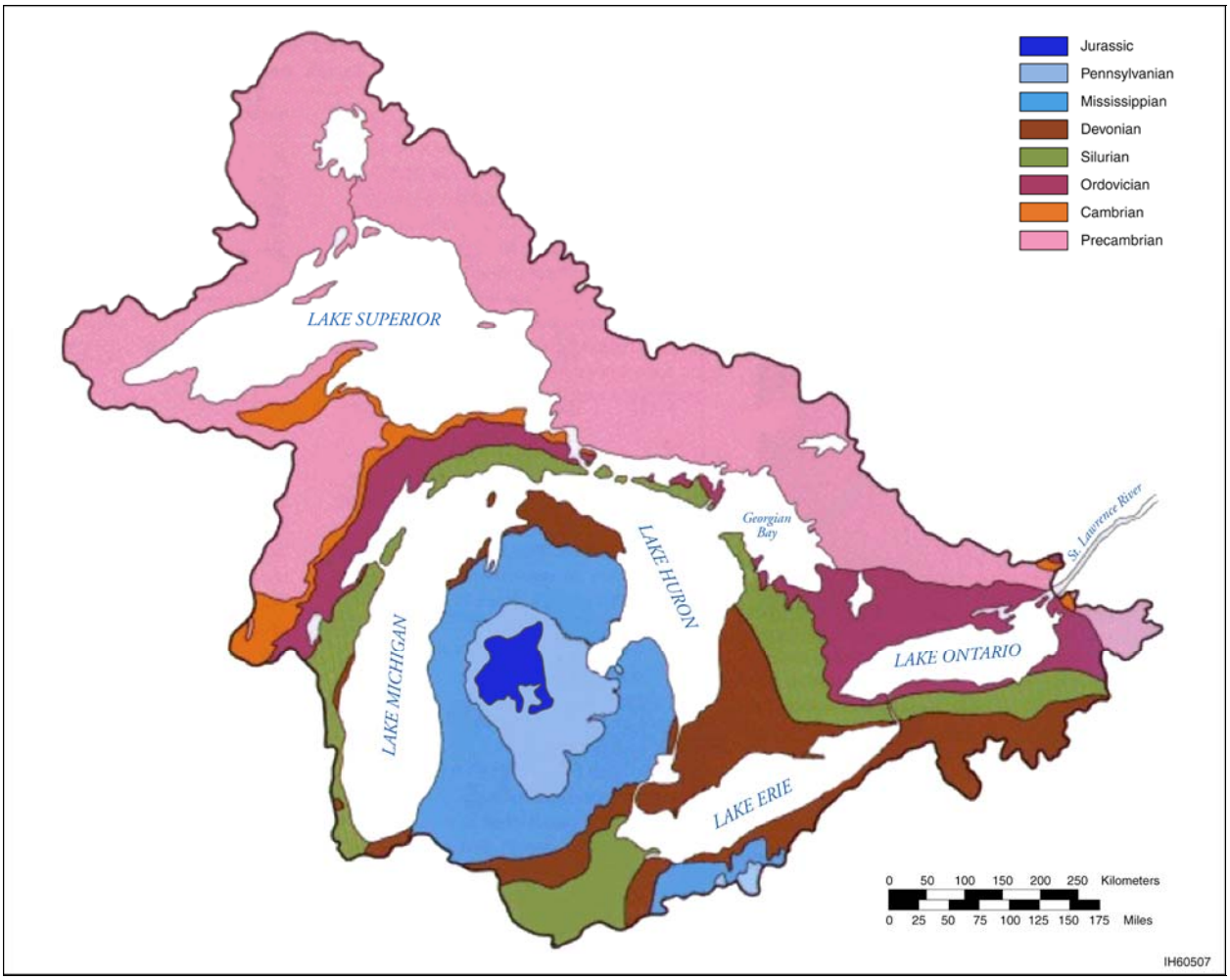

FIGURE 5.3 Geologic Map of the Great Lakes Basin (Sources: Donnan 1961; Catacosinos et al., 1991; EPA and Government of Canada 1995)

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,

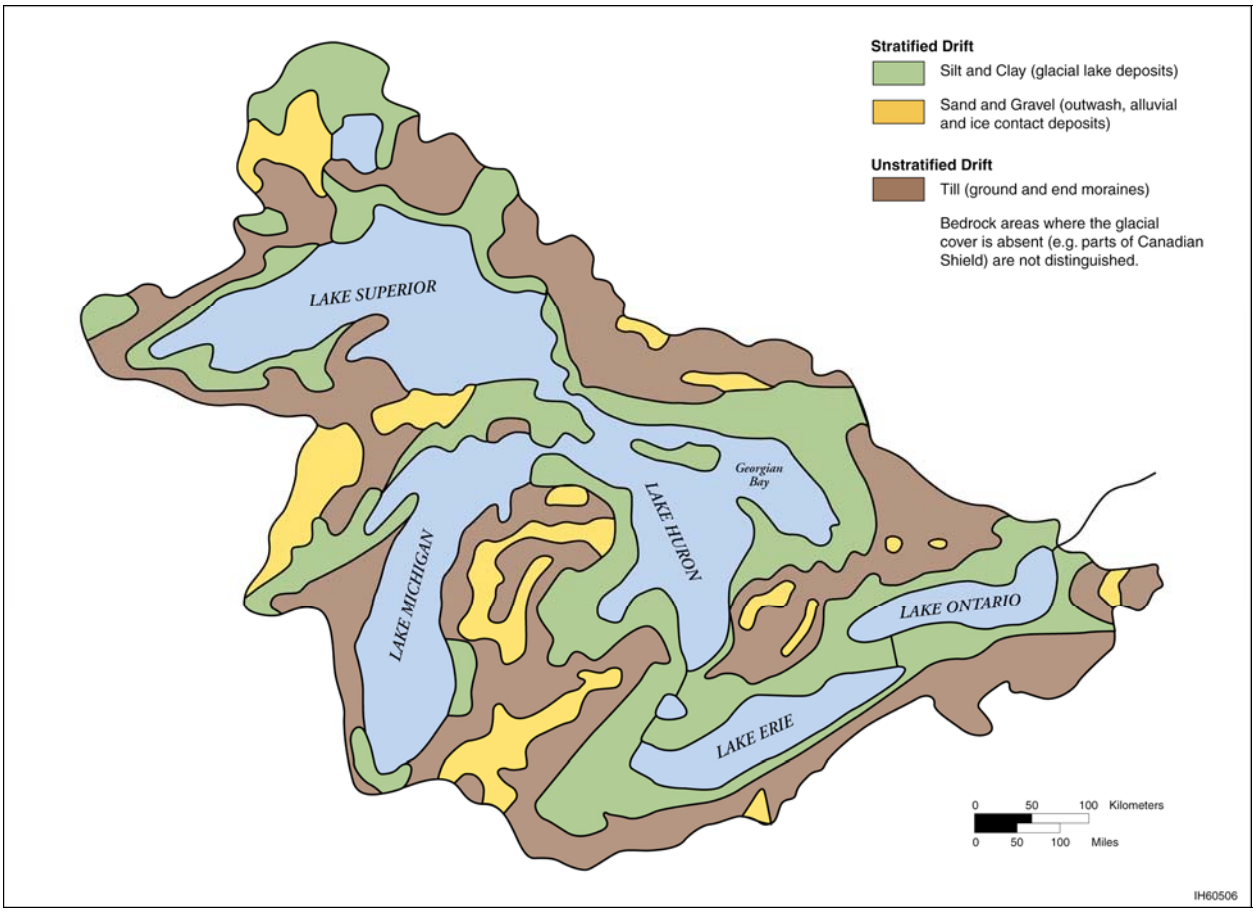

FIGURE 5.4 Glacial Deposits of the Great Lakes Basin (Source: EPA and Government of Canada 1995)

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.

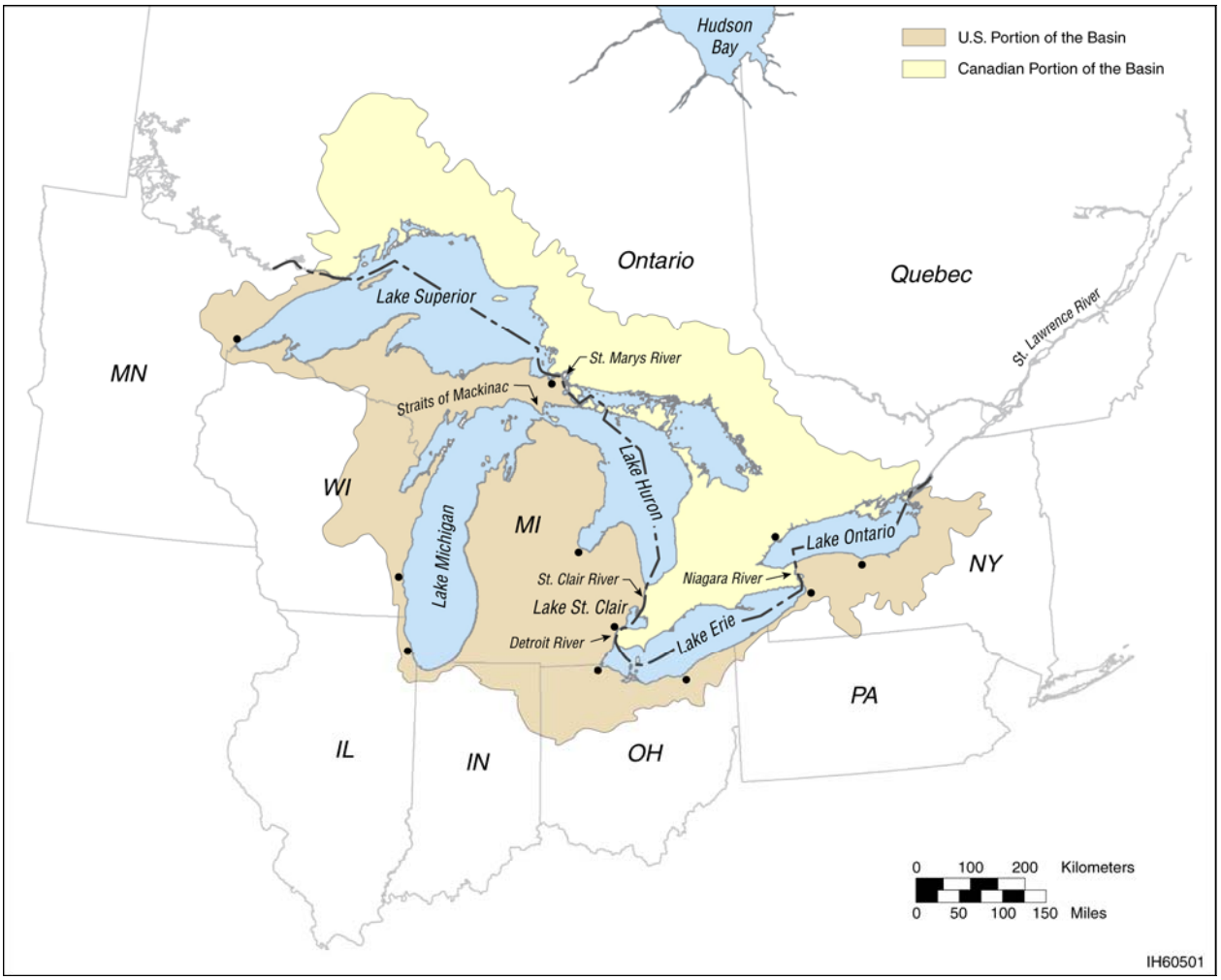

FIGURE 5.5 The Great Lakes and Their Connecting Channels

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).

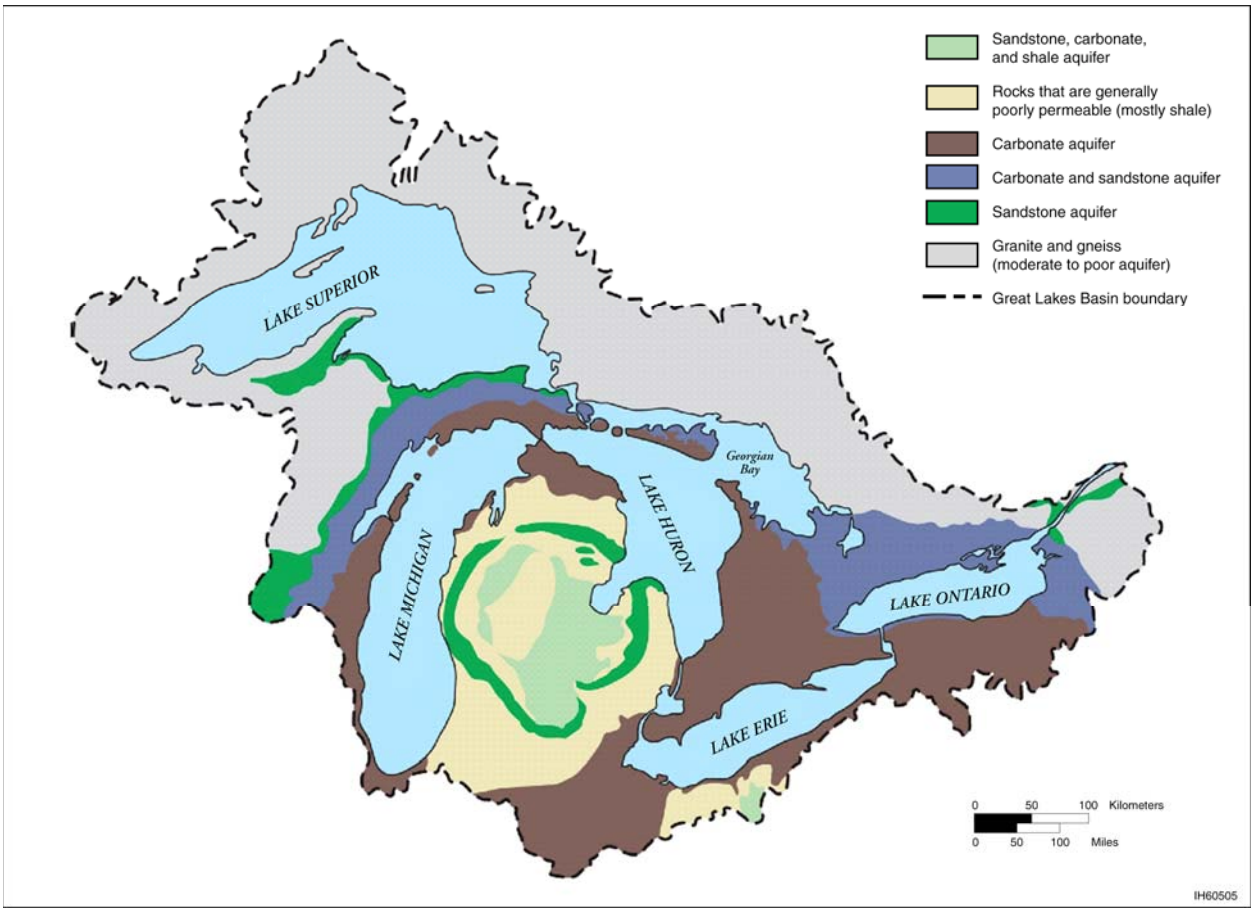

FIGURE 5.6 Bedrock Aquifers of the Great Lakes Basin (Source: GLBC 1975a)

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.

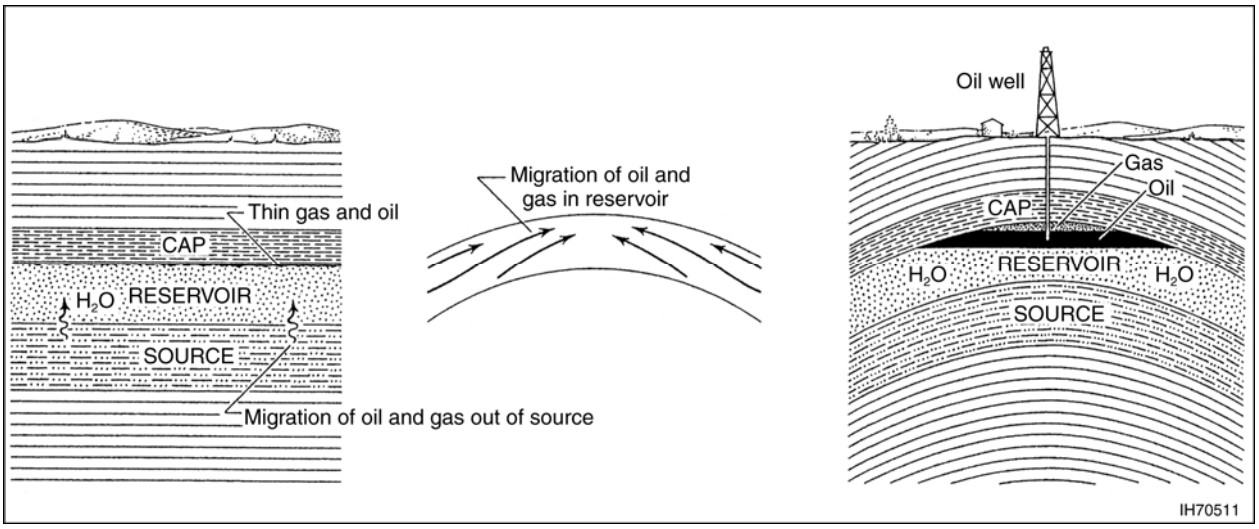

FIGURE 5.7 Essentials of Oil and Gas Accumulation (Left: Migration from source rock into porous and permeable reservoir rock is halted beneath an impermeable seal or cap. Center: Inclination of reservoir boundaries favors movement toward higher regions of a structure, with consequent localization of 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).

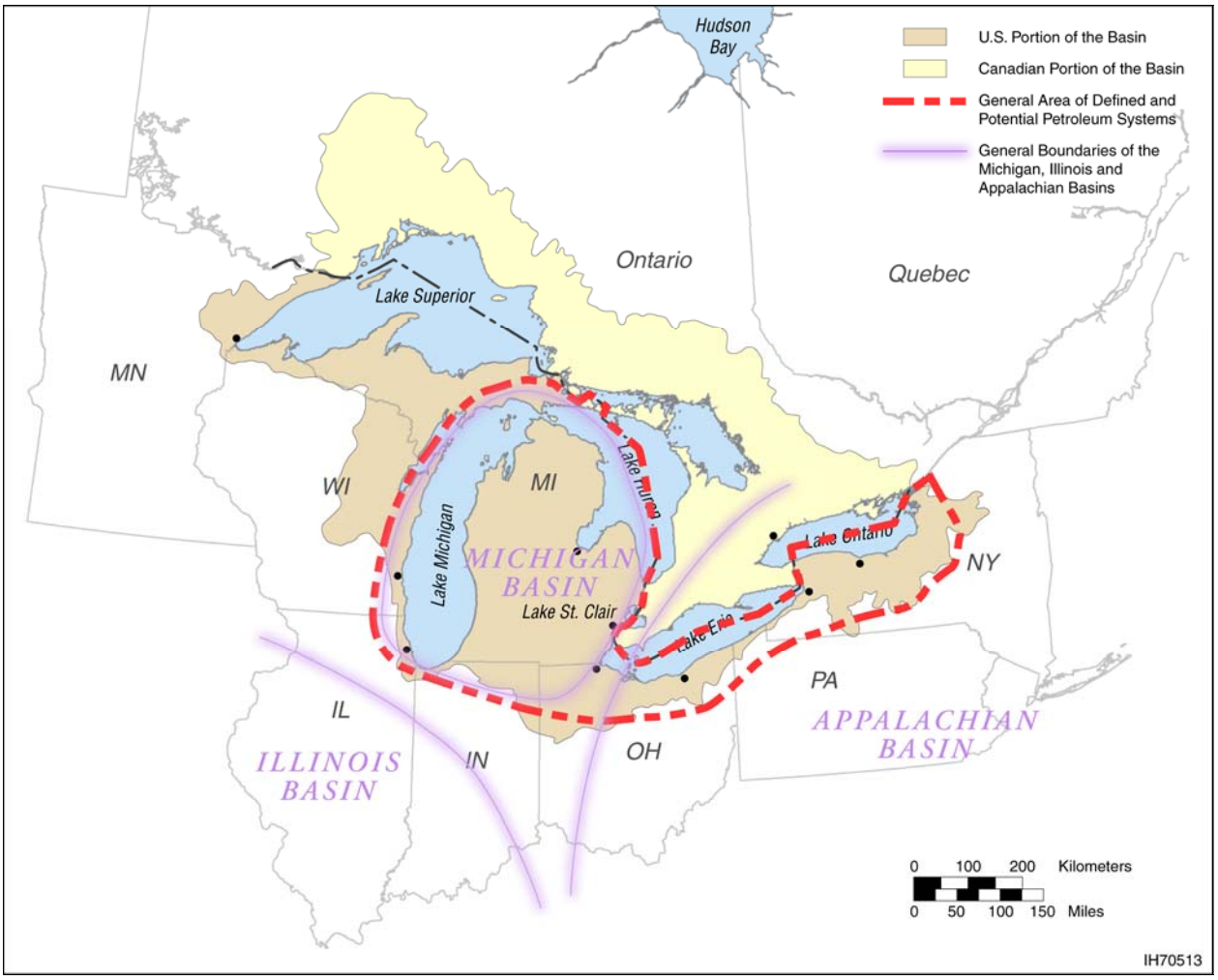

FIGURE 5.8 General Area of Defined and Potential Petroleum Systems within the Great Lakes Basin (Sources: Developed from Swezey 2002, 2004; Milici et al. 2003; Repetski 2004)

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

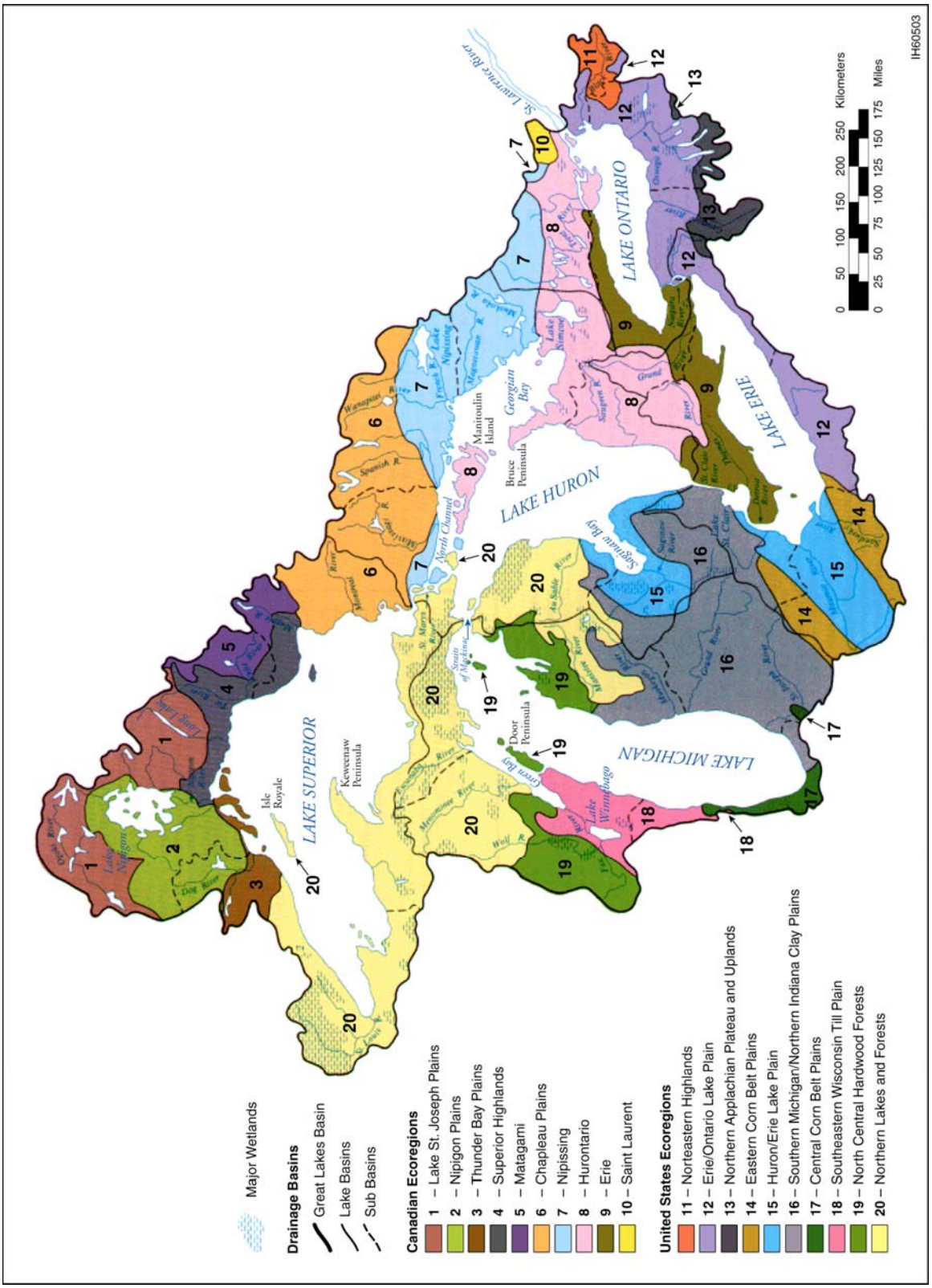

FIGURE 5.9 Ecoregions, Wetlands, and Drainage Basins of the Great Lakes Basin (Source: Modified from EPA and Government of Canada 1995)

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

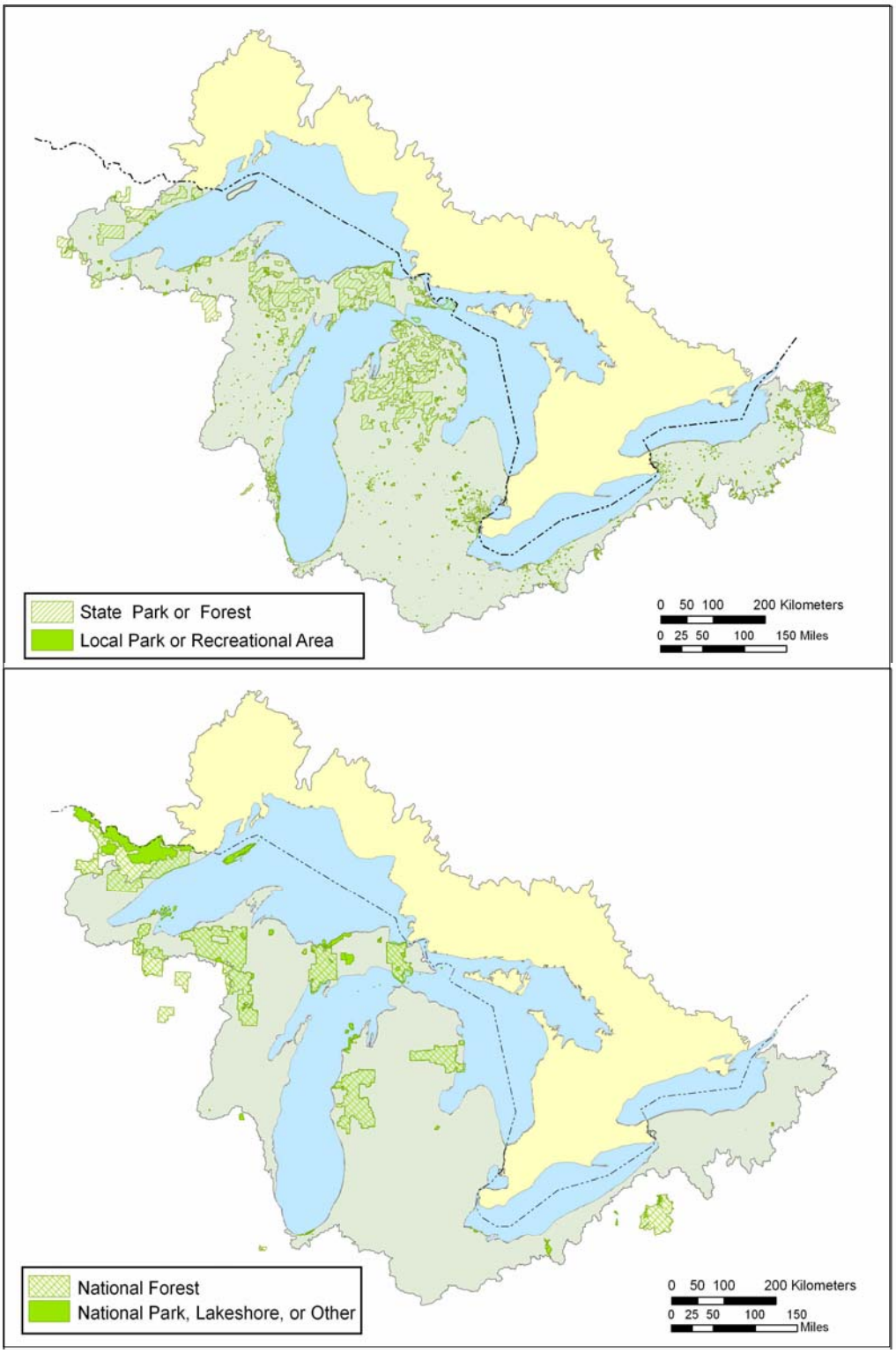

FIGURE 5.11 National Lakeshores, Wildlife Refuges, Forests, Monuments, Historic Sites, State and Local Parks, Preserves, and Natural Areas within the Great Lakes Basin

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).

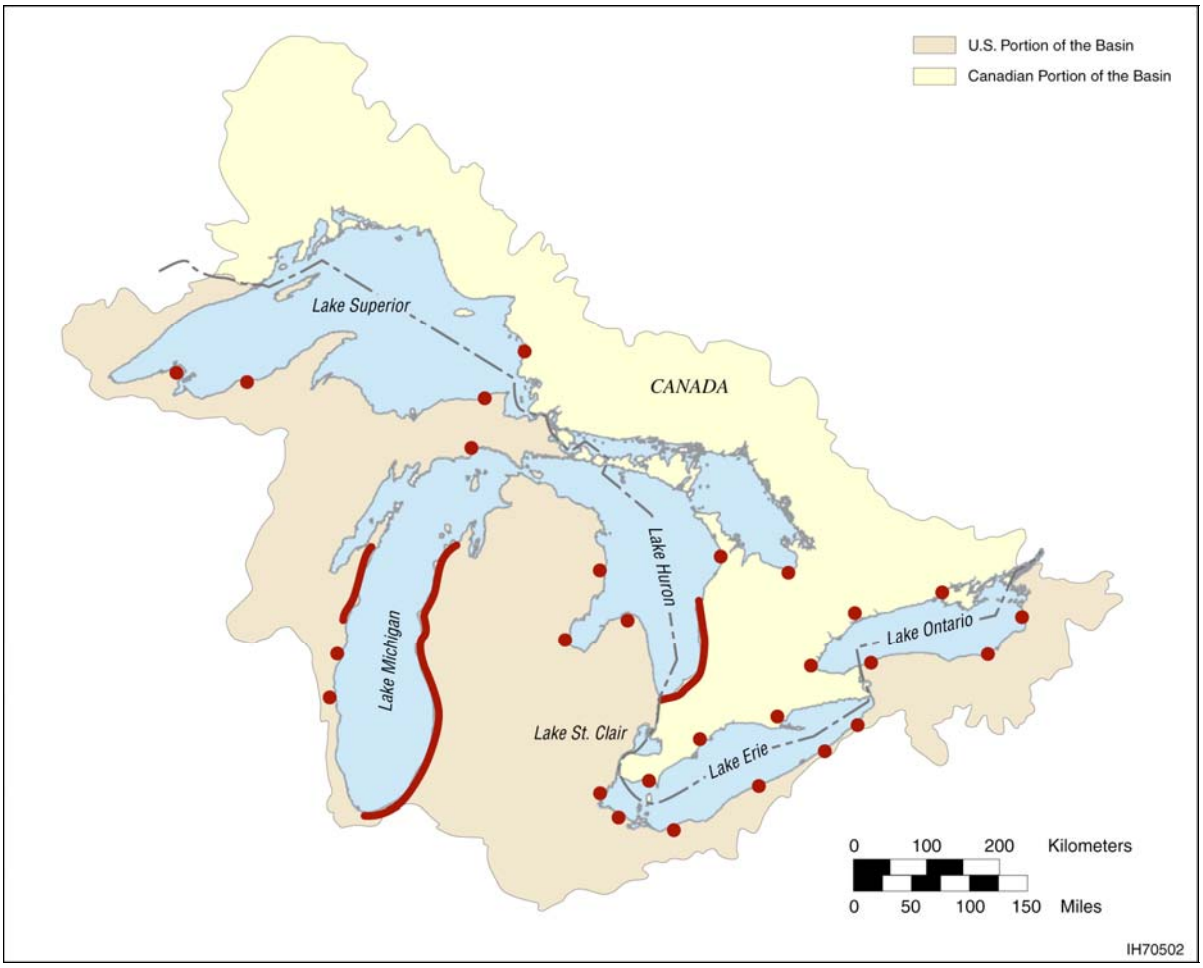

FIGURE 5.12 Great Lakes Sand Beaches (Sources: Reid and Holland 1997; NOAA 1994)

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

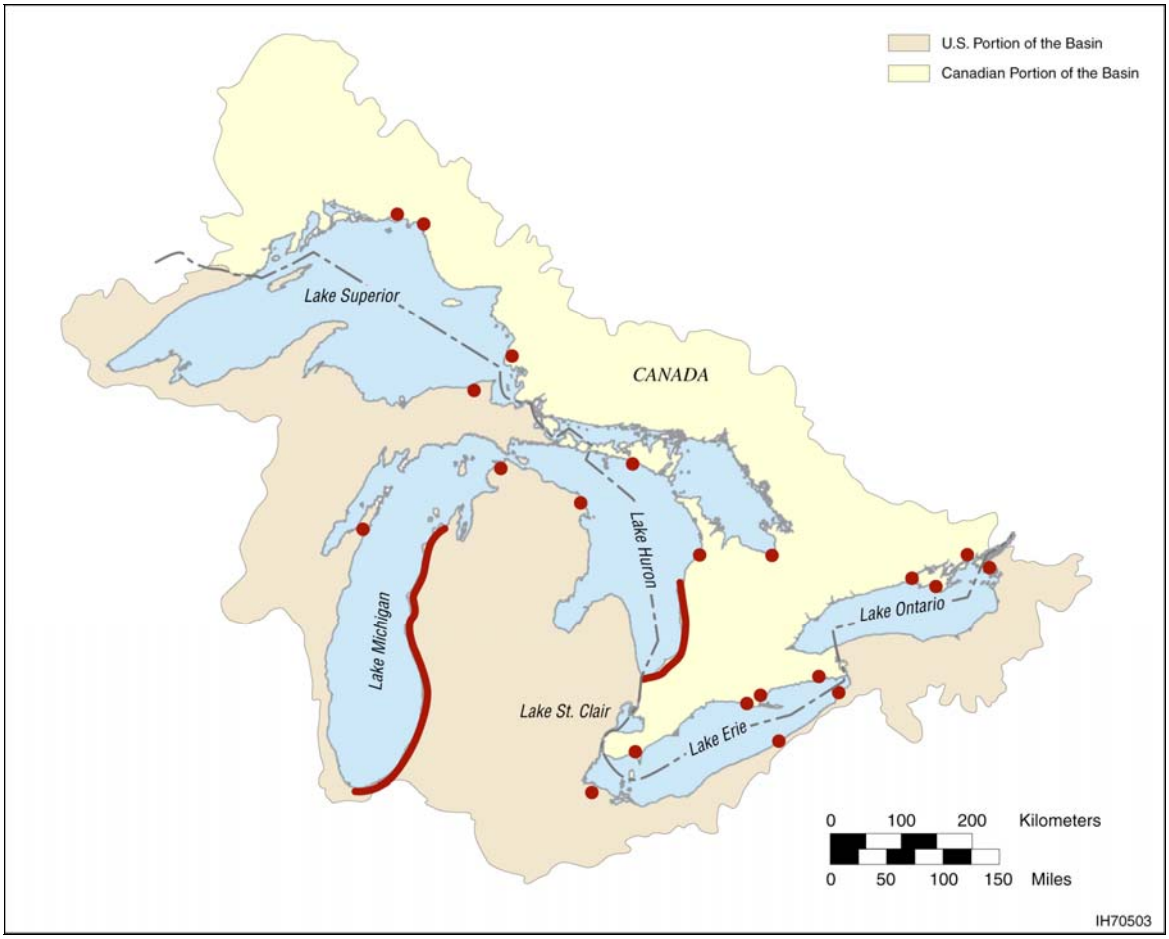

FIGURE 5.13 Great Lakes Sand Dunes (Source: Reid and Holland 1997)

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).

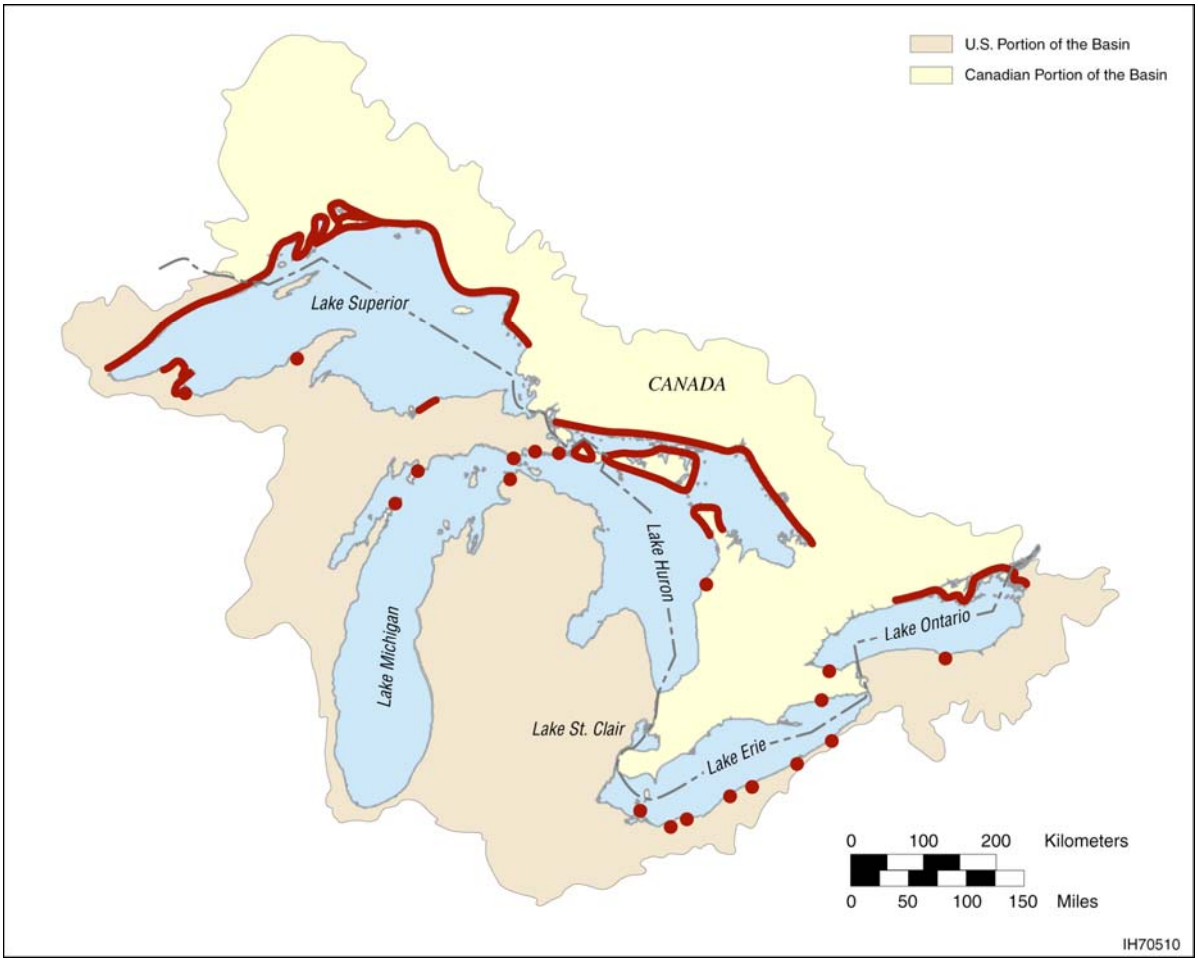

FIGURE 5.14 Great Lakes Bedrock and Cobble Beaches (Sources: Reid and Holland 1987; NOAA 1994)

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.

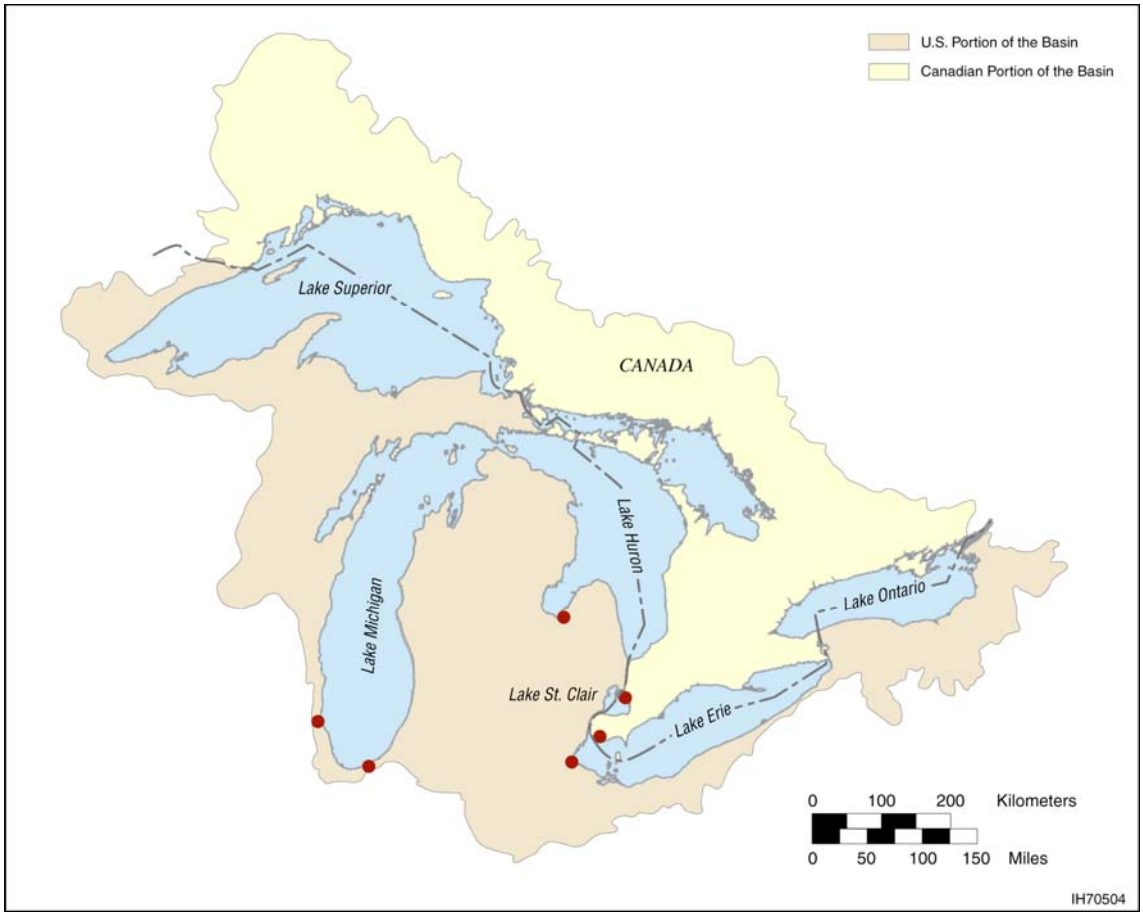

FIGURE 5.15 Great Lakes Lakeplain Prairies (Source: Reid and Holland 1997)

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

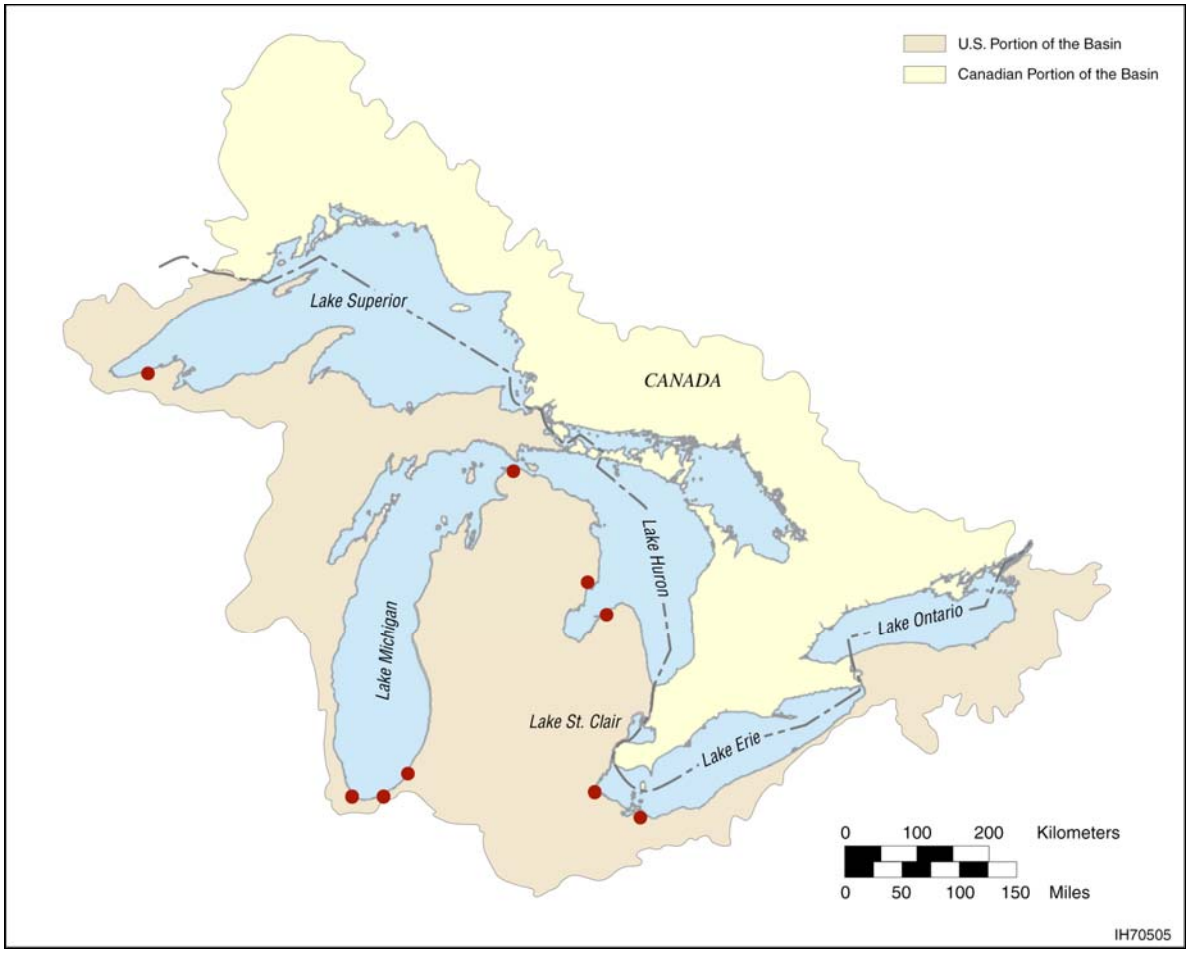

FIGURE 5.16 Great Lakes Sand Barrens (Source: Reid and Holland 1997)

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

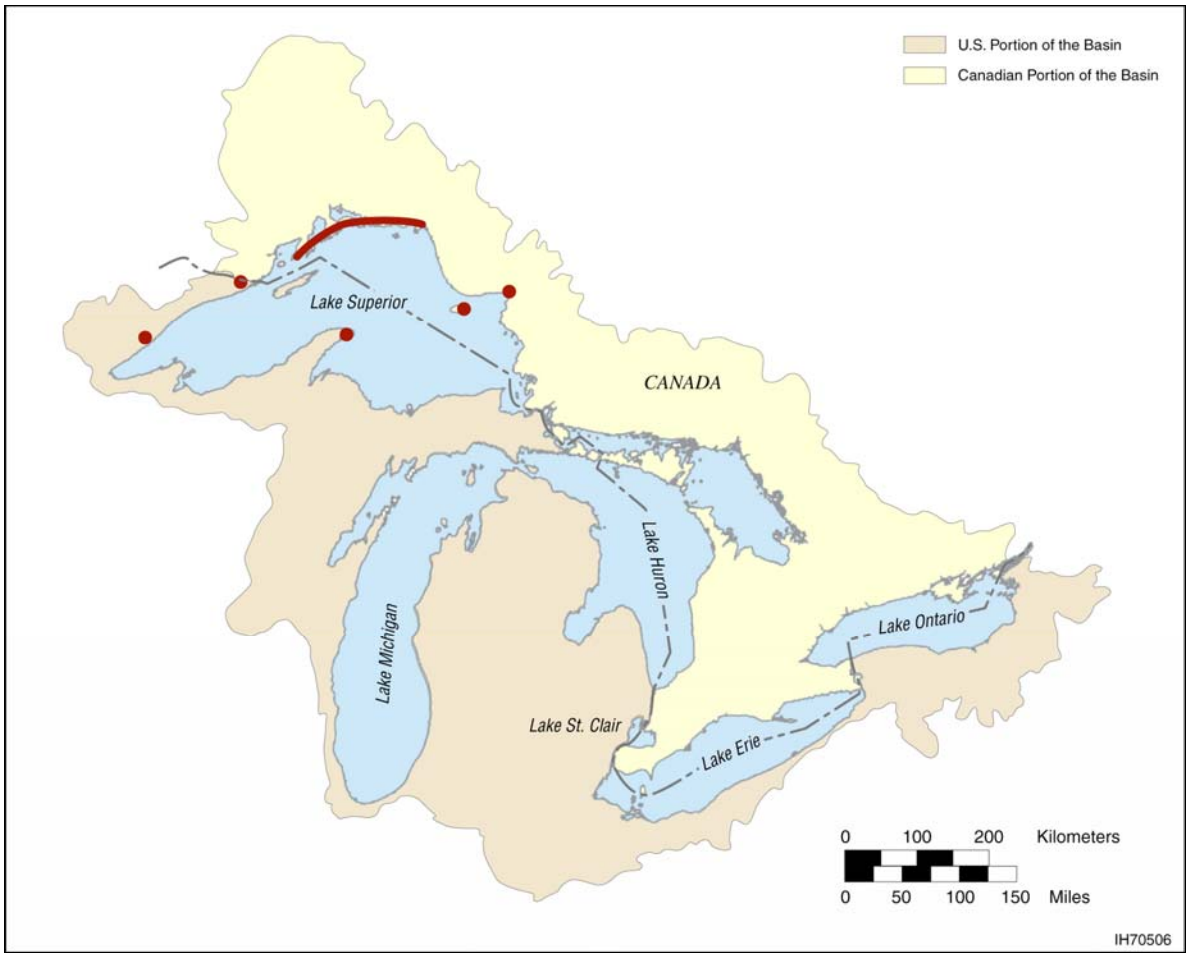

FIGURE 5.17 Great Lakes Artic-Alpine Disjunct Communities (Source: Reid and Holland 1997)

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

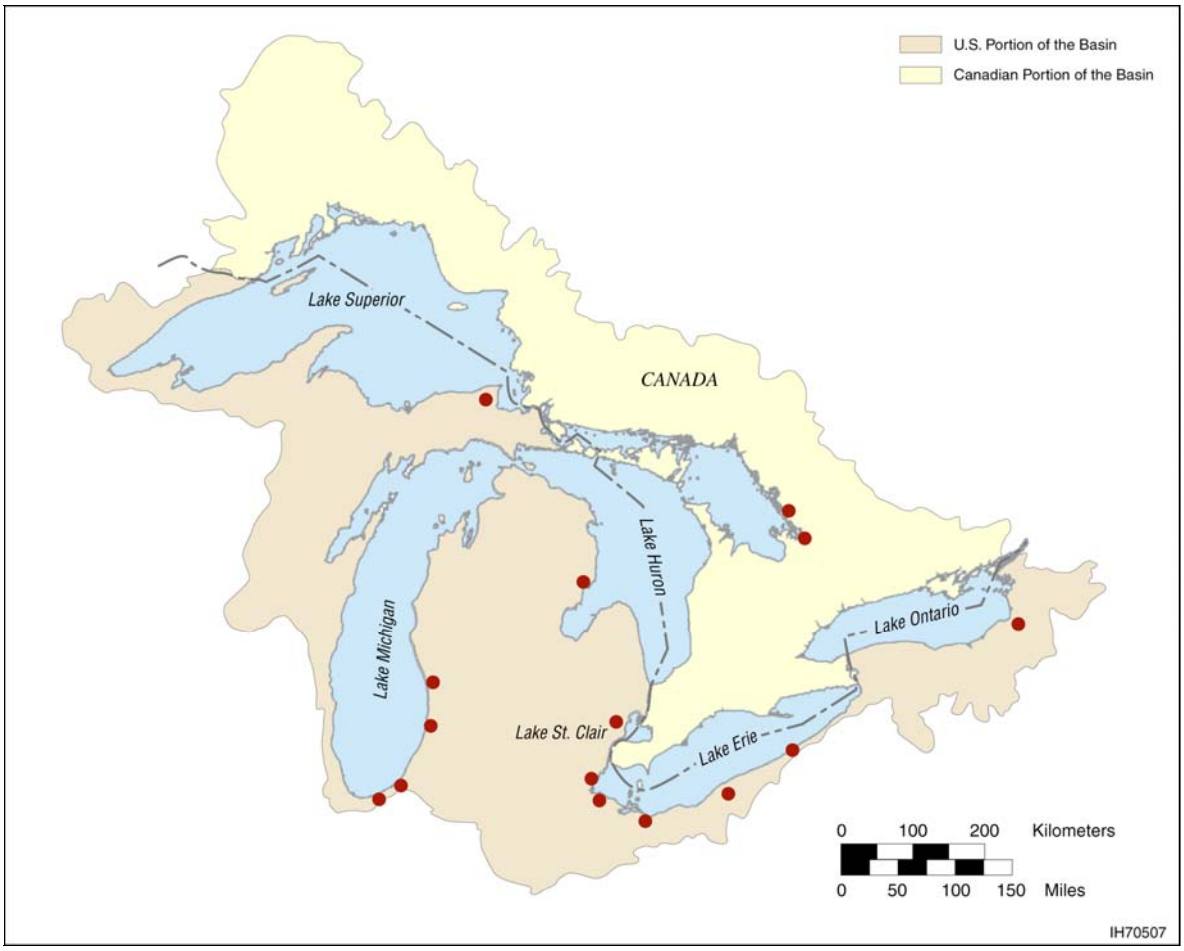

FIGURE 5.18 Great Lakes Atlantic Coastal Plain Disjunct Communities (Source: Reid and Holland 1997)

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

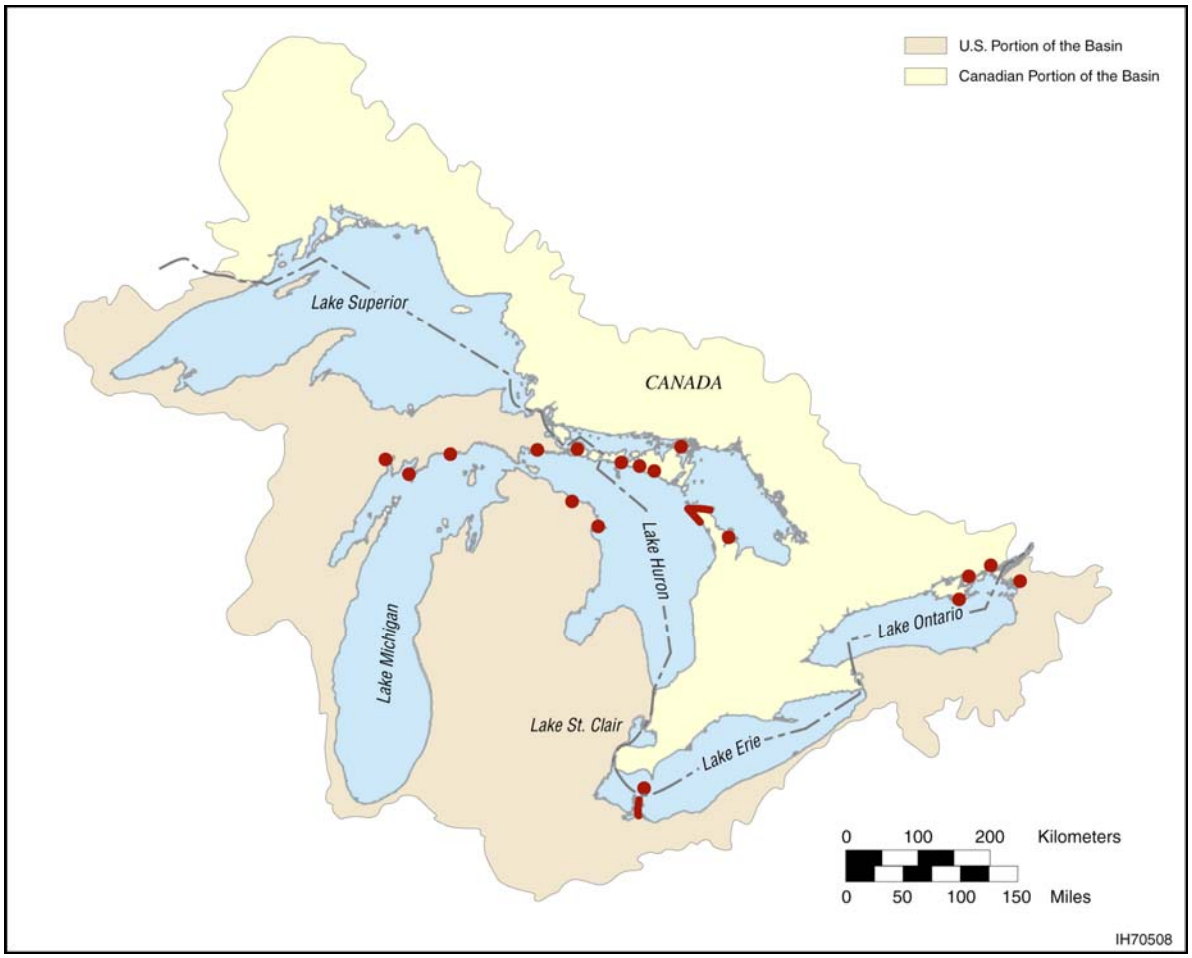

FIGURE 5.19 Great Lakes Shoreline Alvars (Sources: Reid and Holland 1997; Catling and Brownell 1995)

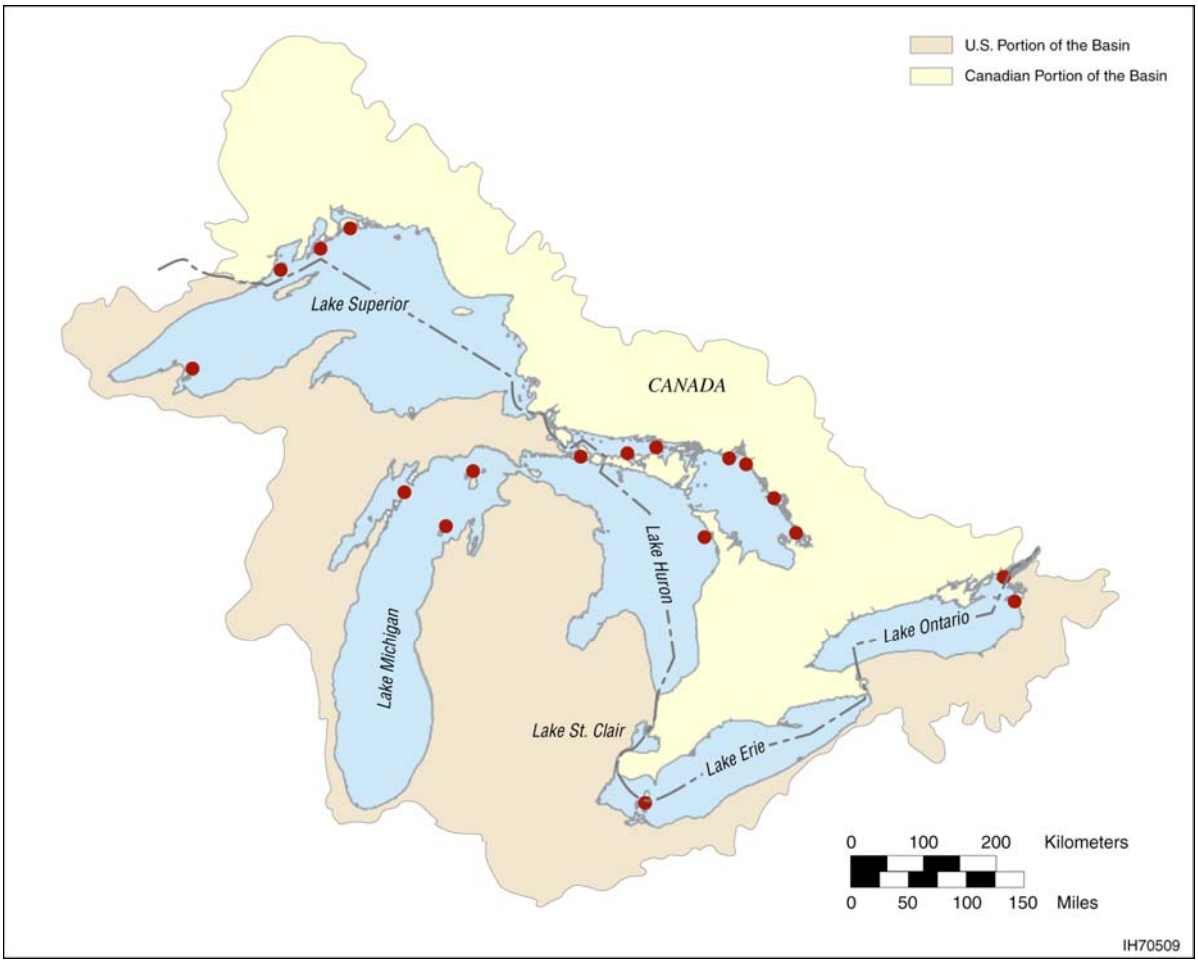

FIGURE 5.20 Great Lakes Island Clusters (Sources: Reid and Holland 1997; NOAA 1994)

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.

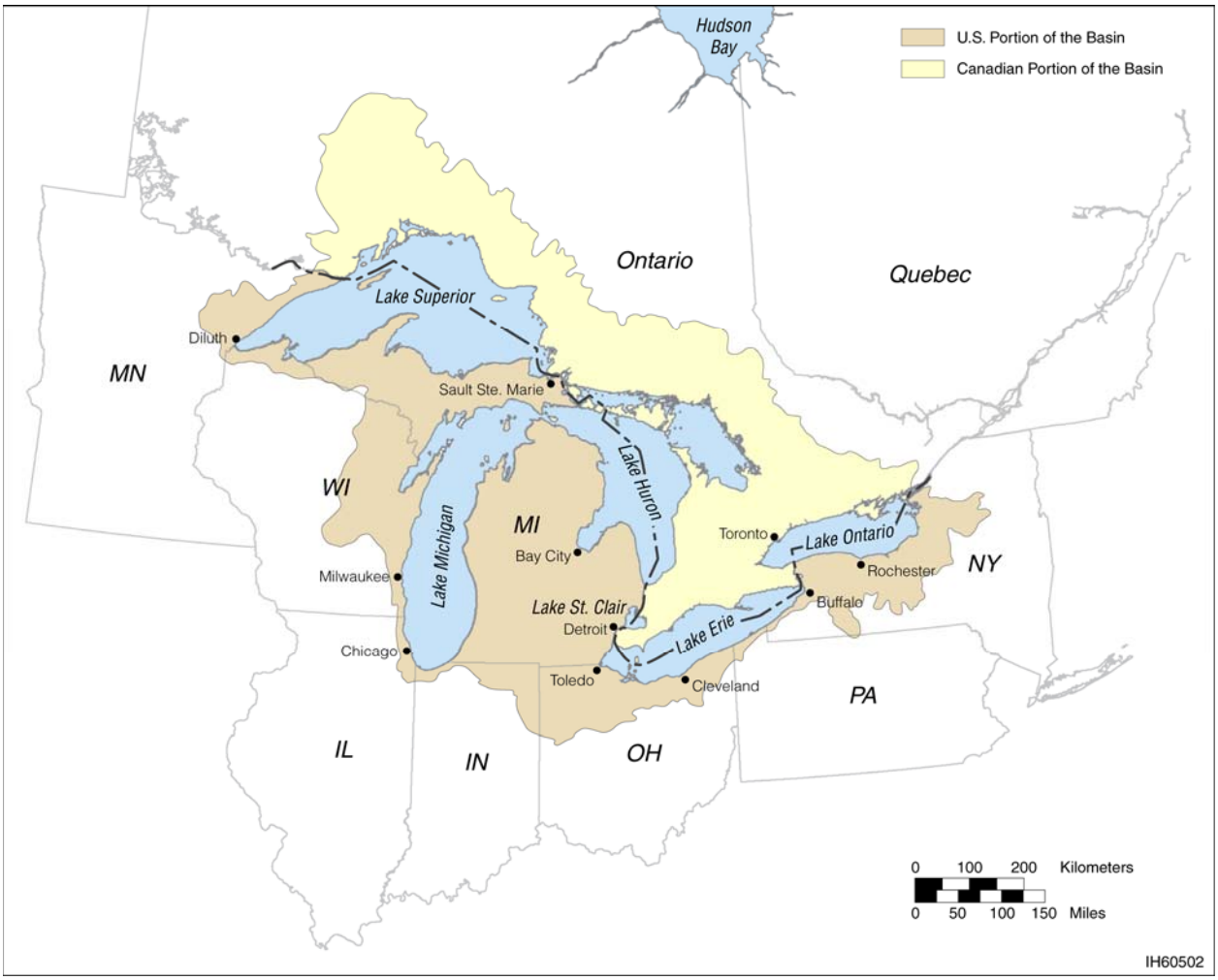

FIGURE 5.21 Major Urban Centers on the Great Lakes Basin

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

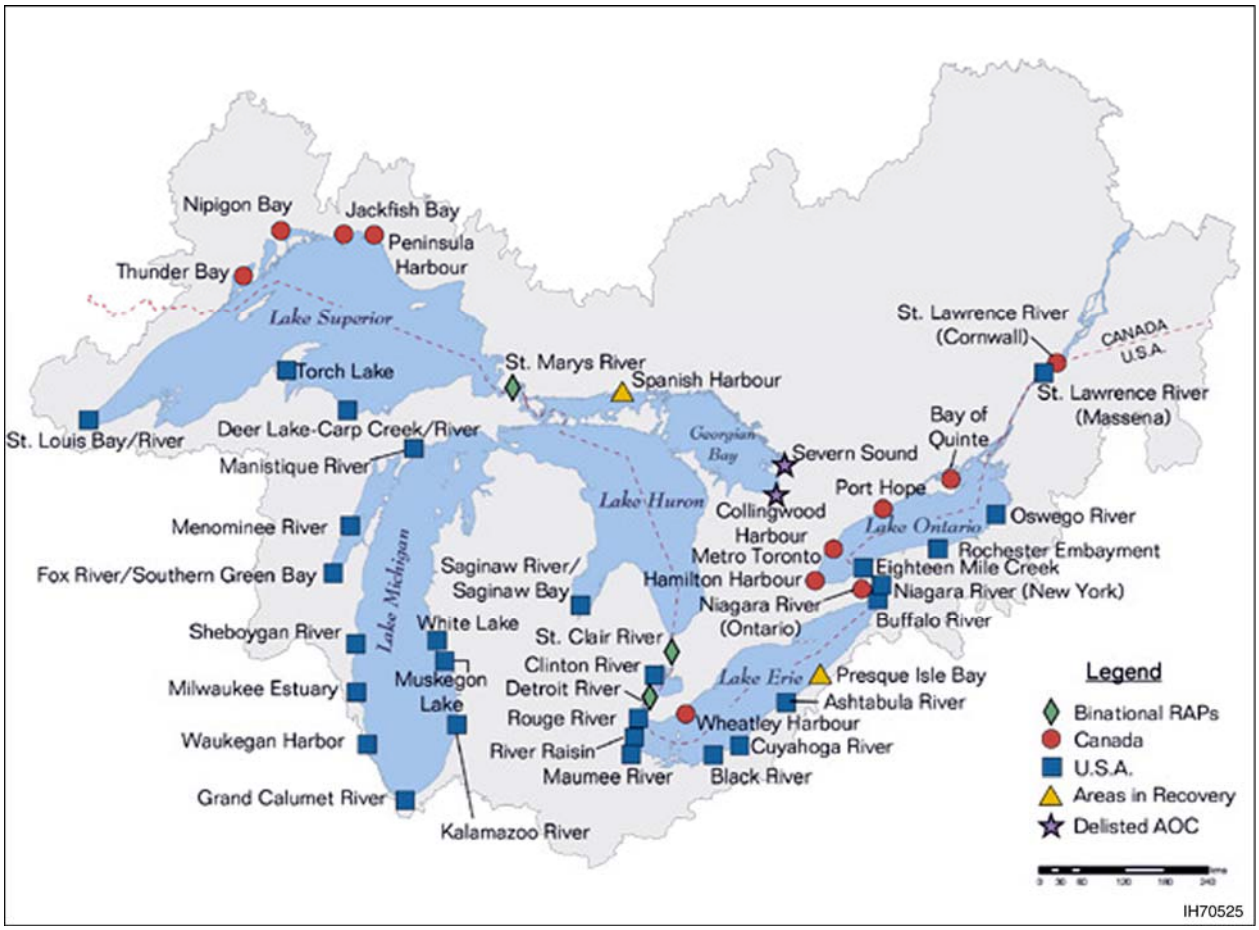

FIGURE 5.22 Areas of Concern in the Great-Lakes-St. Lawrence River Basin (Source: EC 2004)

(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).

6 POTENTIAL ENVIRONMENTAL EFFECTS OF OIL AND GAS DRILLING ON GREAT LAKES RESOURCES

A variety of environmental effects have been associated with oil and gas projects in the United States and abroad. The likelihood, nature, and magnitude of these effects depend on a variety of factors, including:

- The specific phase of the oil and gas development (exploration, well completion, and production);
- The specific location of the energy development activity;
- The nature and condition of the environmental resources present in surrounding areas;
- The nature and extent of human development and activities (including land and water use) in the surrounding areas;
- The technology employed to extract and process the oil and gas;
- The disposal of waste materials produced during drilling and extraction; and
- The permit stipulations and mitigation measures that could apply to oil and gas production at a specific location.

Figure 6.1 identifies the activities associated with each phase of oil and gas development that could result in environmental effects within the Great Lakes Basin; it is these activities that will be considered in greater detail in the evaluation of environmental effects of oil and gas drilling in the Great Lakes. Each of the activities identified in this figure may generate one or more environmental stressors that could affect natural resources and human activities. An environmental stressor is defined as a physical, chemical, or biological entity that can induce an adverse response (EPA 1997; 1998). For this evaluation, physical stressors include temperature, noise, fugitive dust, turbidity, as well as activities that physically alter a habitat. Chemical stressors are substances that elicit adverse responses from exposed biota and may thereby alter a designated use of a resource. Examples of chemical stressors include oil- and gas-related compounds, dissolved oxygen, and pH. Biological stressors include disease agents and introduced species that could result in adverse population and higher-level trophic effects. Figure 6.2 shows the general types of stressors associated with oil and gas development. In addition, the presence of oil and gas infrastructure and activities may elicit adverse reactions in nearby human populations.

The identification of potential site-specific environmental effects is beyond the scope of this report. Instead, this report focuses on the nature and extent, rather than on the magnitude, of potential effects that may be incurred by environmental resources (including impacts on land and water use by humans) with any future development of the oil and gas reservoirs

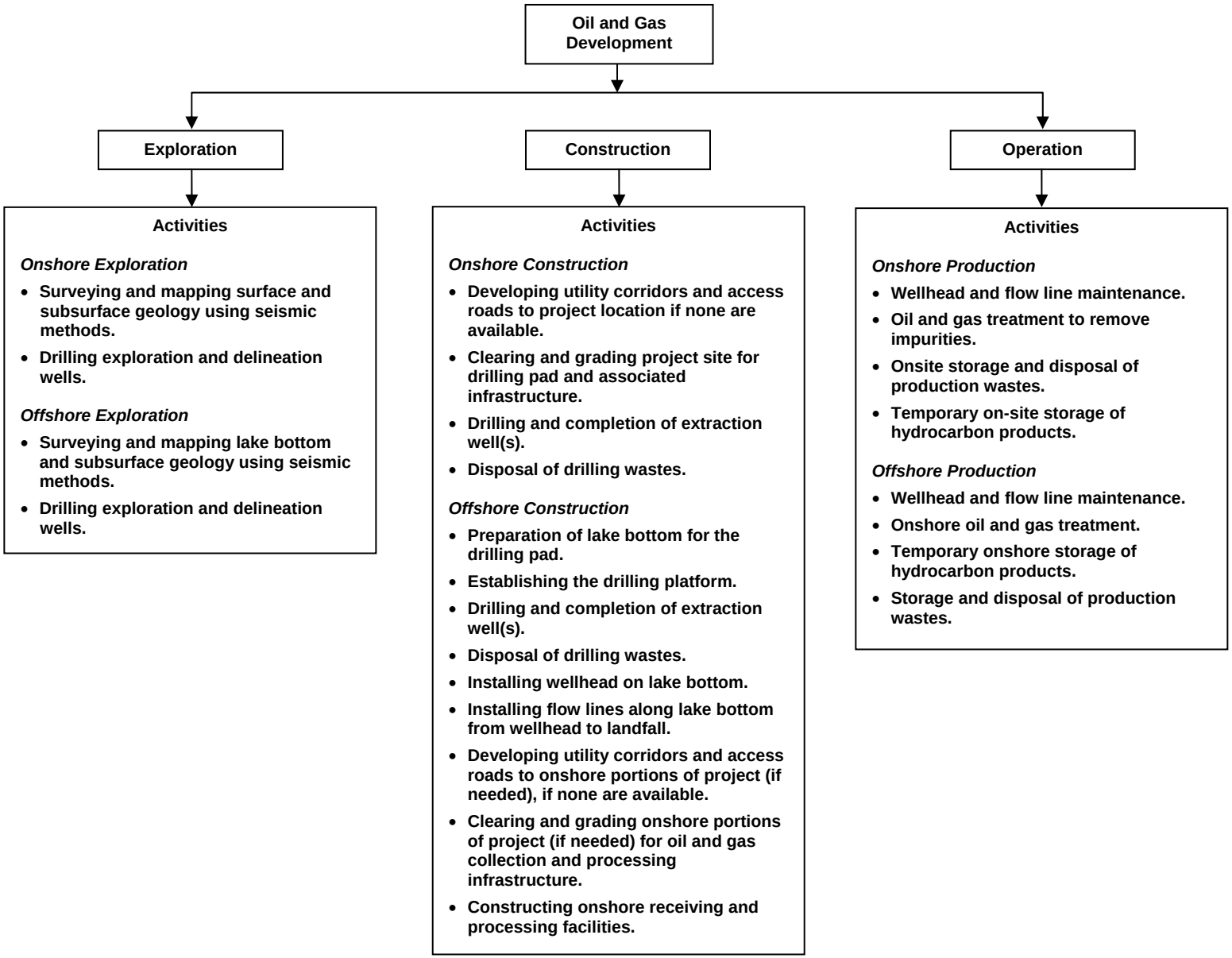

FIGURE 6.1 Activities Associated with Different Aspects of Oil and Gas Development
("Onshore" includes facilities with onshore extraction, processing, and storage facilities. "Offshore" includes facilities with offshore extraction wells and onshore pipelines, and processing and storage facilities.)

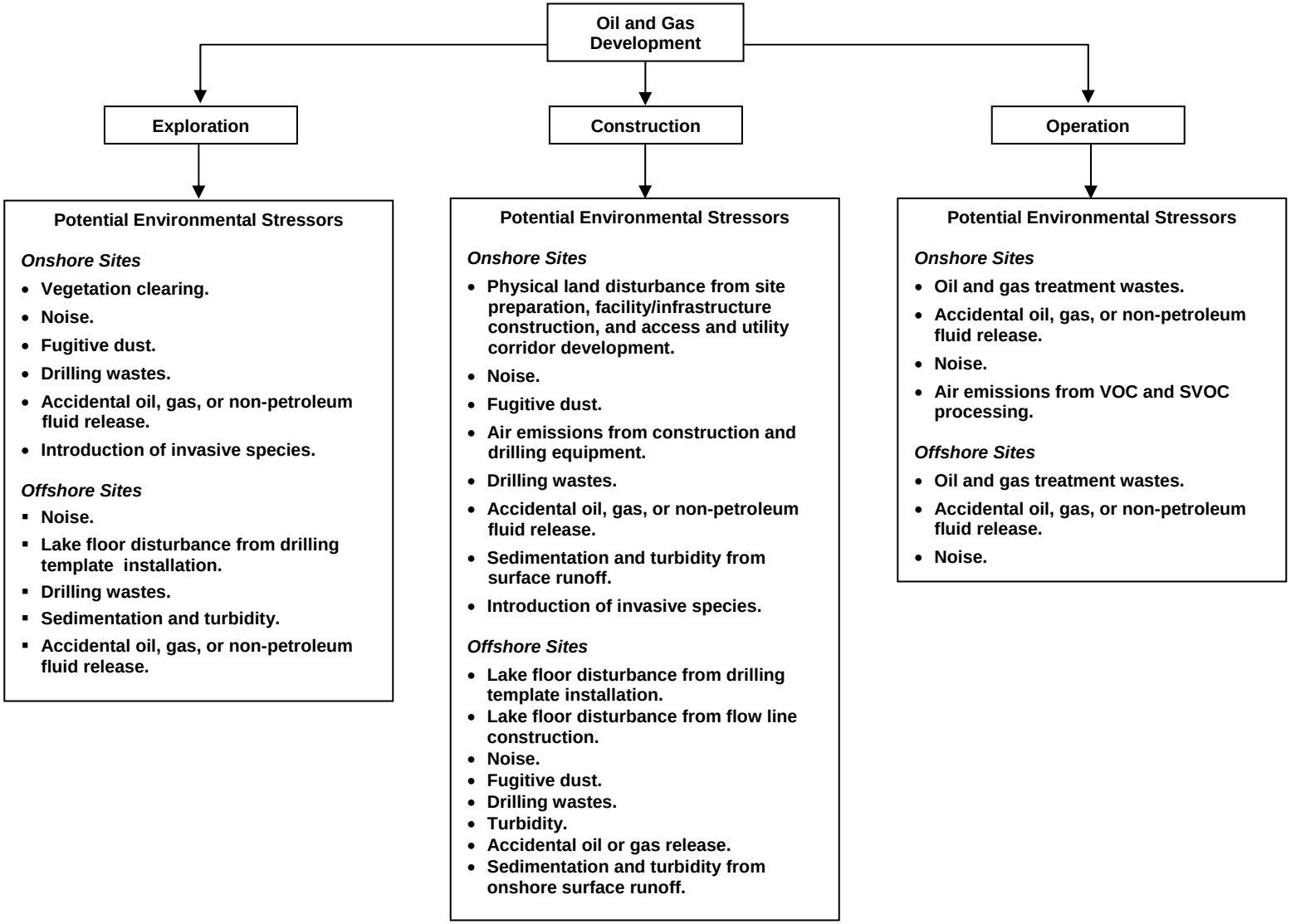

FIGURE 6.2 Environmental Stressors Potentially Associated with Different Aspects of Oil and Gas Development
("Onshore" includes facilities with onshore extraction, processing, and storage facilities. "Offshore" includes facilities with offshore extraction wells and onshore pipelines, and processing and storage facilities.)

beneath the Great Lakes. Thus, the following discussions apply to those areas of the Great Lakes with known or suspected oil and gas systems — the areas with the highest likelihood of undergoing future oil and gas development — and the resources and land and water uses in those areas.

It is outside the scope of the study and this report to address the magnitude of any potential site-specific effects because these are a direct function of the following:

- The specific location where oil or gas exploration and development is occurring;
- The size of the production site;
- The density of production sites within a specific area;
- The nature and condition of the environmental resources present in the project area;
- Land and water use in the project area;
- The regulatory requirements that would govern the project at that location;
- The physical and chemical characteristics of petroleum and associated petroleum fluids;
- The nature and magnitude of any accidental release of oil, gas, or drilling and post-extraction processing wastes; and
- The mitigation measures that would be required or could be included for the project.

Because this study does not address a specific Federal action or location with the Basin, much of the above information could not be identified.

6.1 MITIGATING FACTORS AFFECTING THE MAGNITUDE OF POTENTIAL ENVIRONMENTAL EFFECTS

The following sections (Sections 6.2 through 6.7) discuss the types of environmental effects that might be incurred during the exploration, construction, and operation phases of oil and gas development. Potential effects (associated with the stressors identified in Figure 6.2) to natural and cultural resources, land and water uses, and human health are associated with three primary activities: (1) exploration; (2) construction of wells, pipelines, and associated infrastructure; and (3) accidental releases of oil or gas or drilling, production, and processing wastes. The likelihood and severity of potential adverse effects will be influenced by a variety of mitigating factors. These factors include:

- Existing land and water setting and use;
- Facility design, size, siting, and density;
- Availability of existing infrastructure;
- Use of good engineering practices;
- Project scheduling;
- State siting restrictions;
- State and Federal regulations and restrictions governing activities potentially affecting protected species and other natural resources; and
- Existing spill response programs and requirements.

Consideration of these factors during all phases of an oil or gas development may prevent or greatly reduce potential environmental effects of oil and gas exploration, construction, and operation. The role that each of these factors may have on mitigating potential environmental effects is discussed in the following sections.

6.1.1 Existing Land and Water Use

The potential for adverse effects on environmental resources will be strongly dependent on the setting of the area and its existing land and water uses where a well may be developed. For example, industrial areas will have few if any ecological resources or unique habitats that could be affected by construction or operation of oil and gas wells and pipelines, and no change in existing land use or potential for future land use would be expected with oil or gas development. In contrast, recreational areas may be expected to support considerable ecological resources that could be affected by oil or gas development. Similarly, areas with predominantly recreational water use will likely also contain quality ecological resources and may thus incur greater impacts than surface water areas in industrial or large urban settings.

6.1.2 Facility Design, Size, Siting, and Density

Careful consideration of facility design may minimize the likelihood and magnitude of potential environmental effects of a new oil or gas well and associated infrastructure. With proper design, seismic survey corridors, access roads, and infrastructure corridors may be routed to avoid sensitive resources. Similarly, incorporation of monitoring and mitigation measures, such as the use of measuring equipment to monitor atmospheric H_2S concentrations, may enhance accident identification and response times, thus reducing potential impacts to human health or the environment.

The size, siting, and density of wells may have a significant role in determining the magnitude and extent of environmental effects that may occur with an oil or gas development. Oil or gas well sites (including pumping unit and collection and processing equipment) may vary considerably in size, and the greater the size of the site, the more land or lake bottom must be disturbed and habitat removed. The size of a facility is affected, in part, by the depth of the hydrocarbon deposits to be developed and the geographic extent of the reservoir. Deeper wells need bigger pads, pumps, and other drilling and well equipment and thus require greater surface disturbance. The width and length of any new pipelines, access roads, and utility corridors also affect the amount of habitat that may need to be disturbed in order to provide for these facilities.

Siting an onshore facility to avoid nearshore sensitive or rare communities, habitats, or known cultural resources should generally be possible, because slant drilling well locations may be as far as 2.5 mi [4.02 km] from the shoreline. However, avoidance may be difficult in locating pipeline corridors from offshore drilling sites to landfalls in areas with extensive nearshore habitats (e.g., where beach or dune communities extend for miles along the shoreline). Siting new wells and associated infrastructure away from recreational areas, such as state parks and beaches, would reduce the potential for impacts on recreational land and water use. Development in highly visible recreational areas, such as public beaches, along hiking or biking trails, or near heavy-use commercial fishing docks would result in adverse aesthetic impacts. Ideal locations from a visual standpoint would be previously disturbed industrial sites.

The density of wells, which will depend in part on state siting regulations, that could be implemented in a new area would also directly affect the magnitude and extent of potential environmental effects. The greater the density of wells, the greater is the potential for adverse environmental effects such as habitat loss and fragmentation, or visual impacts on recreation and tourism. Depending on the land use, the density of wells may have relatively little or considerable impact on environmental resources. For example, fewer ecological, cultural resource, or recreational land use impacts would be expected with high well density in an industrial land use setting. However, a high density of wells within a more natural setting, such as forest land in northern Michigan, would likely result in considerably greater environmental impact due in part to greater loss of habitat, greater habitat fragmentation, and greater likelihood of affecting the recreational use of the area.

Current directional drilling technology allows for multiple wells to occur within a single bore hole, thereby reducing the numerical density of individual well pads within a given area. This also reduces the amount of land area (and associated construction impacts) that would be needed for the individual well sites.

6.1.3 Availability of Existing Infrastructure

Siting onshore wells or pipeline landfalls, pipeline and utility corridors, and access roads as close as possible (e.g., collocating) to existing roads, pipelines, and utility corridors may greatly reduce the amount of land disturbance that would be required for new construction, thereby reducing the disturbance or loss of wildlife habitat and the potential to affect sensitive or unique species or communities. Such siting may also reduce the potential for habitat

fragmentation as well as impacts to cultural resources and existing land use. The availability of existing infrastructure may be limited in the less developed areas of the Basin.

6.1.4 Use of Good Engineering Practices

Many of the potential effects discussed in this report are related to construction activities. The implementation of good engineering practices, such as the use of siltation fences to control surface runoff from construction areas, may reduce or eliminate the likelihood for, or magnitude of, some types of impacts. Examples of good engineering practices include:

- Employing proper well construction and completion practices (e.g., casing placement and cement);
- Grading cleared areas away from adjacent wetlands or surface waters to control sediment input;
- Controlling fugitive dust generation through the use of water sprays;
- Covering soil stockpiles with tarps to limit erosion and runoff during storm events;
- Maintaining equipment mufflers to limit noise disturbance of wildlife or nearby humans;
- Properly selecting culverts to maintain natural flows and allow for fish passage at all access road and pipeline stream crossings; and
- Restoring and revegetating disturbed soil areas to reduce erosion potential.

6.1.5 Project Scheduling

Some potential effects from new oil and gas development are associated with noise generated during exploration activities and during the construction of well sites, pipelines, access roads, and utility corridors. Noise and human activity during exploration and construction may disturb and adversely affect biota (such as nesting birds) or humans (such as tourists, beachgoers, hikers, or nearby residents). It may be possible to schedule construction activities to minimize such impacts. For example, construction may be scheduled to avoid the season when nearby colonial bird nest areas are active, to avoid the early morning and late afternoon periods when humans may be disturbed, or to avoid disturbing aquatic habitats during fish spawning periods.

6.1.6 State Siting Restrictions

Many of the Great Lakes states have regulations that govern the siting of gas and oil wells and pipelines. While these regulations vary among the states with regard to specific details, compliance with these regulations will reduce the potential for many of the effects identified in connection with construction of wells and associated infrastructure. For example, existing drill sites in Michigan are as close as 700 ft (213 m) from the shoreline (MESB 1997). Out of concern about potential impacts on wetland and other nearshore habitats and other natural resources, the Michigan DNR and Department of Environmental Quality have adopted oil and gas leasing regulatory changes that require a minimum 1,500-ft (457-m) setback from the Great Lakes coastline for directionally drilled wells and for new storage and treatment equipment and access roads associated with those wells. This setback may greatly reduce the likelihood of affecting coastal or nearshore habitats and recreation areas. Other restrictions address well density. For example, Ohio requires a minimum spacing of one well per 20 acres (8 ha), while New York prohibits wells from being drilled closer than 660 ft (183 m) from a lease boundary line or closer than 1,320 ft (402 m) from another producing well.

6.1.7 State and Federal Regulations Governing Protected Species and Other Natural Resources

The ESA, as well as state regulations governing protected species, would likely play a major role in the siting of new oil and gas facilities in the Great Lakes. For example, the development and siting of new wells in Michigan may be especially influenced by the ESA and similar state regulations. The coastal and nearshore areas of the upper Lake Michigan region support a number of Federally listed species, as well as sensitive or unique habitats and communities. Oil or gas development in areas with these resources will require careful siting and design, and likely extensive mitigation during construction. While fewer listed species or sensitive or unique habitats may be encountered along the central and eastern basins of Lake Erie, similar siting and design considerations would apply if listed species or unique habitats and communities are present in the vicinity of a potential drill site. Areas with known species listed under the ESA could be off limits to oil and gas exploration or development. Similarly, CWA wetland regulations will preclude the placement of well sites within wetlands and affect the siting and design of facilities located adjacent to many wetlands. Pipelines, access roads, and utility corridors crossing wetlands will also likely be strongly affected by wetland regulations.

6.1.8 Existing Spill Prevention and Response Programs and Requirements

Of greatest concern with any new oil or gas development is the occurrence of an accidental spill or release. The magnitude and extent of environmental effects that would result from such an event will be related to the spill prevention and response programs that are in place within the Great Lakes states. In particular, the speed and effectiveness of a spill response will directly influence the subsequent environmental effects of the accident. A number of Federal and state programs and requirements are currently in place that are intended to facilitate rapid spill

notification, response, and cleanup. Application of and compliance with these programs and requirements will reduce the magnitude of potential effects that could occur in the event of a well or pipeline release.

The EPA is the lead Federal agency for responding to spills in inland waters and has developed a number of programs, measures, and requirements for preventing, reporting, and responding to oil spills. For example, the EPA Region 5 Oil Planning and Response Section has developed an Area-Regional Contingency Plan that identifies risks and resources for response and sets policies for Federal responders to follow specialized techniques, such as in situ (in place) burning of oil and chemical countermeasures. The plan encompasses all of the Great Lakes states except Pennsylvania and New York. To address site-specific concerns, EPA Region 5 has identified 20 subareas and developed, together with state and local governments, subarea response plans that address such localized issues as response jurisdictions, response tactics on specific waterways, and command structures during response actions. In addition, NOAA operates a Great Lakes spill response center in Ann Arbor, Michigan.

Fixed onshore and offshore oil well drilling facilities, oil production structures, and some pipelines must also comply with the SPCC Regulation (40 CFR Part 112), which requires owners or operators of regulated facilities to prepare and implement SPCC plans. These plans must identify:

- Operating procedures the facility implements to prevent oil spills;
- Control measures installed to prevent oil from entering navigable waters or adjoining shorelines; and
- Countermeasures to contain, clean up, and mitigate the effects of an oil spill that has an impact on navigable waters or adjoining shorelines.

Individual states also have spill response programs and requirements intended to identify and respond to accidental release as quickly as possible. For example, the Michigan Department of Environmental Quality Pollution Emergency Alerting System requires that well permitees notify the system within 8 hours of a spill or discovery of a release. In Indiana, all spills that have not been cleaned up or for which cleanup has not been initiated in compliance with state regulations must be reported to the Indiana Department of Emergency Management within two hours of discovery.

At locations with sensitive or important resources (such as nature preserves, drinking water intakes, and recreational beaches), spill prevention plans may already be in place to address accidental spills (from all sources) that threaten those resources. For example, the Old Woman Creek National Estuarine Research Reserve at Huron, Ohio, on Lake Erie, has developed a detailed spill response plan to address oil spills that could impact the estuary.

One factor that may greatly affect effective spill response is the remoteness of the well site or pipeline where the spill or leak is occurring. Remote locations may not be easily accessible, and responders may have difficulty in accessing the location. To address this issue,

some states have developed tools for reporting spills to help spill responders reach locations. For example, the State of Ohio has developed an Oil and Gas Well Emergency Response System that assists in online reporting of a release at permitted wells within the state, as well as providing location information of a well by map, well number, permit number, or latitude and longitude (available at http://199.218.11.215/). Such tools and programs will aid in reducing spill response times and in minimizing the duration and magnitude of a spill and its environmental effects.

Thus, the implementation of existing Federal, state, and site-specific programs, requirements, and tools should act to minimize the magnitude and extent of environmental effects from accidental oil spills that may occur at oil wells and pipelines.

6.2 POTENTIAL EFFECTS ON ECOLOGICAL RESOURCES

Ecological resources in the Great Lakes Basin may be affected during normal activities of all phases of oil and gas development. During normal operations, potential effects could be associated with seismic exploration; the drilling of E&P wells; the construction of the drill pads, pipelines, access roads, and utility corridors; and noise during operations. Biota and their habitats may also be affected by the accidental release or spill of oil or gas, as well as by the accidental release of drilling, production, and processing wastes. The magnitude of any adverse effects will depend on a number of factors, including the size and location of the oil and gas facility and on the magnitude and duration of any oil, gas, or waste product release that might occur. Both onshore and offshore wells have the potential to affect aquatic and terrestrial biota and habitats. Oil and gas development currently occurs throughout many of the Basin states, while oil and gas pipelines are present in all the states (Section 5.7). Regulations governing this existing production may be expected to apply to any new development of offshore reservoirs, thus mitigating many of the potential impacts identified in the following sections.

6.2.1 Coastal and Nearshore Habitats

The potential effects on coastal and nearshore habitats from slant drilling for oil and gas exploration, well construction, and production will be associated with:

- Direct impacts from ground-disturbing activities associated with well site construction;
- Direct and indirect effects of seismic exploration;
- Direct and indirect impacts from water quality degradation and altered hydrology associated with soil erosion, surface runoff, and water infiltration;
- The physical and chemical characteristics of petroleum and associated non-petroleum fluids;

- Direct and indirect effects of accidental releases of oil, gas, drilling wastes, and processing wastes; and

- Direct impacts from exposure to air emissions during extraction and processing activities.

Offshore oil and gas development may also affect coastal and nearshore habitats if accidental oil spills or waste releases are transported to shoreline areas and deposited into wetlands and other habitats by lake currents and waves. Impacts might also possibly result from ground disturbance associated with the landfall of pipelines originating at the offshore wellheads and from the construction of onshore storage and processing facilities.

6.2.1.1 Wetlands

Numerous wetlands occur along the coastlines and other nearshore areas of the Great Lakes (Section 5.2.2.1). Where oil and gas resources may be located in the northern Lower Peninsula of Michigan, along Lakes Michigan and Huron, coastal wetlands are especially abundant. Wetlands along the Lake Erie coastline are primarily located in the western portion of the lake, while oil and gas resources may be located in all portions of the lake. Onshore drilling sites would generally be located within 2.5 mi (4.02 km) of the shoreline. Impacts on wetlands from onshore development would be largely associated with the damage or loss of vegetation and habitat from seismic exploration, drilling, and construction activities. Offshore drilling to access oil and gas resources beneath the Great Lakes may impact coastal wetlands through the construction of offshore pipeline landfalls, onshore pipelines, storage and processing facilities, and access roads and utility corridors. Because regulations prohibit direct impacts to wetlands from exploration and construction, only indirect impacts would be expected to occur. Activities that would impact wetlands would require permits from the Corps and/or state agencies (see Section 4). The use of good engineering practices in the construction of well sites and facilities can greatly minimize impacts to wetlands. Table 6.1 summarizes the environmental effects that could occur from both onshore and offshore oil and gas development.

For both onshore and offshore sites, impacts from normal operation could be associated with maintenance activities or decreases in air or water quality. Wetlands could be affected during any of the phases of developing an oil or gas site by the accidental spill or release of oil or gas during exploratory drilling, well completion, and production, as well as by accidental releases of drilling, production, and processing wastes.

In addition to wetlands, other special aquatic sites also occur in nearshore areas of the Great Lakes (see Section 5.2.2.1). These sites could also be affected by oil and gas development in a manner similar to that of wetlands.

6.2.1.1.1 Exploration. Wetlands occur in all areas of oil and gas potential within the Great Lakes (Section 5.2.2.1). Although avoidance of wetlands during onshore exploration and drill site selection would generally be possible, direct impacts could potentially occur in some

TABLE 6.1 Potential Effects on Wetlands from the Development of Oil and Gas Resources Located beneath the Great Lakes

Development Phase	Nature and Cause	Duration and Extent
Onshore Development		
Exploration	Trampling of wetland vegetation and compaction of wetland substrates (e.g., sediments or soils) from vehicle and foot traffic during conduct of seismic evaluations.	Localized, may be long-term, limited to footprint of, and routes taken by, exploration teams and vehicles.
	Destruction of wetland vegetation during drilling of exploratory wells and logging.	Localized to drilling location. May be short-term if well is abandoned; long-term if well site is developed for production. Likely where long-term invasive vegetation becomes established.
Construction	Disturbance or loss of wetland vegetation and substrates from clearing and grading of well pad site and access road, pipeline, and utility corridor locations.	Long-term within facility and access road footprints, short-term and/or long-term within pipeline and utility corridors.
	Disturbance of adjacent wetland vegetation and function from altered surface and subsurface hydrology and increased sedimentation during site construction activities.	Long- and/or short-term, depending on types of wetlands adjacent to the well site and existing hydrologic regimes.
	Establishment of invasive, non-native vegetation (such as purple loosestrife) in areas disturbed by clearing and grading activities.	Long-term establishment of invasive vegetation, which could spread to adjacent wetland habitats.
	Fragmentation of wetland habitat due to siting of wellhead; storage and processing facilities; and pipeline, access road, and utility corridor.	Long-term. Extent dependent on quality and areal extent of wetlands that would be fragmented.
Operation	Disturbance from maintenance activities; reduced air quality and water quality near facilities; reduced water quality beyond facility if groundwater is affected.	Localized to facility location; generally intermittent and short-term; long-term and greater areal extent if groundwater is affected.
Accidental Spill or Release	Exposure of wetland vegetation and substrates to accidental releases of oil or gas, or of drilling, production, and processing wastes; potentially affecting vegetation survival, growth, or reproduction, and wetland quality and function, in immediate area of the release.	May be short-term, pending small spill size and rapid release containment and site cleanup. Potentially long-term depending on spill size, cleanup effectiveness, toxicity of released materials, and sensitivity of exposed wetlands biota. Duration and magnitude of effects would depend on toxicity of the released materials, the magnitude and duration of the release, and the condition and quality of affected habitats and biota.

TABLE 6.1 (Cont.)

Development Phase	Nature and Cause	Duration and Extent
Offshore Development		
Exploration	No effects expected.	No effects expected.
Construction	Disturbance or loss of wetland vegetation and substrates from onshore clearing and grading at pipeline landfall, storage and processing facilities, access road, utility corridors, and staging areas for pipeline construction.	Long-term within facility and access road footprints, short-term and/or long-term within pipeline and utility corridors.
	Disturbance of wetland vegetation and function from altered surface and subsurface hydrology and increased sedimentation during onshore construction activities.	Long- and/or short-term, depending on types of wetlands adjacent to the onshore locations and existing hydrologic regimes.
	Establishment of invasive, non-native vegetation in areas disturbed by clearing and grading activities.	Long-term establishment of invasive vegetation, which could spread to adjacent wetland habitats.
	Fragmentation of wetland habitat due to siting of wellhead; storage and processing facilities; and pipeline, access road, and utility corridor.	Long-term. Extent dependent on quality and areal extent of wetlands that would be fragmented.
Operation	Disturbance from maintenance activities; reduced air quality and water quality near facilities; reduced water quality beyond facility if groundwater is affected.	Localized to facility location; generally intermittent and short-term; long-term and greater areal extent if groundwater is affected.
Accidental Spill or Release	Exposure of shoreline wetland vegetation and substrates from accidental well or pipeline release, or of extraction and processing wastes; potentially affecting vegetation survival, growth, or reproduction, and the quality and function of exposed wetlands. Oil exposure of shoreline wetlands from offshore well blowout and subsequent coastline deposition.	Short-term, pending rapid release containment and site cleanup. Potentially long-term, depending on cleanup effectiveness. Duration and magnitude of effects would depend on toxicity of the released materials, the magnitude and duration of the release, and the condition and quality of affected habitats and biota.

areas. Impacts to wetlands (crushing of vegetation or substrate compaction) may occur as a result of the exploration teams and equipment conducting the seismic evaluations entering wetland areas during exploration. Survival of many native plant species and seedling establishment may be adversely affected. Soil compacting may also convert some vegetated wetland areas to open water or submerged vegetation communities. Such impacts could potentially result in long-term or major impacts on local wetlands, with effects in some cases lasting decades. Some wetland vegetation would also be disturbed or lost during installation of exploratory wells. It is very

likely that invasive plant species would colonize areas of disturbance, resulting in probable long-term effects.

6.2.1.1.2 Construction. For onshore wells, construction of a permanent drilling pad and associated structures (pipelines, access roads, and utility corridors) near the coastline may result in both temporary and permanent impacts on wetlands. Construction impacts may include:

- Permanent loss of vegetation and associated habitat from clearing and grading of the drill pad location;
- Permanent loss or disturbance of vegetation and habitat from clearing and grading of any required access roads, pipeline routes, utility corridors, and any associated construction support areas;
- Increased sedimentation in adjacent wetlands due to erosion and runoff from construction areas;
- Disturbance of local wetland vegetation and biota due to changes to surface and subsurface hydrology from altered surface runoff and infiltration patterns and rates;
- Disturbance of local wetland vegetation due to changes in groundwater hydrology from groundwater removal during drilling; and
- Habitat fragmentation due to siting of the drill pad, access roads, and pipeline and utility corridors.

Onshore drill sites may range from up to 5 or more acres (2 ha) in size, and site development would require the removal of vegetation and disturbance of soil and/or sediments from the drill site. Should the drill pad location necessitate that any pipelines, access roads, and/or utility corridors cross streams or other aquatic habitats (such as wetlands), additional removal of wetland vegetation, soils, and sediments would also occur, resulting in further loss of wetland habitat. These wetland losses (potentially long-term in nature) could result in the localized reduction or loss of wetland functions, such as fish and wildlife habitat, attenuation of flooding and shoreline erosion, and removal of substances that reduce water quality. Construction of drill sites, pipelines, roads, and utility corridors could also result in habitat fragmentation and separation of wetland areas, especially if construction took place in areas with existing roads and other facilities.

Indirect impacts on wetlands from the construction of onshore well sites may include altered hydrology from changes in surface drainage patterns or separation of surrounding wetland areas from adjacent water sources. Some wetlands, such as marshes and swamps (Section 5.2.2.1), are maintained in part by surface water flows, and the development of an oil or gas production site may result in both temporary and long-term changes to surface water inflow and/or outflow rates or patterns. Maintaining natural drainage patterns during site development

can minimize such effects. Soil compaction resulting from construction adjacent to wetlands may reduce the infiltration rates of precipitation into the soil and underlying groundwater, thereby increasing surface water runoff rates as well as the sediment load carried by the runoff. Increased surface water runoff from the well site and any access road and pipeline corridors may also increase the fluctuation of water surface elevations in adjacent wetlands (especially during precipitation events), resulting in greater extremes of high and low water levels, including reductions of the base flows and increases in flood flows of adjacent streams.

Fens and bogs (Section 5.2.2.1), which generally are not supported by surface flows, may be greatly affected by altered subsurface and surface hydrology. Water removal during drilling or the disposal of produced water may alter the subsurface hydrology on which the fens and bogs greatly depend. Hydrologic alteration of wetlands may result in an increase or decrease in the frequency, duration, depth, or extent of soil saturation or inundation, which is critical for many wetland plant species. Fens may also experience a reduction in groundwater inflow if a high degree of development (with its introduction of impervious surfaces) occurs within the recharge area. The establishment of buffer zones around wetlands, areas in which soil disturbance and use of heavy equipment is avoided, can minimize many indirect impacts to wetland hydrology.

Changes in surface and subsurface hydrology may result in the replacement of one wetland community type for another, or they may promote wetland losses by conversion to upland communities or conversion of wetland vegetation communities to open water. Soil compaction may also result in the loss of species richness and diversity. Many native wetland species indicative of high-quality habitats are sensitive to disturbance and may be displaced by species more tolerant of disturbance or by invasive non-native species, thereby reducing biodiversity. Invasive plant species typically develop high population densities and thereby exclude most other plant species, reducing native species abundance and diversity. Diversity in invertebrate, fish, and wildlife communities utilizing that habitat may also subsequently be reduced.

Degradation of water quality as a result of increased sedimentation from construction areas and/or groundwater disposal of produced water may also affect wetlands. Without proper site preparation, erosion of disturbed soils or insufficiently stabilized soils and unstable slopes following site grading may result in sediment inputs and turbidity in wetlands that receive storm water runoff. Runoff from exposed soil surfaces, such as the drill site, access roads, or pipeline rights-of-way (ROWs), may create turbidity in wetlands, increased temperature, and lower dissolved oxygen. Runoff from washdown areas may contain cuttings when air drilling is used. Erosion may occur at pipeline stream crossings. Sedimentation can alter plant communities, reducing plant density and biodiversity, decreasing sensitive species, and creating opportunities for invasive species establishment. The implementation of best management practices and good engineering practices, such as the use of silt fences for erosion and sedimentation control, would minimize such impacts to wetlands.

Offshore oil and gas wells will require onshore facilities, including pipelines, storage and processing facilities, access roads, and utility corridors. Impacts on wetlands from the construction of these onshore facilities would be similar to those identified for onshore oil and gas development. Wetland vegetation would be permanently disturbed within the facility

footprints, while potential alterations to surface and subsurface hydrology could affect wetlands in adjacent areas. Although offshore oil and gas development would not have an onshore well pad, the need for pipelines that transport the gas or oil from the wellhead on the lake bottom to an onshore processing and storage facility could affect more wetlands than would onshore oil and gas development. The construction of pipelines from offshore drilling rigs to onshore processing and storage facilities may also result in erosion of exposed soils and unstable slopes at pipeline landfalls, potentially affecting wetlands at those locations.

A number of Federal, state, and local regulations address the protection of wetlands. Refer to Section 4 for regulatory issues associated with these potential disturbances.

6.2.1.1.3 Operation. Access roads and utility corridor ROWs may allow for increased access and disturbance from recreational activities in previously undisturbed areas; the ROWs may also provide opportunities for invasive species to colonize these areas. Normal operations would include a variety of routine monitoring and maintenance activities that would not be expected to result in adverse environmental effects under normal circumstances. However, should concerns with a pipeline (e.g., unacceptable level of pipeline corrosion) or waste storage facilities (e.g., integrity concerns for on-site disposal pits for drilling muds) be identified during maintenance or monitoring, measures to address those concerns may include replacement or repair (such as the replacement of a section of buried pipeline), which could result in additional environmental impacts. In such an event, impacts would be similar in nature to those identified for construction, but would likely be of lesser magnitude because the resources would have previously been disturbed during facility construction.

Air quality near operating facilities may be reduced during normal operations. Exhaust emissions from equipment, atmospheric releases from wells or processing facilities, or fugitive dust generated from exposed soils could have local adverse effects on wetland vegetation. Storage or handling of waste products could introduce contaminants into wetlands, and contaminants could be present in storm water runoff that flows into wetlands. However, required pollution reduction measures would minimize air and water quality reductions near facilities, and these occurrences would generally be intermittent and infrequent. Subsequently, potential impacts to wetlands would be minimized.

Shallow groundwater may become degraded from disposal or injection of produced water and could potentially affect wetlands that receive groundwater discharge, such as fens, beyond the immediate facility location, vegetation and if biota are exposed to toxic contaminants. Subsequent effects may persist long-term. Injection is a widely accepted method for disposing of produced water (Section 2.3.2). However, local and state regulations would likely direct operational requirements for the protection of groundwater, and collection, rather than discharge, of fluids may be required.

6.2.1.1.4 Accidental Spills and Releases. Spills of oil or drilling and processing waste materials may occur during each of the phases of oil and gas development, and these may affect wetland communities. With slant drilling, there is little potential for oil to migrate from the

bottom hole (which would be located under the lake bottom) to overlying surface water, because the geologic units above the oil-bearing units will act to prevent such an upward movement of oil or gas. For example, in Lake Michigan, the Niagaran Reef reservoirs are overlain by thousands of feet of impermeable rock strata (MESB 1997). Because of these layers, oil or gas can only come to the surface through the well borehole. More likely is an accidental release at the wellhead because of a blowout. However, the use of blowout preventers (see Section 2.2.2) significantly reduces (but does not eliminate) the likelihood of such a release.

Uncontrolled onshore spills may cover vegetation and wetland soils and sediments (Figure 6.3) and may result in the elimination of wetland biota in affected areas, including aquatic invertebrates and vegetation. The severity of the effect will depend on the chemical and toxicological nature of the released materials and the duration and frequency of the release. Spills of some petroleum products, such as diesel fuel, can result in higher mortality and poorer recovery of vegetation than would result from crude oil spills.

FIGURE 6.3 Oiled Wetland Sediments and Vegetation (EPA 2005f)

Exposure to spills may result in a decrease in the abundance of wetland plants and animals. Onshore spills that enter streams may impact delta, estuarine, and riverine wetlands along Great Lakes tributaries. Spills that subsequently enter the lake may also affect coastal lagoon, solution basin, and fringing wetlands along the coastline.

Spills may also result in the loss of sensitive wetland plant species, which often occur in high-quality undisturbed wetlands, and affected areas may become populated only by more tolerant species. Disturbance of wetland communities very often leads to colonization by invasive plant species, many of which are non-native. Therefore, spills may also promote the establishment of invasive plant species that may compete with and potentially displace native wetland vegetation. This would result in a decrease in the quality of the wetland and affect its role in providing wildlife habitat. Although spills from a variety of sources may affect wetlands, spills at onshore well sites are typically contained by barriers constructed around the well site.

Offshore oil spills may occur at well sites or along lake-bottom pipelines. An offshore well may also experience an accidental release of production wastes. At a well site, an oil or gas release may occur as a result of inadequate well completion and casing, or from a well blowout (Figure 6.4), due to sudden, uncontrolled releases of fluids from a wellbore or wellhead resulting from improperly balanced well pressures. The use of blowout preventers reduces (but does not eliminate) the likelihood of such a release (Section 2.2.2). Surface water affected by a release of oil or drilling wastes may enter coastal wetlands that have hydrologic connections to the lake, especially estuarine, coastal lagoon, solution basin, and fringing wetlands, thus also affecting nearshore wetlands. Coastal wetlands are ranked most sensitive (10 on a scale of 1 to 10) in environmental sensitivity indices (ESIs) (NOAA 1985, 1994; Herdendorf 1987) Wetlands may also be affected by spills from onshore pipelines and storage and processing facilities. A large

number of pipelines currently exist within the Great Lakes Basin near the lake shores. Pipeline leaks occasionally occur (see Section 3), with risks to wetlands similar to those of newly constructed pipelines. Natural gas may also be released during the drilling or production of natural gas from offshore reservoirs; however, such gas leaks may be masked by the natural production and release of methane from nearshore wetland substrates.

Oil spills that are not cleaned up may persist in wetland soils and sediments for considerable periods of time, even decades, resulting in long-term impacts on wetland vegetation and biota (Herdendorf 1987; NOAA 1985). Spill cleanup may require the excavation and removal of contaminated soils, resulting in additional loss of wetland vegetation beyond that lost during site construction. Where oil spills occur in flooded areas or on saturated soils, recovery of vegetation is generally better than that on unsaturated soils (DOI 2002).

6.2.1.2 Other Nearshore Habitats and Vegetation

FIGURE 6.4 Extreme Example of Offshore Well Blowout (The IXTOC 1 exploratory well blew out on June 3, 1979, in the Bay of Campeche off Ciudad del Carmen, Mexico.) (Source: NOAA 2005b)

The potential effects on other nearshore habitats, such as beaches, dunes, sand barrens, and islands (see Section 5.2.3), from either onshore or offshore oil and gas development would be similar to those identified for wetlands. Potential effects from onshore well development would be largely associated with ground-disturbing activities (during exploration and construction) and accidental releases of oil and gas or of drilling, production, and processing wastes. The development of offshore wellheads may affect nearshore habitats in a similar manner, namely through (1) the accidental offshore release of oil and drilling wastes and their subsequent transport to nearshore habitats by lake currents and wave action; (2) the construction and operation of offshore pipeline landfalls and onshore pipelines, storage and processing facilities, and access roads and utility corridors; and (3) the accidental release of oil or processing wastes from onshore pipelines, storage facilities, and processing facilities. Table 6.2 summarizes the potential environmental effects from onshore and offshore development.

Nearshore habitats that have been identified as unique and/or of concern (see Section 5.2.3 for descriptions and distributions of these habitats) and that are present along the coastlines of Lakes Michigan, Huron, and Erie where oil and gas development may occur include:

- Sand beaches around northern Lake Michigan, especially along the northwestern coast of the lower peninsula of Michigan (Figure 5.12);

- Sand beaches along the coastlines of Lake Erie (Figure 5.12);

TABLE 6.2 Potential Effects on Other Nearshore Habitats and Vegetation from the Development of Oil and Gas Resources Located beneath the Great Lakes

Development Phase	Nature and Cause	Duration and Extent
Onshore Development		
Exploration	Trampling of vegetation and compaction of substrates (e.g., sand, gravel, cobble, and soil) from vehicle and foot traffic during conduct of seismic evaluations.	Localized, may be long-term; limited to footprint of, and routes taken by, exploration teams and vehicles.
	Destruction of vegetation and disturbance of substrates during drilling of exploratory wells and logging.	Localized and limited to drilling location. Short- or long-term, depending on type of vegetation affected and whether the well is abandoned. Long-term if well site is developed for production.
Construction	Disturbance or loss of vegetation and substrates from clearing and grading of well pad site and access road, pipeline, utility corridor locations, and construction staging areas.	Long-term within facility and access road footprints, short-term and/or long-term within pipeline and utility corridors.
	Disturbance of adjacent habitats and vegetation from altered surface and subsurface hydrology during site construction activities.	Long- and/or short-term, depending on types of habitats and vegetation adjacent to the well site and their sensitivity to altered hydrologic conditions.
	Establishment of invasive, non-native vegetation in areas disturbed by clearing and grading activities.	Long-term establishment of invasive vegetation, which could spread to adjacent habitats and compete with native vegetation.
	Fragmentation of habitats due to location of the wellhead; storage and processing facilities; and pipeline, access road, and utility corridor.	Long-term. Extent and magnitude dependent on quality and areal extent of the habitats that could be fragmented.
Operation	Disturbance from maintenance activities; reduced air quality near facilities; reduced water quality if groundwater is affected.	Localized to facility location; generally intermittent and short-term; long-term and greater areal extent if groundwater is affected.
Accidental Spill or Release	Exposure of adjacent habitats, vegetation, and substrates from accidental release of oil (due to well blowout) or of extraction and processing wastes, potentially affecting survival, growth, and reproduction of vegetation and habitat quality.	Short-term, pending rapid release containment and site cleanup. Potentially long-term, depending on cleanup effectiveness. Duration and magnitude of effects would depend on toxicity of the released materials, the magnitude and duration of the release, and the condition and quality of affected habitats and biota.

TABLE 6.2 (Cont.)

Development Phase	Nature and Cause	Duration and Extent
Offshore Development		
Exploration	No effects expected.	No effects expected.
Construction	Disturbance or loss of habitat, vegetation, and substrates from onshore clearing and grading at pipeline landfall, storage and processing facility, access road, utility corridor locations, and construction staging areas.	Long-term within facility and access road footprints, short-term and/or long-term within pipeline and utility corridors.
	Disturbance of habitats and vegetation from altered surface and subsurface hydrology and increased sedimentation associated with onshore construction activities.	Long- and/or short-term, depending on types of wetlands adjacent to the onshore locations and existing hydrologic regimes.
	Establishment of invasive, non-native vegetation in areas disturbed by clearing and grading activities.	Potential long-term establishment of invasive vegetation, which could spread to adjacent wetland habitats.
	Fragmentation of habitats due to siting of wellhead; storage and processing facilities; and pipeline, access road, and utility corridor.	Long-term. Extent dependent on quality and areal extent of wetlands that would be fragmented.
Operation	Disturbance from maintenance activities; reduced air quality near facilities; reduced water quality if groundwater is affected.	Localized to facility location; generally intermittent and short-term; long-term and greater areal extent if groundwater is affected.
Accidental Spill or Release	Exposure of vegetation and substrates to accidental onshore pipeline releases or onshore releases of production and processing wastes, potentially affecting survival, growth, and reproduction of vegetation and habitat quality. Exposure of coastline vegetation and habitats (such as sand beaches) from offshore well blowout and subsequent coastline deposition.	Short-term, pending rapid release containment and site cleanup. Potentially long-term, depending on cleanup effectiveness. Duration and magnitude of effects would depend on toxicity of the released materials, the magnitude and duration of the release, and the condition and quality of affected habitats and biota.

- Sand beaches along the western shore of Lake Huron and the lower peninsula of Michigan (Figure 5.12);
- Sand dunes along the northern coastline of the lower peninsula of Michigan, Lakes Michigan and Huron (Figure 5.13);
- Bedrock and cobble beaches on the western shore of Lake Huron, the lower peninsula of Michigan, and the coastline of Lake Erie (Figure 5.14);

- Lakeplain prairies along Saginaw Bay, Lake Huron (Figure 5.15);
- Sand barrens in the lower peninsula of Michigan, along the western coast of Lake Huron and the northern tip of Lake Michigan (Figure 5.16);
- Shoreline alvars along the northern shores of Lakes Michigan and Huron on the upper peninsula of Michigan, as well as in the western basin of Lake Erie (Figure 5.19); and
- Islands in northeastern Lake Michigan and western Lake Erie (Figure 5.20).

Arctic-alpine disjunct communities and Arctic coastal plain disjunct communities are extremely rare along U.S. Great Lakes shorelines. These communities are highly vulnerable to disturbance, but neither of them occurs in areas of oil and gas resources, and thus they would not be expected to be affected by oil and gas development.

For many unique nearshore habitats, their natural characteristics and environmental conditions make them very susceptible to disturbance and make restoration and recovery following any kind of disturbance very difficult. For example, vegetation in bedrock and cobble beaches is generally very limited because of wave and ice action, and revegetation of disturbed sites within these communities may be very difficult. Similarly, shoreline alvars occur on very thin soils over bedrock and normally experience flood and drought conditions. They are easily disturbed by ground surface activities, which may make restoration of disturbed areas very difficult.

6.2.1.2.1 Exploration. Impacts on nearshore habitats and vegetation would be similar to those identified for wetlands and other special aquatic sites (see Section 6.2.1.1). Impacts from onshore development may include trampling of vegetation and compaction of substrates by foot and vehicle traffic, loss of vegetation within the immediate drilling footprint, and accidental exposure of vegetation and substrates to oil and drilling wastes (Table 6.2). Seismic acquisition activities conducted in shallow water of the near-shore zone or in bays, lagoons, and quiet water areas near beach habitats may substantially impact near-shore habitats. Offshore exploration activities are not expected to affect nearshore habitats.

6.2.1.2.2 Construction. Impacts from onshore construction activities for onshore wells would be associated with clearing and grading operations for drill site preparation, pipeline ROWs, roadways, and utility corridors. These impacts would be similar to those identified for wetlands and special aquatic sites and include short- and long-term losses of vegetation and habitat, reduced habitat quality, and establishment of invasive vegetation. Other site work that could affect nearshore habitats may include excavation and the placement of fill materials to provide a stable subsurface for drilling pads, pipelines, or other structures, such as in areas of sandy soils. In addition to direct habitat losses, erosion of sand beaches and dunes may be induced because of storm water runoff, wind erosion, or sloughing of unstable slopes.

Stabilization of dune margins may be difficult, and establishment of vegetation cover may be slow, possibly resulting in prolonged losses of dune habitat near construction areas. Similar effects may be incurred for offshore well development, except that offshore construction of the wellhead and lake-bottom pipeline would not be expected to affect nearshore habitats.

6.2.1.2.3 Operation. Normal operations would include a variety of routine monitoring and maintenance activities that would not be expected to result in adverse environmental effects under normal circumstances. However, should concerns with a pipeline (e.g., unacceptable level of pipeline corrosion) or waste storage facilities (e.g., integrity concerns for on-site disposal pits for drilling muds) be identified during maintenance or monitoring, measures to address those concerns may include replacement or repair (such as the replacement of a section of buried pipeline), which could result in additional environmental impacts. In such an event, impacts would be similar in nature to those identified for construction, but they would likely be of lesser magnitude because the resources would have previously been disturbed during facility construction.

Air quality near constructed facilities may be reduced during normal operations. Exhaust emissions from equipment, atmospheric releases from wells or processing facilities, or fugitive dust generated from exposed soils could have local adverse effects on vegetation. However, required pollution reduction measures would minimize air quality reductions near facilities, and these occurrences would generally be intermittent and infrequent. Subsequently, potential impacts to nearshore habitats would be minimized.

Shallow groundwater may become degraded from disposal or injection of drilling muds, cuttings, or produced water and could potentially affect vegetation through root uptake of contaminants. Subsequent effects may persist long-term. However, local and state regulations would likely direct operational requirements for the protection of groundwater, and collection, rather than discharge, of fluids may be required.

6.2.1.2.4 Accidental Spills and Releases. Shoreline habitats would be affected by accidental oil spills from wellheads, storage tanks, or pipelines. Accidental releases of drilling wastes and processing wastes may also affect nearshore habitats. Oil and other released materials would quickly penetrate nearshore habitats with permeable substrates (such as sand beaches, sand dunes, and cobble beaches); even with cleanup, residual oil could remain below the surface for many years (Short et al. 2001, 2004; DOI 2003). Sand and cobble beaches are ranked as moderately sensitive in ESI ranking (sand beaches = 4, cobble beaches = 6 on a 1 to 10 scale, 10 being most sensitive), and bedrock shores are ranked low (ESI = 2) (Herdendorf 1987; NOAA 1985, 1994). Oil left on uncleaned cobble beaches may become asphalt-like. Although oil may penetrate cracks in bedrock shores, oil persistence is generally limited to days or weeks. Although oil may be largely removed from cobble beaches in highly exposed locations through wave and ice action, oil may remain in the shallow subsurface for extended periods of time, thus affecting the reestablishment or health (from bioaccumulation of toxic substances) of vegetation and other biota.

Because of their rarity and vulnerability to disturbance, some nearshore habitats such as alvars and dunes could be severely affected by accidental spills of oil, gas, and/or production and processing wastes. Oil or other toxic materials spilled onto ground surfaces may result in direct mortality of plants and animals, and migration through the soil may make recovery and restoration difficult. Nearshore habitats with highly permeable soils, such as sand beaches, dunes, and barrens, may experience rapid migration of contaminants through the root zone. Mortality of vegetation is generally greater, and recovery poorer, from oil spills on upland soils than on saturated or flooded soils (DOI 2002). Communities on surface or near-surface bedrock, such as bedrock beaches and alvars, would likely experience a wide surface coverage of spilled fluids, with potentially more extensive ground surface contamination and injury to biota than would occur on permeable soils.

Under certain conditions, accidental spills from an offshore wellhead and lake-bottom pipelines could reach nearshore habitats such as beaches and dunes, via currents and wave action. Shoreline currents of the Great Lakes generally flow in a counterclockwise direction around the lake perimeter (Hough 1958). Exceptions are a clockwise movement at the western tip of Lake Superior and most of the Wisconsin shoreline of Lake Michigan. Flow is generally to the east in most of Lake Ontario and in Lake Erie shorelines near the Detroit and Niagara Rivers. Onshore releases could directly affect nearshore habitats if present along the pipeline or adjacent to any storage or processing facilities. Exposed biota could suffer reduced reproduction, growth, or survival, while substrates could become contaminated with the released materials. The magnitude and extent of environmental effects from such exposure would depend on the volume and duration of the release, the toxicity of the materials released, the specific habitats and biota exposed to the release, and the speed and effectiveness of cleanup and restoration activities.

6.2.2 Offshore Habitats

Effects of oil and gas development on off-shore habitats, such as artificial reefs and shallow water areas used as spawning or nursery habitats, especially the fish spawning reefs of western Lake Erie, would be primarily associated with (1) the disturbance of lake-bottom habitats from well installation and lake-bottom pipeline construction, (2) the degradation of overlying water quality during off-shore drill platform and pipeline construction, and (3) from accidental spills and releases (Table 6.3). Onshore oil and gas development would not be expected to affect offshore habitats unless the release entered the lake and was transported to the offshore habitats. Such a scenario is highly unlikely; however, nearshore reefs and islands have a relatively higher risk.

6.2.2.1 Exploration

Exploration activities may affect offshore habitats by disturbing a relatively small amount of lake-bottom habitat during exploratory drilling and by the accidental release of oil and drilling wastes. Sediments disturbed during exploratory drilling may be expected to quickly resettle, with little lasting effect on overlying water quality or habitat quality at the drill location. Drill cuttings may be washed and discharged into the lake, as is currently practiced in Canadian waters of

Lake Erie. Cutting discharges typically cover a bottom area with a 250-ft (76-m) radius and meet chemical criteria for lakefill material set by the Province of Ontario. Drilling muds are collected for reuse.

TABLE 6.3 Potential Effects on Offshore Habitats from the Development of Oil and Gas Resources Located beneath the Great Lakes

Development Phase	Nature and Cause	Duration and Extent
Onshore Development	No effects expected.	No effects expected.
Offshore Development		
Exploration	Disturbance of lake-bottom habitats during installation of a drilling rig and/or drilling template.	Very localized and short-term if the well is abandoned.
	Reduced water quality because of increase in suspended sediments potentially affecting nearby biota.	Very localized, limited to drilling location, and short-term.
Construction	Disturbance or loss of bottom habitat from the permanent installation of the drilling template and possibly the drilling platform, and from the construction of a pipeline from the well location to an onshore storage and processing facility.	Long-term habitat loss within drilling template and pipeline footprints. Additional long-term habitat loss if jack-up or submersible rigs (Section 2.2.2) are employed.
	Reduced water quality because of increase in suspended sediments in the lake water overlying the wellhead and pipeline locations, potentially affecting biota in surrounding habitats.	Short-term. Extent and magnitude of potential effects would depend on the existing water quality in these areas and on the biota that use the habitats in these areas.
Operation	No effects expected. Potential exposure to directly discharged production water; potentially affecting growth, survival, or reproduction of exposed biota.	No effects expected. Effects associated with production water discharge would be very localized and likely minor.
Accidental Spills or Releases	Exposure of adjacent habitats, sediments, and biota to accidental release of oil because of well blowout or pipeline failure, or the release of extraction and processing wastes; potentially affecting the distribution, survival, growth, and reproduction of biota and habitat quality in surrounding areas.	Short-term pending rapid release containment and site cleanup. Potentially long-term, depending on cleanup effectiveness. Duration and magnitude of effects would depend on toxicity of the released materials, the magnitude and duration of the release, and the condition and quality of affected habitats and biota.

6.2.2.2 Construction

Sediments could be disturbed during (1) the construction and anchoring of offshore drilling platforms (jack-up and submersible rigs; see Section 2.2.2), (2) installation of drilling templates and wellheads, and (3) installation of lake-bottom pipelines. This disturbance could increase turbidity and decrease water quality in the vicinity of the construction activity. The suspended sediments may not only affect the habitats at the well location, but may also be transported by lake currents to nearby off-shore habitats. Resulting siltation in these habitats could adversely affect invertebrate populations or the productivity of aquatic vegetation; however, some suspension of bottom sediments generally occurs under natural conditions such as storm events. Fish species that are dependent on these habitats may subsequently be affected, temporarily fleeing the construction area. Because construction would be relatively short term, potential impacts associated with increased turbidity and siltation would not be expected to last beyond the construction period. If the disturbed bottom sediments are also contaminated (see Section 5.6), local biota may be further affected by exposure to the contaminated sediments.

The construction of pipelines in shallow-water habitats may result in the localized elimination of small areas of habitat and an associated loss of biota (invertebrates and aquatic vegetation). For each mile of unburied pipeline constructed in the nearshore zone, approximately 1 acre (2 ha) of shallow-water habitat may be disturbed (USACE 1982). This loss of habitat would remain for the life of the facilities. However, benthic communities recover to pre-construction levels in approximately 1 year following the construction of buried pipelines.

Drilling wastes produced during well completion may adversely affect offshore habitats. Water-based muds and cuttings may contain constituents (see Section 2.3.1) or have pH levels that could affect biota if released into waters at the drill site.

6.2.2.3 Operation

During operations, offshore habitats may be affected by the release of produced water. Depending on applicable regulatory requirements, produced water may be directly discharged to the lake or may be accidentally released following injection into a disposal well (see Section 2.3.2). Exposure to these wastes may affect biota in the immediate vicinity of the production site. These constituents may also be carried by lake currents from the well location to other offshore habitats and adversely affect biota at those locations.

6.2.2.4 Accidental Spills and Releases

Releases of drilling wastes during exploratory and production well drilling, as well as accidental oil releases from wellheads and pipelines, may not only affect surrounding offshore habitats, but also be transported by lake currents to more distant offshore habitats. Oil that is not readily cleaned up may form deposits on bottom sediments, thus affecting the survival, growth, and reproduction of some bottom-dwelling fauna and aquatic vegetation. Oil that is not

subsequently removed may remain on or in the bottom sediments for extended periods of time, resulting in chronic exposure of some biota.

The magnitude and extent of environmental effects from such exposure would depend on the volume and duration of the release, the toxicity of the materials released, the specific habitats and biota exposed to the release, and the speed and effectiveness of cleanup and restoration activities.

6.2.3 Inland Habitats and Vegetation

Potential effects of oil and gas E&P on inland terrestrial habitats would be similar to those described for wetlands and nearshore habitats (Section 6.2.1). These effects would be primarily associated with ground disturbance, changes in groundwater and surface water quality and flow, habitat fragmentation, accidental oil and gas releases, and accidental releases of drilling and processing wastes (Table 6.4). Offshore development would similarly affect inland habitats or vegetation along onshore pipelines, processing and storage facilities, access roads, utility corridors, and platform or pipeline construction staging areas.

Many of the terrestrial habitats occurring in the oil- and gas-producing area of northern Lakes Michigan and Huron support coniferous and deciduous forests, with timber management and agriculture being common land uses. Grasslands are present, mostly on the Wisconsin side of Lake Michigan. The oil and gas production areas of Lake Erie contain extensive areas of agriculture, as well as urban and industrialized areas, with beech-maple woodlots. These communities have generally been greatly affected by human activities since European settlement, and undisturbed habitats are primarily small and relatively rare. Generally, the current habitat types are common in much of the Great Lakes Basin. Ecological impacts to terrestrial habitats may be less in agricultural or industrial areas if activities occur on disturbed agricultural or industrial land.

Staging areas for pipeline construction and fabrication yards for large offshore platforms may disturb large areas of inland habitat. While direct impacts (vegetation loss and soil disturbance) would occur during the construction period, habitat recovery may require extended periods beyond the completion of all construction activities.

6.2.3.1 Exploration

Impacts on inland habitats and vegetation during exploration would be similar to those identified for wetlands and nearshore habitats. Impacts would be associated with the trampling of vegetation and soils by foot and vehicle traffic, disturbance of vegetation and soils during drilling, and the accidental release of oil and gas and drilling wastes (Table 6.4). In addition, air drilling (instead of using muds) can generate dusts that may affect nearby biota. Runoff from washdown areas may contain cuttings.

TABLE 6.4 Potential Effects on Inland Vegetation and Habitats from the Development of Oil and Gas Resources Located beneath the Great Lakes

Development Phase	Nature and Cause	Duration and Extent
Onshore Development		
Exploration	Trampling of vegetation and soils from vehicle and foot traffic during conduct of seismic evaluations.	Localized, may be long-term; limited to footprint of, and routes taken by, exploration teams and vehicles.
	Destruction of vegetation and disturbance of soils during drilling of exploratory wells and logging.	Localized and limited to drilling location. Short- or long-term, depending on type of vegetation affected and whether well is abandoned. Long-term if well site is developed for production.
Construction	Disturbance or loss of vegetation and soils from clearing and grading of well pad site, access road, pipeline, utility corridor locations, waste disposal facilities, and construction staging areas.	Long-term within facility and access road footprints, short-term and/or long-term within pipeline and utility corridors.
	Disturbance of vegetation in adjacent habitats from altered surface and subsurface hydrology during site construction activities.	Long- and/or short-term, depending on types of habitats and vegetation adjacent to the well site and their sensitivity to altered hydrologic conditions.
	Establishment of invasive, non-native vegetation in areas disturbed by clearing and grading activities.	Long-term establishment of invasive vegetation, which could spread to adjacent habitats and compete with native vegetation.
	Fragmentation of habitats because of the location of the wellhead; storage and processing facilities; and pipeline, access road, and utility corridor.	Long-term. Extent and magnitude dependent on quality and areal extent of the habitats that could be fragmented.
Operation	Potential disturbance from maintenance and monitoring activities; reduced air quality near facilities; reduced water quality if groundwater is affected.	Localized to facility location; generally intermittent and short-term; long-term and greater areal extent if groundwater is affected.
Accidental Spill or Release	Exposure of habitats, biota, and soils from accidental release of oil (due to well blowout) or of drilling and processing wastes; potentially affecting survival, growth, and reproduction of biota and reducing habitat quality.	Short-term, pending rapid release containment and site cleanup. Potentially long-term, depending on cleanup effectiveness. Duration and magnitude of effects would depend on toxicity of the released materials, the magnitude and duration of the release, and the condition and quality of affected habitats and biota.

TABLE 6.4 (Cont.)

Development Phase	Nature and Cause	Duration and Extent
Offshore Development		
Exploration	No effects expected.	No effects expected.
Construction	Disturbance or loss of habitat, vegetation and substrates from onshore clearing and grading at pipeline landfall, storage and processing facilities, access roads, utility corridor locations, and construction staging areas.	Long-term within facility and access road footprints, short-term and/or long-term within pipeline and utility corridors.
	Disturbance of habitats and vegetation from altered surface and subsurface hydrology and increased sedimentation associated with onshore construction activities.	Long- and/or short-term, depending on types of wetlands adjacent to the onshore locations and existing hydrologic regimes.
	Establishment of invasive, non-native vegetation in areas disturbed by clearing and grading activities.	Potential long-term establishment of invasive vegetation, which could spread to adjacent wetland habitats.
	Fragmentation of habitats because of siting of wellhead; storage and processing facilities; and pipeline, access road, and utility corridor.	Long-term. Extent dependent on quality and areal extent of wetlands that would be fragmented.
Operation	Potential disturbance from maintenance and monitoring activities of onshore facilities; reduced air quality near facilities; reduced water quality if groundwater is affected.	Localized to facility location; generally intermittent and short-term; long-term and greater areal extent if groundwater is affected.
Accidental Spill or Releases	Exposure of habitats, biota, and soils associated with onshore facilities (such as pipelines) from accidental release of oil or of production and processing wastes; potentially affecting survival, growth, and reproduction of biota and reducing habitat quality.	Short-term, pending rapid release containment and site cleanup. Potentially long-term, depending on cleanup effectiveness. Duration and magnitude of effects would depend on toxicity of the released materials, the magnitude and duration of the release, and the condition and quality of affected habitats and biota.

6.2.3.2 Construction

Construction of drill pads, pipelines, access roads, drilling and processing waste facilities, and utility corridors would result in losses of habitat because of clearing and grading of the well site and associated facility locations (Table 6.4). Construction would result in the loss or disturbance of habitat and vegetation within the immediate footprint of the well pad, pipeline, storage and processing facilities, and utility corridors; this effect would be long term. Staging areas for pipeline construction and fabrication yards for large offshore platforms may disturb large areas

of inland habitat. Although direct impacts (vegetation loss and soil disturbance) would occur during construction, habitat recovery following construction may require extended periods. Shallow groundwater may become degraded during disposal; injection of drilling muds, produced water, or cuttings could potentially affect vegetation through root uptake. Local and state regulations would likely direct operations requirements for the protection of groundwater, and collection, rather than discharge, of drilling muds may be required.

Vegetation in the vicinity of the drill site may also be affected during construction by fugitive dust generated from exposed soils during clearing, grading, and construction activities, and from unpaved access roads. The deposition of fugitive dust on vegetation may result in reduced photosynthesis and primary production in adjacent habitats. However, such impacts would likely be minor and of short duration.

Depending on the siting of the drill rig and any associated access roads, pipelines, and utility corridors, the development of an oil or gas well site may result in the fragmentation of the habitat where the well site is located. The consequences of any such fragmentation would depend on the nature of the habitat being affected, including its size and occurrence in the area of the well site development.

6.2.3.3 Operation

During normal operation, erosion may be induced adjacent to pipelines at landfalls as a result of the effect of ice and storms. Losses of soil and vegetation may be considerable. Normal operations would include a variety of routine monitoring and maintenance activities that would not be expected to result in adverse environmental effects under normal circumstances. However, should concerns with a pipeline (e.g., unacceptable level of pipeline corrosion) or waste storage facilities (e.g., integrity concerns for on-site disposal pits for drilling muds) be identified during maintenance or monitoring, measures to address those concerns may include replacement or repair (such as the replacement of a section of buried pipeline), which could result in additional environmental impacts. In such an event, impacts would be similar in nature to those identified for construction, but they would likely be of lesser magnitude because the resources would have previously been disturbed during facility construction.

Air quality near constructed facilities may be reduced during normal operations. Exhaust emissions from equipment, atmospheric releases from wells or processing facilities, or fugitive dust generated from exposed soils could have local adverse effects on vegetation. However, required pollution reduction measures would minimize air quality reductions near facilities, and these occurrences would generally be intermittent and infrequent. Subsequently, potential impacts to inland habitats would be minimized.

Shallow groundwater may become degraded from disposal or injection of drilling muds, cuttings, or produced water and could potentially affect vegetation through root uptake of contaminants. Subsequent effects may persist long-term. However, local and state regulations would likely direct operational requirements for the protection of groundwater, and collection, rather than discharge, of fluids may be required.

6.2.3.4 Accidental Spills and Releases

Accidental releases of oil and gas from the wellhead or pipelines, or of processing wastes, could result in direct exposure of terrestrial biota, potentially affecting growth, survival, and reproduction of exposed biota and reducing habitat quality. Following a release, some contaminants would move into the soil and potentially migrate to shallow groundwater, subsequently entering the root zone of and affecting nearby vegetation. The magnitude and extent of environmental effects from such exposure would depend on the volume and duration of the release, the toxicity of the materials released, the specific habitats and biota exposed to the release, and the speed and effectiveness of cleanup and restoration activities.

6.2.4 Fish

Fish may be affected during all phases of oil and gas development (Table 6.5). For onshore development, fish may be affected by the accidental release of oil or gas from a well head or pipeline, by the accidental release of drilling and processing wastes, and by degraded water quality and habitats due to erosion and runoff from construction areas. The effects on fish from offshore development would be similar, except that the likelihood for, and magnitude of, impacts on fish and their habitats may be greater, and more habitat disturbance may occur as a result of offshore pipeline construction. As previously discussed, it is unlikely that a release into overlying surface waters from the bottom hole of an onshore directionally drilled well would occur (see Section 6.2.1.1.4).

Potential effects from onshore wells would be largely limited to fish and their habitats present in surface waters that receive surface water runoff (and, to a lesser extent groundwater discharge) from the well site and its associated facilities or that are crossed by pipelines, access roads, and utility corridors. Offshore wells have a potential for affecting a greater number of fish and their habitats, because of the presence of an offshore well and a lake-bottom pipeline and also of an onshore pipeline and storage and processing facilities. Thus, offshore wells will likely be associated with more surface water habitat than would an onshore well. The greatest impacts would be associated with spills or releases that affect spawning habitats and nursery areas, which could result in population-level effects for some species. Effects may include reduced habitat quality and availability, reduced reproductive success, and reduced growth and survival. Depending on the species affected and the nature and magnitude of any effects, population-level effects could be experienced by some species.

6.2.4.1 Exploration

Exploration for onshore development could affect fish through the temporary disturbance of aquatic habitats by exploration vehicles crossing small streams (Table 6.5). During offshore exploration, fish could be affected by sound levels generated during seismic surveys, by the turbidity that would be generated during installation of the drilling template, and by the accidental release of oil and drilling wastes (Table 6.5). Potential effects would likely be short-term, localized, and relatively minor. Fish affected by the seismic surveys or increased turbidity

TABLE 6.5 Potential Effects on Fish from the Development of Oil and Gas Resources Located beneath the Great Lakes

Development Phase	Nature and Cause	Duration and Extent
Onshore Development		
Exploration	Avoidance of habitats because of reduced water quality associated with increased turbidity and disruption of aquatic habitats in streams crossed by exploration vehicles and equipment. May affect reproduction if spawning habitats affected.	Largely short-term and localized, limited to the immediate area of actual stream crossings. Long-term if spawning affected.
Construction	Increased turbidity and sedimentation because of erosion and runoff from construction areas, affecting habitat quality and potentially impacting reproduction by covering nests and eggs with silt.	Short-term in aquatic habitats receiving runoff from construction areas; duration largely limited to period of construction. Potential local population level effects, depending on season and fish spawning characteristics.
	Reduced habitat availability because of altered surface and subsurface hydrology during site construction activities, potentially affecting spawning and feeding.	Long- and/or short-term, depending on the duration of the altered hydrologic conditions. Potential local population-level effects.
	Habitat disturbance or loss in streams requiring pipeline and/or access road crossing.	Localized, short-or long-term depending on crossing requirements and design (e.g., culvert or pipeline burial). Potential effect on fish spawning movements in streams.
	Establishment of invasive, non-native vegetation in aquatic habitats disturbed by stream crossings.	Long-term establishment of invasive vegetation, which could affect fish habitat quality and spread to adjacent aquatic habitats, potentially resulting in local population-level effects.
Operation	Potential disturbance of normal behaviors of fish in nearby habitats during monitoring and maintenance activities.	Short-term; disturbed individuals likely to habituate to normal operations, while monitoring and maintenance activities expected to be short-term, not continuous.
Accidental Spill or Release	Exposure of adjacent habitats, biota, and sediments to accidental release of oil (because of well blowout) or of drilling and processing wastes; potentially impacting survival, growth, and reproduction of biota and reducing habitat quality.	Short-term exposure pending rapid release containment and effective site cleanup. Potential long-term effects, depending on cleanup effectiveness. Duration and magnitude of effects would depend on toxicity of the released materials, the species and life stage exposed, the magnitude and duration of the release, and the condition and quality of affected habitats and biota. Potential local population-level effects.

TABLE 6.5 (Cont.)

Development Phase	Nature and Cause	Duration and Extent
Offshore Development		
Exploration	Avoidance of seismic survey and exploratory drill locations.	Very localized and short-term if the well is abandoned. Fish expected to return following completion of seismic surveys and exploratory drilling.
	Reduced water quality because of increase in suspended sediments during drilling of exploratory wells; potentially affecting the distribution, survival, growth, and reproduction of exposed biota.	Very localized and short-term, limited to drilling location.
Construction	Loss of bottom habitat from the installation of the drilling template, blowout preventer, and possibly the drilling platform (Section 2.2.2), and from the construction of a pipeline from the well location to an onshore storage and processing facility.	Long-term habitat loss within drilling template and pipeline footprints. Additional long-term habitat loss if jack-up or submersible rigs (Section 2.2.2) are employed.
	Reduced quality because of increase in suspended sediments (increased turbidity) in the lake water overlying the wellhead and pipeline locations; potentially affecting survival, growth, and reproduction of biota in surrounding habitats.	Short-term or long term. Extent and magnitude of potential effects would depend on the existing water quality in these areas and the species that use the habitats in these areas, and whether the construction activity occurs in active spawning or nursery habitats.
	Increase in habitat associated with presence of new submerged structures could increase local abundance of some fish.	Long-term until subsurface structures removed.
Operation	No effects expected. Potential exposure to directly discharged production water; potentially affected growth, survival, or reproduction of exposed biota.	Minor and localized effects associated with production water discharger.
Accidental Spill or Release	Exposure of habitats, biota, and sediments to accidental release of oil (because of well blowout) or of drilling and processing wastes; potentially affecting survival, growth, and reproduction of fish and their food, and reducing habitat quality.	Short-term, pending rapid release containment and site cleanup. Potential long-term effects, depending on cleanup effectiveness. Duration and magnitude of effects would depend on toxicity of the released materials, the species and life stage exposed, the magnitude and duration of the release, and the condition and quality of affected habitats and biota. Potential population-level effects.

would likely leave the area, while fish exposed to an accidental release could incur a variety of lethal or sublethal effects. If spawning activities and reproduction are affected, local population levels may be impacted.

6.2.4.2 Construction

Effects from the construction of onshore and associated facilities would be similar to those identified for exploration, except that they could be of longer duration and potentially of greater magnitude (Table 6.5). Fish habitats could be affected by erosion and runoff from construction areas, as well as by changes in the surface and subsurface hydrology of the area where the well and associated facilities are being constructed. Effects from erosion and runoff may include a degraded habitat quality from the increased turbidity and sedimentation, as well as avoidance of the affected habitats, and affected fish would likely leave the disturbed habitats. These effects could be short or long term, depending on the nature of the receiving water body (e.g., small or large size, flowing or still water) but would largely cease following completion of construction activities. In addition, the likelihood and magnitude of adverse effects would be mitigated with careful site design and implementation of good engineering practices. Habitat disturbance because of altered hydrologic regime would be long term.

Construction of offshore wells and pipelines could result in the loss of benthic (lake bottom) fish habitat within the footprint of the drilling template, drill rig (if in contact with the lake bottom), and lake-bottom pipelines. Increases in turbidity during construction of these facilities may result in the temporary avoidance of nearby habitats by fish and in a temporary reduction in local habitat quality. Local population-level effects may be incurred if the affected habitats are active spawning or nursery habitats. Alternately, submerged structures could act as artificial reefs and increase habitat availability and attractiveness for some fish species.

6.2.4.3 Operation

Fish and their habitats are not expected to be affected by normal operations of either onshore or offshore wells and associated facilities (Table 6.5). Depending on applicable regulatory requirements, produced water from offshore wells may be directly discharged to the lake (see Section 2.3.2). Exposure to these wastes may affect the abundance, survival, or reproduction of biota in the immediate vicinity of the production site. These constituents may also be carried by lake currents from the well location to other offshore habitats and adversely affect biota at those locations. The presence of submerged wellheads in offshore areas may provide additional habitat for some species (similar to artificial reefs). Normal operations would include a variety of routine monitoring and maintenance activities that would not be expected to result in adverse environmental effects under normal circumstances. However, should concerns with a pipeline (e.g., unacceptable level of pipeline corrosion) or waste storage facilities (e.g., integrity concerns for on-site disposal pits for drilling muds) be identified during maintenance or monitoring, measures to address those concerns may include replacement or repair (such as the replacement of a section of buried pipeline), which could result in additional environmental impacts. In such an event, impacts would be similar in nature to those identified

for construction (related to the loss of bottom habitat, increased turbidity, and sediment resuspension), but they would likely be of lesser magnitude because the resources would have previously been disturbed during facility construction.

6.2.4.4 Accidental Spills and Releases

Accidental releases of oil, drilling and production wastes, and processing wastes may expose fish to contaminants that could adversely affect growth, reproduction, and survival. Accidental releases may also result in the deposition of oil or oil residues in spawning and nesting habitats, as well as habitats utilized by juvenile and adult fish for feeding; such releases may affect fish and their habitats not only in the vicinity of the release but also in other areas where currents may transport the released materials. Oil that is not readily cleaned up may form deposits on bottom sediments, thus affecting the survival, growth, and reproduction of bottom-dwelling fauna and aquatic vegetation, and thus, the habitat quality for some fish.

Exposure to the released materials may result in acute or chronic toxic effects, reducing survival, growth, and reproduction. Local or regional population-level effects may result if the release affects eggs or young fish, or reduces spawning and nursery habitat quality. Oil that is not subsequently removed may remain on or in the bottom sediments for extended periods of time, resulting in chronic exposure of some biota. Depending on the magnitude of the release, the speed with which the release is contained, the effectiveness of the cleanup, the location of the release or spill, and the species and life stage (egg, larvae, or adult) of the exposed fish, exposure to an accidental spill or release could result in local or regional population-level effects. Currently, all states have programs and requirements for addressing hazardous material releases. These would be implemented in the event of an accidental release, thus reducing the likelihood for and magnitude of impacts to fish.

6.2.5 Wildlife

Wildlife may be affected by a variety of factors related to oil and gas development. Wildlife may be disturbed by human presence and noise associated with exploration and construction activities; loss of habitat from clearing and grading activities; loss of less mobile wildlife (such as some amphibians and reptiles) in construction areas; noise and human activity during operations; and exposure to accidental releases of oil, gas, drilling and production wastes, and processing wastes (Table 6.6). Onshore activities may affect amphibians, reptiles, birds, and mammals, while effects at offshore locations would be largely limited to aquatic birds (waterfowl, gulls, and terns).

6.2.5.1 Exploration

Impacts associated with either onshore or offshore seismic surveys, would be largely limited to disturbance of biota by the presence and activity of the exploration teams and their equipment. Most biota would be expected to either temporarily leave the immediate exploration

area, or seek shelter in burrows and nests until the disturbance was over. Seismic disturbance on wildlife would be short-term, localized, and minor.

TABLE 6.6 Potential Effects on Wildlife from the Development of Oil and Gas Resources Located beneath the Great Lakes

Development Phase	Nature and Cause	Duration and Extent
Onshore Development		
Exploration	Disturbance of wildlife and their habitats from vehicle and foot traffic during conduct of seismic evaluations.	Short-term, limited to footprint of, and routes taken by, exploration teams and vehicles.
	Destruction of wildlife habitat during drilling of exploratory wells and logging.	Short-term if well is abandoned. Long term if well site is developed for production.
	Disturbance of wildlife because of increased noise and human presence. Disturbed wildlife may abandon or avoid exploration areas. Disturbance of colonial-nesting birds may affect reproductive success.	Short-term unless site is selected for full development. May be long term if disturbance affects reproductive success.
Construction	Disturbance or loss of habitat from clearing and grading of well pad site and access road, pipeline, and utility corridor locations.	Long-term within facility and access road footprints, short-term and/or long-term within pipeline and utility corridors.
	Disturbance of adjacent habitats from altered surface and subsurface hydrology during site construction activities.	Long- and/or short-term, depending on types of habitats disturbed and the wildlife that utilize those habitats.
	Avoidance or abandonment of adjacent habitats because of construction noise and activity. Disturbance of colonial-nesting birds could result in population level effects.	Short-term until construction activities completed. Long-term if reproduction affected.
	Establishment of invasive, non-native vegetation in areas disturbed by clearing and grading activities, reducing quality of wildlife habitat.	Long-term if invasive vegetation becomes established and spreads to adjacent habitats.
	Fragmentation of wildlife habitat from siting of wellhead; storage and processing facilities; and pipeline, access road, and utility corridor.	Long-term. Extent dependent on quality and areal extent of habitats that would be fragmented.
Operation	Disturbance of wildlife in adjacent habitats due to noise and human activity. Disturbance of colonial nesting birds could result in abandonment of nesting habitat and affect reproduction success, resulting in population level effects.	Short-term for species that may habituate to operational activities. Long-term for other species.

TABLE 6.6 (Cont.)

Development Phase	Nature and Cause	Duration and Extent
Accidental Spill or Release	Exposure of wildlife and adjacent habitats to accidental release of oil or of extraction and processing wastes. Survival, growth, and reproduction of exposed wildlife, as well as habitat quality, may be reduced, affecting local or regional wildlife populations.	Short-term, pending rapid release containment and site cleanup. Potential long-term effects depending on cleanup effectiveness. Duration and magnitude of effects would depend on toxicity of the released materials, the species and life stage exposed, the magnitude and duration of the release, and the condition and quality of affected habitats and biota. Potential local population-level effects.
Offshore Development		
Exploration	Exploration near shore-nesting birds may disturb adults and affect reproductive success. No other effects expected.	Potential long-term effects if reproductive success affected. No other effects expected.
Construction	Disturbance or loss of wildlife habitat from onshore clearing and grading at pipeline landfall, storage and processing facility, access road, and utility corridor locations.	Long-term within facility and access road footprints, short-term and/or long-term within pipeline and utility corridors.
	Disturbance of onshore wildlife habitat from altered surface and subsurface hydrology and increased sedimentation during onshore construction activities.	Long- and/or short-term, depending on types of habitats affected.
	Abandonment or avoidance of adjacent habitats because of construction noise and activity. Disturbance of colonial nesting birds could affect reproduction success and result in population level effects.	Short-term until construction activities completed. Long-term if reproduction affected.
	Establishment of invasive, non-native vegetation in onshore areas disturbed by clearing and grading activities, reducing the quality of wildlife habitat at the site and surrounding areas.	Long-term with establishment of invasive vegetation.
	Fragmentation of wildlife habitat from siting of wellhead; storage and processing facilities; and pipeline, access road, and utility corridors.	Long-term. Extent dependent on quality and areal extent of habitats that would be fragmented.
Operation	Disturbance of waterfowl and other aquatic birds by noise and human activities on well platforms. Disturbed biota may avoid operating platforms.	Short-term for species that readily habituate to noise and human activities. Long-term for sensitive species.

TABLE 6.6 (Cont.)

Development Phase	Nature and Cause	Duration and Extent
Operation	Offshore platforms (extending above the water surface) could provide resting locations for birds migrating across open waters of some lakes (especially Lake Erie), potentially increasing crossing-success for some birds.	Long-term until platform is removed.
Accidental Spill or Release	Exposure of wildlife and habitats from accidental onshore pipeline release or of extraction and processing wastes, affecting the quality of adjacent habitats. Exposure of coastline habitats and wildlife using shoreline and offshore habitats (i.e., diving birds and waterfowl) from offshore well blowout and subsequent coastline deposition. Ingestion of contaminated media or food may affect growth, survival, or reproduction.	Short-term, pending rapid release containment and site cleanup. Potential long-term effects, depending on cleanup effectiveness. Duration and magnitude of effects would depend on toxicity of the released materials, the species and life stage exposed, the magnitude and duration of the release, and the condition and quality of affected habitats and biota. Potential local population-level effects.

Construction of exploration wells could result in longer periods of disturbance, especially if the exploration well is developed. Should potentially sensitive biota, such as colonial-nesting birds, be disturbed, some population-level effects may be incurred.

6.2.5.2 Construction

Construction of onshore wells and associated facilities, and of the onshore portions of offshore wells, may affect wildlife in a similar manner. Effects would be associated with habitat loss at construction areas, loss of less mobile wildlife within the construction areas, avoidance of nearby habitats because of construction noise and activity, disturbance of adjacent habitats from altered surface and subsurface hydrology, reduction of habitat quality because of the establishment of non-native vegetation, and fragmentation of some habitats because of siting of pipelines, access roads, and utility corridors.

Habitat loss would be long-term within facility footprints. Reduced habitat quality because of altered hydrologic regimes would be long-term, but likely of limited extent. The disturbance of local biota by construction noise and activity would be short term and localized and would largely cease upon completion of the construction. However, construction noise and activities may result in the abandonment of nest areas or the disruption of normal nesting behaviors, which in the case of colonial nesting birds such as gulls, cormorants, and some herons, could result in some local population-level effects.

6.2.5.3 Operation

Under normal operations, nearby wildlife may be disturbed by noise and human activities associated with the site. Disturbed wildlife may abandon the area, while others may avoid the site. Some species may become habituated and return to normal behaviors, while others may leave the area for the duration of operations. If sensitive species or groups, such as colonial-nesting birds (gulls or cormorants), are disturbed, reproductive success may be affected. If offshore platforms that extend above the lake surface are employed, these platforms may providing rest areas for birds migrating across the open waters of the Great Lakes.

Normal operations would include a variety of routine monitoring and maintenance activities, and these are not expected to result in adverse environmental effects under normal circumstances. Wildlife could leave the area during maintenance or monitoring, but because these activities would not be continuous (i.e., may be weekly or monthly and not hourly or more frequent), affected biota may be expected to return following completion of the monitoring or maintenance activity. However, should maintenance or monitoring identify concerns such as with a pipeline (e.g., pipeline monitoring identifies unacceptable level of corrosion) or waste storage facility (e.g., integrity concerns for on-site disposal pits for drilling muds), measures to address those concerns may require replacement or repair, which could result in additional environmental impacts. In such an event, impacts would be similar in nature to those identified for construction (related the habitat loss, noise, and disturbance), but would likely be of lesser magnitude because some of the resources (i.e., habitat) would have previously been disturbed during facility construction.

6.2.5.4 Accidental Spills and Releases

Accidental releases of oil, drilling and production wastes, and processing wastes may expose wildlife and their habitats to contaminants that may adversely affect growth, reproduction, and survival. Accidental releases may also result in the deposition of oil or oil residues on shoreline or wetland nesting habitats of some birds, as well as habitats utilized by some birds for feeding (such as beaches used by shorebirds). Releases from offshore wells and pipelines may affect wildlife and their habitats not only in the vicinity of the release but also in other areas where currents may transport the released materials.

Exposure to the released materials may result in acute or chronic toxic effects, reducing survival, growth, and reproduction. Local or regional population-level effects may result if, following ingestion of contaminated food or incidental ingestion of contaminated media (sediments or soil), reproduction is affected (e.g., reduced egg production and increased malformations of embryos). Oil that is not subsequently removed may remain on or in the habitats for extended periods of time, resulting in chronic exposure of some biota through direct contact and uptake or through the food chain. Depending on the magnitude of the release, the speed with which the release is contained, the effectiveness of the cleanup, the location of the release or spill, and the species and life stage (egg, young, or adult) exposed, exposure to a spill or release could result in local or regional population-level effects.

6.3 POTENTIAL EFFECTS ON THREATENED AND ENDANGERED SPECIES

Species listed as threatened or endangered under the ESA, as well as other species similarly listed by state statutes, could be adversely affected by each of the three phases of oil and gas development. Approximately 172 species have been classified under the ESA as threatened or endangered in the eight Great Lakes states (Table 5.7). Among these species, 50 occur in habitats in or near coastal areas where onshore oil and gas well sites to access potential offshore resources might occur (Table 6.7). In addition to these Federally listed species, there are many more species listed by the individual states that could be affected in an identical manner.

TABLE 6.7 Number of Federally Listed Threatened and Endangered Species That Could Be Affected by Oil and Gas Development

Taxonomic Group	NY	PA	OH	MI	IN	IL	WI	MN
Plants	1	–[a]	2	8	2	3	4	–
Terrestrial invertebrates	1	–	3	3	1	2	2	–
Aquatic invertebrates	–	2	3	3	3	–	2	–
Fish	–	-	–	–	–	–	–	–
Amphibians	–	–	–	–	–	–	–	–
Reptiles	1	1	2	1	–	–	–	–
Aquatic birds	2	2	2	2	2	3	2	2
Terrestrial birds	–	–	–	1	–	–	–	–
Mammals	1	–	1	2	1	1	1	2

[a] A dash (–) indicates no species of that taxonomic group identified for the state.

Some of the Federally listed species occur within some of the Great Lakes Basin states as occasional visitors or migrants, while others have known populations, nesting areas, or winter roost sites. For example, the Federally threatened piping plover is listed in each of the Basin states, but it has known breeding areas within the Basin only on beaches along northern Lake Michigan and Lake Superior in Michigan (USFWS 2005). In other areas of the Basin, this species is a transient visitor. In contrast, species such as the Federally endangered Michigan monkey flower are endemic to the Basin and are found only in some coastal counties of Michigan along the northern coast of Lake Michigan and the northwestern coast of Lake Huron. While exploration and construction would not be allowed where listed species are present and may be affected, species with such restricted distributions, such as the Michigan monkey flower, and the Lake Erie watersnake may be especially at risk from accidental spills and releases and habitat alterations associated with the construction of the well site and associated infrastructure.

Potential effects would be similar to those previously identified for vegetation, fish, and wildlife (see Tables 6.1 through 6.6), namely exposure to accidentally released oil, gas, drilling and production wastes, and processing wastes; habitat alteration; and disturbance by noise and human activities (Table 6.8). In addition, listed plant species may be especially affected if

TABLE 6.8 Potential Effects on Threatened and Endangered Species from the Development of Oil and Gas Resources Located beneath the Great Lakes[a]

Development Phase	Nature and Cause	Duration and Extent
Onshore Development		
Exploration	For mobile species, avoidance of habitats because of increased noise and human presence.	Short-term, unless site selected for full development or the species is very sensitive to the presence of humans.
Construction	Disturbance or loss of habitat due to clearing and grading at the well site and along any new access roads and utility and pipeline corridors, potentially resulting in a reduced number of individual present in the area.	Long-term habitat loss within the facility and access road footprints, short-term and/or long-term within pipeline and utility corridors. Short- or long-term reduction in numbers, depending on habitat requirements of the species in the area.
	Avoidance of habitats because of construction noise and activity.	Short-term, until construction activities are completed.
	Establishment of invasive, non-native vegetation in areas disturbed by clearing and grading activities, thereby reducing the quality of important habitat or directly competing with the listed plant species.	Long-term if invasive vegetation becomes established and reduces habitat quality or directly competes with listed vegetation.
	Fragmentation of habitat from siting of wellhead; storage and processing facilities; and pipeline, access road, and utility corridor.	Long-term. Extent dependent on quality and areal extent of habitats that would be fragmented.
Operation	Wildlife species in nearby habitats may be disturbed by noise and human activities.	Long- or short-term depending on sensitivity of disturbed species.
Accidental Spill or Release	Exposure of species and their habitats to accidental releases of oil or drilling wastes during exploratory drilling, potentially affecting the growth, survival, and reproduction of exposed species and also habitat quality.	Short-term, pending rapid release containment and site cleanup. Potential long-term effects depending on cleanup effectiveness. Duration and magnitude of effects would depend on the toxicity of the released materials, the species and life stage exposed, the magnitude and duration of the release, and the condition and quality of affected habitats and biota. Potential population-level effects.

TABLE 6.8 (Cont.)

Development Phase	Nature and Cause	Duration and Extent
Offshore Development		
Exploration	Avoidance of habitats because of increased noise and human presence.	Short-term, unless site selected for full development or the species is very sensitive to the presence of humans.
Construction	Disturbance or loss of habitat from onshore clearing and grading at pipeline landfall, storage and processing facility, access road, and utility corridor locations, potentially resulting in reduced number of individuals present.	Long-term habitat loss within facility and access road footprints, short-term and/or long-term within pipeline and utility corridors. Short- or long-term reductions in numbers, depending on the habitat requirements of species in the area.
	Disturbance of nearby habitats from altered surface and subsurface hydrology and increased sedimentation during onshore construction activities.	Long- and/or short-term, depending on the types of habitats affected.
	Avoidance of area habitats because of construction noise and activity.	Short-term until construction activities are completed.
	Establishment of invasive, non-native vegetation in areas disturbed by clearing and grading of onshore facility locations, thereby reducing the quality of important habitat or directly competing with the listed plant species.	Long-term if invasive vegetation becomes established and reduces habitat quality or directly competes with listed vegetation.
	Fragmentation of habitat from siting of wellhead; storage and processing facilities; and pipeline, access road, and utility corridor.	Long-term. Extent dependent on quality and areal extent of habitats that would be fragmented.
Operation	No adverse effects expected. Offshore platforms extending above the lake surface could provide rest sites for listed bird species migrating across open waters of the lakes.	No adverse effects expected. Long-term rest sites until platform is removed.
Accidental Spill or Release	Exposure of shoreline habitats and species utilizing those habitats to accidental releases of oil or drilling wastes during exploratory drilling, thereby affecting survival, growth, and reproduction of exposed species and reducing habitat quality in the immediate area of the release.	Short-term, pending rapid release containment and site cleanup. Potential long-term effects, depending on cleanup effectiveness. Duration and magnitude of effects would depend on toxicity of the released materials, the species and life stage exposed, the magnitude and duration of the release, and the condition and quality of affected habitats and biota. Potential population-level effects.

[a] Assumes compliance with ESA and similar state regulations, restrictions, and requirements.

invasive vegetation becomes established in construction areas, spreads to adjacent habitats, and competes directly with listed plant species. Because of the protection afforded to Federal species by the ESA, and to state-listed species by state-specific species protection regulations and oil and gas permit stipulations and siting requirements, most of the effects identified in Table 6.8 may be considered very unlikely, although impacts that may occur can have very serious consequences for the affected species. Any proposals for oil or gas development in areas supporting ESA-listed species would undergo extensive review by the USFWS (and likely by appropriate state agencies) before any approval to proceed with exploration would be granted. Proposed development in areas containing threatened or endangered species or in areas where such species could be adversely affected would not be expected to be approved.

6.4 POTENTIAL EFFECTS ON CULTURAL RESOURCES

The determination of effects on cultural resources must be handled at the project-specific level. There is no meaningful way to quantitatively characterize, across such a large region as the Great Lakes, the probability of an oil or gas development encountering cultural resources. However, the likelihood would be rather high on the basis of the current numbers of recorded sites provided in Table 5.9 (Section 5.4.3) for coastal counties along the Great Lakes and the large numbers of shipwrecks. The types of cultural resources that could be present in the vicinity of a development site are described in Section 5.4. Literature searches and field surveys would likely be necessary to determine the presence or absence of cultural resources (i.e., archaeological sites, historic structures and features, including shipwrecks, and traditional cultural properties). Consultations with the appropriate SHPO and government-to-government consultations with affected Tribal governments would also be required under the NHPA, as amended, to assess the significance of resources present and the potential for adverse effects on those resources that have been determined to be significant.

Impacts on cultural resources would be associated with well installation during exploration and construction and with the construction of the well pad, pipelines, storage and processing facilities, access roads, and utility corridors (Table 6.9). In addition, accidental spills or releases could contaminate some resources, affecting the chemical or physical condition of the resource, as well as potentially affecting future analysis and characterization of the resource. In the event of an accidental spill or release, cultural resources could also be affected during spill containment and cleanup. The nature and duration of effects related to accidental spills and releases would depend on the extent of the release, the nature of the resource affected, and the type of activity that would be required to contain and clean the release.

Potentially adverse effects could occur if significant cultural resources are present in a given project area, whether it is located onshore or offshore. Coastal regions have been heavily utilized by different cultures throughout history, and therefore the potential for sites to occur in a given project area is relatively high. Ground disturbance, such as grading, excavating, or trenching, would have the most obvious and direct effect if an archaeological site or traditional cultural property is present in the area to be disturbed. These sites would be destroyed during the proposed activity. For historic buildings or sites with structural remains, the direct effect would be demolition and removal.

TABLE 6.9 Potential Effects on Cultural Resources from the Development of Oil and Gas Resources Located beneath the Great Lakes

Development Phase	Nature and Cause	Duration and Extent
Onshore Development		
Exploration	Destruction of artifacts or sites during drilling of exploratory wells.	Permanent, long-term. Likelihood of encountering artifacts unknown.
	Trampling of surface and subsurface artifacts and sites by vehicle and foot traffic during seismic surveys and exploratory drilling.	Short- or long-term, depending on nature of the resource.
	Identification of previously unknown resources.	Permanent, long-term.
Construction	Destruction of artifacts or sites during construction of drill pad, pipelines, access roads, and utility corridors, and during well completion.	Permanent, long-term.
	Trampling of surface and subsurface artifacts and sites by construction vehicles and foot traffic.	Short- or long-term, depending on the nature of the resource.
	Disturbance or loss of artifacts and sites from increased erosion because of altered surface hydrology.	Long-term.
	Visual disturbance of sacred locations; visual disturbance of overall cultural setting of a significant cultural resource (such as a historic home).	Short-term for impacts related to construction equipment.
	Interference with access to sacred sites.	Short- or long-term.
	Identification of previously unknown resources.	Permanent, long-term.
Operation	Visual disturbance of sacred locations; visual disturbance of overall cultural setting of a significant cultural resource (such as a historic home).	Long-term.
	Interference with access to sacred sites.	Short- or long-term.
Accidental Spill or Release	Exposure of resources from accidental oil release due to well blowout or pipeline leak, or release of extraction and processing wastes.	May alter the physical or chemical characteristics of the affected resource, potentially affecting future characterization. Spill containment and cleanup may also result in loss of some resources.
	Interference with access to sacred sites.	Short- or long-term.

TABLE 6.9 (Cont.)

Development Phase	Nature and Cause	Duration and Extent
Offshore Development		
Exploration	Destruction of artifacts or sites during drilling of exploratory wells.	Permanent, long-term.
	Identification of previously unknown resources.	Permanent, long-term.
Construction	Destruction of offshore and/or offshore artifacts or sites during construction of drill pad, pipelines, access roads, and utility corridors, and during well completion.	Permanent, long-term.
	Trampling of surface and subsurface artifacts and sites at onshore construction locations by vehicle and foot traffic.	Short- or long-term, depending on the nature of the resource.
	Disturbance or loss of artifacts and sites from increased erosion because of altered surface hydrology at onshore construction areas.	Long-term.
	Interference with access to sacred sites.	Short- or long-term.
	Identification of previously unknown resources.	Permanent, long-term.
Operation	Interference with access to sacred sites.	Short- or long-term.
Accidental Spill or Release	Exposure of resources from accidental oil release due to well blowout or pipeline leak, or release of extraction and processing wastes.	May alter the physical or chemical characteristics of the affected resource, potentially affecting future characterization. Spill containment and cleanup may also result in loss of some resources.
	Interference with access to sacred sites.	Short- or long-term.

For archaeological sites and traditional cultural properties in the vicinity of the directly disturbed area, other general, construction-related issues must be considered at the site-specific level. For example:

- Changing drainage patterns could cause erosion, thereby displacing artifacts and damaging the nearby site(s);

- Staging areas for equipment and supplies, as well as traffic lanes and parking areas, may compact a site(s), thus destroying and/or displacing artifacts or significant resources such as plants; more damage is likely if the area becomes wet and vehicles and equipment further disturb the surface (e.g., creating ruts

and depressions that could further displace artifacts and destroy possible features or other significant resources); and

- Pedestrian traffic and presence also could affect a surface archaeological site and increase the potential for collection of artifacts or vandalism (either illicit or unintentional).

The general placement of a project may affect a Tribal member's ability to access or view an important or sacred location. Additional visual impacts are possible if the project is in view of a significant cultural resource, such as a historic home, whereby the project affects the overall cultural setting.

Offshore development impacts could include physical damage to underwater archaeological resources, such as shipwrecks. These impacts would most likely occur during exploration or construction. Impacts to known resources can likely be avoided; however, there is a great potential for encountering unidentified and unrecorded underwater resources. Few underwater archeological surveys have been conducted, and, depending on the depth and location (and even weather conditions), surveys can be difficult and expensive to conduct. These unrecorded resources are likely to be the most susceptible to impact (see discussion that follows on unexpected discoveries).

For areas where no significant cultural resources have been identified through survey and appropriate consultations, there is a significant potential for encountering unexpected buried material (such as an unmarked human burial) either onshore or offshore during construction. In these instances of unexpected discovery, work should be halted immediately and the appropriate persons notified (e.g., SHPO or Tribal Preservation Officer), so that mitigative actions can be implemented. Workers should also be trained that if there is any doubt about whether an item is a cultural resource, it should be treated as if it is, and the appropriate persons should be notified. This practice is very important, since most individuals would not necessarily recognize, for example, debris from a fragmentary shipwreck.

Impacts on cultural resources associated with a spill would most likely occur as a result of cleanup operations, rather than from the spill itself. Several spill-specific and site-specific factors would determine the extent of the impacts (size of spill, type of equipment, number of people on cleanup crew, and proximity to cultural resource). The impacts would generally be the same as those described for construction, but without the ability to mitigate the impacts beforehand. In general, the appropriate persons should be immediately notified (as in unexpected discoveries), to determine if some mitigation measures can be employed without delaying cleanup efforts and to determine what course of action can be taken to recover data from an affected cultural resource.

Accidental spills or releases may also affect the chemical or physical condition of an artifact, potentially resulting in permanent damage or even loss of the artifact. Contamination in soils associated with an artifact or site could also affect some techniques used for characterizing the site, such as pollen grain analysis.

Mitigation of the potential direct effects of construction activities is possible, with avoidance of impacts being the preferred option. Impacts on archaeological sites and historic buildings and features can be mitigated through data recovery (either full or partial) as a least-preferred option. Mitigation of indirect effects can encompass a multitude of options, including avoidance (again preferred), erosion controls, fencing, training, monitoring, etc. Mitigation for impacts of concern to Native Americans would have to be addressed during government-to-government consultations.

6.5 POTENTIAL EFFECTS ON LAND AND WATER USE

6.5.1 Potential Effects on Land Use

Land use may be affected by (1) the conversion of land from a nonindustrial to an industrial use, (2) the disturbance of some land uses on adjacent lands by noise, air emissions, and the presence of equipment during construction and operation activities, and (3) an accidental spill or release that may prevent a designated land use on adjacent lands until containment and cleanup are completed. The magnitude and importance of any potential effect would depend on the existing use of the affected area and on the basis for the effects (i.e., land conversion).

Figure 6.5 Aerial View of Rattlesnake Canyon Habitat Management Area, New Mexico, Showing Well Pads and Access Roads

The installation of a production and storage facility and its associated infrastructure (disposal pits, pipeline, access road, and utility corridor) would likely require a change to an industrial use from some other use, such as timber production or agriculture. This would result in a relatively small but permanent change in land use at a local scale. However, aggressive oil and gas development may result in a mosaic of production facilities that could conflict with existing or planned land use in surrounding areas (Figure 6.5).

6.5.1.1 Recreational Land Use

The coastal and nearshore portions of the Great Lakes where oil and gas development may be possible contain a number of recreational areas, including four national lakeshores, two national parks, numerous state parks, and other tourist destinations (see Section 5.5.1). Visual impacts affecting recreational lands may occur during exploration, construction and operation, and waste storage. The presence of exploration and construction equipment, as well as a well pad and/or pipeline, can detract from the visual setting of certain “pristine” areas enjoyed for their natural state (Figure 6.6) and also high-use public areas such as beaches or resorts. The visual

impacts may be temporary (if associated with exploration or construction equipment, or with equipment associated with spill cleanup) or long term (associated with the presence of a well and pipeline), remaining for the duration of the well operating period (which may be 20 or more years). Noise generated during all phases of oil and gas development could disturb recreational users of nearby areas, decreasing the quality of their recreational experience. Other possible impacts on recreational land use could include placement of wellheads or platforms in areas of future recreational use, thereby limiting the full recreational potential of an area (e.g., preventing trail expansion).

Figure 6.6 Example of a Typical Producing Well Site in West Virginia (Source: Coleman 2005)

Many states have permit requirements that specify minimum locations of wells to recreation areas, specifically to address concerns regarding recreational land use impacts. These requirements act to minimize the likelihood or magnitude of impacts to recreational land use. For example, Michigan requires well sites to be sited so they are not visible from recreational beaches.

Accidental spills or releases have the greatest potential for affecting recreational land use. Onshore and offshore spills may affect the recreation experience by:

- Restricting use of the area affected by the release (e.g., closure of a beach or fishing area);
- Producing a visual intrusion (by the spill and associated containment and cleanup equipment); or
- Indirectly affecting wildlife or habitats that are targets of a recreational fishery or hunting.

Such effects may be short- or long-term in nature, depending on the site of the spill or release and the duration of subsequent cleanup.

6.5.1.2 Residential Land Use

Impacts on residential land use may also be visual in nature, even where individual private residences would not be directly affected by the well construction or operation. Residential areas may also be affected by noise and air emissions generated during construction and by operating wells and processing equipment. The presence of operating oil or gas wells and pipelines may reduce the desirability of nearby existing residential areas, as well as inhibiting the development of additional residential development, especially in expanding urban areas. Many

states have permit stipulations regarding how close to a residential area an oil or gas well may be located. Such state-specific requirements will act to reduce the likelihood or magnitude of impacts to residential land use.

6.5.1.3 Industrial Land Use

Because of the industrial nature of an oil or gas development, industrial land use is not expected to be affected by such a development. However, in the event of an accidental spill or release, some industrial activities may be affected. For example, an offshore spill may close a portion of a harbor to commercial ship traffic or an industrial water intake while the spill is contained and during cleanup. Similarly, should bottom sediments become contaminated, shipping activities may need to be halted while dredging occurs.

6.5.1.4 Agricultural and Forest Production Land Use

Impacts on agricultural land use are anticipated to be minimal because the amount of land that could be potentially taken out of future use by a well and its associated facilities would be relatively small in comparison with the overall amount of land acreage available and in use within the Basin for agricultural production. On a local scale, however, the establishment of a concentrated oil or gas development (such as that shown in Figure 6.5) may result in a relatively large loss of agricultural land. Placement of oil and gas wells and infrastructure may also interfere with continuity of fields, harvesting, or grazing. If construction of a well site and associated infrastructure (pipelines, access roads, and utility corridors) results in a local change in surface water and groundwater hydrologic regimes, agricultural production may be affected. An accidental spill or release may also affect agricultural production, especially if the spill or release contaminates area soils or an irrigation or livestock watering source.

Impacts on forest lands may also be relatively small for individual wells, while concentrated development sites may locally result in a relatively large loss of forest land. The presence of pipelines, access roads, and utility corridors may also fragment forest lands, affecting harvesting efficiency and forest tree species composition, while changes in hydrology and surface erosion may adversely affect forest production.

6.5.2 Potential Effects on Water Use

The primary affects on water use from onshore and offshore oil and gas development would be associated with (1) poor siting of offshore well platforms and pipelines that may interfere with recreational boating, fishing, and sport diving on shipwrecks, or with industrial shipping corridors; (2) accidental spills or releases that may prevent the withdrawal of water for public drinking water supplies, irrigation and livestock watering, manufacturing and industrial needs, or energy production; and (3) direct use of surface waters for recreational activities. Impacts associated with potentially poor siting may be long term. Impacts associated with spills may be short or long term, depending on the nature of the spill or release, its proximity to a water

intake structure, and the amount of time needed to contain and clean up the spill. Spills could disrupt public drinking water supplies as well as irrigation water; loss of use would depend on the materials released and the effectiveness of the spill cleanup. Because these waters would be used for human consumption or food production, much more stringent cleanup levels would likely be necessary before water use could be reestablished. In contrast, manufacturing and energy production may be less sensitive to water quality, and thus may not be affected for as long a time period.

Placement of offshore wells and pipelines may result in local restrictions on boating and fishing in the immediate vicinity of the well site, especially during drilling and construction. Such restrictions would be short term and would generally end with completion of well and pipeline construction. Burial of pipelines and wellhead protection measures should greatly relieve or eliminate the potential for collisions with watercraft. While anchoring restrictions along submerged pipelines may affect use of these areas for some fishing, the overall impact would depend on whether recreational fishing occurred along the pipeline route prior to its construction. Overall effects of such anchoring restrictions may be considered minor. Recreational water use, similar to recreational land use, may experience long-term effects from accidental spills. Spills may affect swimming and fishing areas and contaminate local fisheries. The duration and magnitude of such effects would depend on the nature and magnitude of the spill and the effectiveness of subsequent containment and cleanup.

The nature and extent of impacts to water use from accidental spills will depend not only on the magnitude of a spill, but also its location. For example, some areas of the Great Lakes, such as the northern portion of Lake Michigan (especially along the Michigan coastline), do not support any major urban industrial or energy-producing centers or facilities. However, this portion of the lake supports a strong recreation and tourism economy, with numerous small towns and resort areas throughout the coastal areas, many of which may rely more heavily on groundwater for drinking water supplies. In addition, inland areas support agriculture and forestry. Thus, water use for agriculture and recreation may be most affected by an accidental spill or release.

In contrast, other areas, such as the central and eastern basins of Lake Erie include major urban and industrial centers (e.g., Cleveland and Buffalo), numerous coal-fired and hydroelectric power plants, a nuclear power plant, and agricultural lands. Many of these rely heavily on water withdrawn from Lake Erie. While recreational water use may not be as predominant as in other areas of the Great Lakes, recreational boating is often strong in the vicinity of major urban centers. Thus, all water uses in these basins of Lake Erie could be affected by accidental spills or releases. In addition, an accidental spill or release in such an area has the potential to affect more users because of the high population densities of urban centers compared with more rural areas of the basin.

6.5.3 Potential Effects on Economically Important Zones

Potential effects of oil and gas development on economically important zones of the Great Lakes would be primarily associated with accidental oil spills or releases that would affect

normal economic activities, such as shipping, manufacturing, or tourism. Along the northwestern shore of the lower peninsula of Michigan is an area that supports an extensive recreation and tourism economy. Tourism and recreation in such areas as Sleeping Bear Dunes National Lakeshore, Grand Traverse Bay, Petoskey, and the Mackinaw Straits could be affected by offshore oil spills. In the event of a spill, short- or long-term impacts on the economies of these areas could be incurred, depending on the magnitude of the spill and how quickly and effectively the spill is contained and cleaned up. Because an offshore spill would be more visible, more difficult to contain, and could affect highly visible beaches and dunes, spills from offshore wells and pipelines may be expected to have a greater potential effect than spills at onshore locations. Similar effects on tourism and recreation could be incurred on the upper coast of Lake Huron as well as along the lower peninsula of Michigan. No major ports or industrial centers are located along the northern coast of Michigan.

All three basins of Lake Erie support a wide range of economies. The western basin includes the major ports of Detroit and Monroe in Michigan, and Toledo, Ohio. The central basin includes the major ports of Lorain, Cleveland, Ashtabula, and Conneaut in Ohio, and Erie in Pennsylvania, while the eastern basin includes Buffalo, New York. In addition, Cleveland and Buffalo represent major industrial and manufacturing centers. While the construction and operation of onshore or offshore oil and gas wells in the vicinity of these areas is not expected to affect shipping and manufacturing, oil spills in these areas could result in short- or long-term impacts on the various economic activities in the lake. However, directional onshore wells or offshore wells may be expected to largely target natural gas rather than oil, and accidental releases of natural gas would likely result in only short-term, localized, and minor disruptions to the shipping, manufacturing, or industrial economies of the lake. Shipping and water withdrawals for manufacturing and industry use would likely not be affected by accidental gas releases.

While Lake Erie supports both recreation and tourism economies in all, the major recreation and tourism zones in Lake Erie are associated with the islands near Sandusky, Ohio, in the western basin of the lake and Presque Isle at Erie, Pennsylvania. While accidental releases of natural gas may be expected to result in only short-term, very localized, and minor disruptions to the recreational and tourism economies in many areas of the lake, releases or spills in these major recreation and tourism areas may result in major impacts on the economics of the islands and surrounding areas.

6.6 POTENTIAL INTERACTIONS WITH CONTAMINATED AREAS

Development of oil and gas resources beneath the Great Lakes may interact with existing areas of contamination within the lakes, primarily through the disturbance and mobilization of contaminated sediments or soils during well and pipeline construction. Depending on the placement of wells and the routes selected for any associated pipelines, some locations may overlie contaminated sites that are currently present in the lakes.

Many contaminated sites within the Great Lakes are located in AOCs, which are designated severely degraded geographic areas within the Great Lakes Basin (GLIN 2005a). The

U.S. and Canadian governments have identified 43 such areas, 26 of which are in U.S. waters (see Section 5.6.1). Most of the AOCs are near the mouths of tributaries where cities and industries are located (Figure 5.17). 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 from upstream sources. Nearly all the AOCs have contaminated sediments (EPA and Government of Canada 1995). There are seventeen AOCs in areas of the Great Lakes where oil and gas development may be feasible (northern Lake Michigan, and Lakes Huron and Erie) (Figure 5.22).

Potential interactions with contaminated sites could occur if oil and gas development is carried out within the AOCs that have not yet been delisted. The Ashtabula River AOC is one such example. The Ashtabula River lies in northeast Ohio, flowing into Lake Erie's central basin at the City of Ashtabula. Its drainage basin covers an area of 137 mi^2 (355 km^2), with 8.9 mi^2 (23.0 $km^{2)}$ in western Pennsylvania. From the 1940s through the late 1970s, unregulated discharges and mismanagement of hazardous waste caused the river's sediments to become seriously contaminated and degraded its biological communities. Regular dredging is being prevented because of the contaminated sediments, seriously impeding both commercial and recreational navigation. Since 1983, a fish consumption advisory has been posted for the AOC. Environmental problems have been caused by sedimentation, cultural eutrophication (nutrients), toxic substances (PCBs, heavy metals, and chlorinated organic compounds), and habitat modification (marina construction and commercial shipping). Sources for these contaminants include bottom sediments, municipal and industrial discharges, commercial development, hazardous waste disposal sites, CSOs, Fields Brook discharge, coal handling facilities, and rail yards.

Contaminated sediments within an AOC would be disturbed by exploratory drilling, well installation, and lake-bottom pipeline construction if the drilling and pipeline locations occur within the AOC boundaries. The disturbed sediments could be mobilized and transported by lake currents or wave action to other locations, potentially including shoreline areas. However, it is unlikely that exploration or well development would be permitted in such areas.

6.7 POTENTIAL HUMAN HEALTH EFFECTS OF ACCIDENTAL RELEASES

Considerable public controversy has arisen over potential environmental and safety risks from U.S. and Canadian offshore and directional oil and natural gas drilling in the Great Lakes. To date, there have been few reported problems (IJC 2002). Nevertheless, some believe that the risks involved in allowing oil and gas exploration companies to conduct directional drilling beneath the Great Lakes outweigh the benefits that would accrue to the public (Jenson 1998).

Two issues that state environmentalists and lakeshore property owners have been extremely concerned about relate to accidental releases (Jenson 1998). The first issue concerns whether anyone can be absolutely sure that a break in an underground pipeline or a crack in rock formations, causing oil or natural gas to seep into the lakes, would not cause irreparable damage. The second issue arises from having wellheads located so close to the Great Lakes; with the

shoreline as a focal point of recreation and tourism, there is a fear that accidental release of H_2S ("sour gas") or other gases may cause large-scale accidents (Jenson 1998).

In 1997, Governor John Engler requested that the MESB conduct an evaluation of the state's regulatory procedures pertaining to directional drilling under the Great Lakes. The panel concluded from a review of available data that there is little to no risk of contamination to the Great Lakes bottom or waters through releases directly above the bottom-hole portion of directionally drilled wells into Niagaran Reef and deeper reservoirs (MESB 1997). They also concluded, however, that there is a small risk of contamination at the wellhead. On the basis of the panel's finding that there exists a greater risk for potential impacts to the shoreline environments where the wellhead and its associated infrastructure are located than to the aquatic environment of the Great Lakes, the panel identified two areas of potential environmental concerns — ecological and social-aesthetic — that could be associated with, and consequently in conflict with, directional drilling on the Great Lakes' shoreline.

The MESB (1997) report defined the social-aesthetic impacts to include "quality of life" parameters, such as noise, odors, congestion, vistas, recreation, and tourism, which may affect physical and mental health, at least indirectly. Although the MESB panel did not focus on specific human health effects from accidental releases, there are still some concerns that may arise from directional drilling, including explosions, leaks, air quality, and seismic activity.

The final programmatic environmental impact statement (PEIS) for the development of Lake Erie natural gas resources modeled four accident scenarios for offshore gas development (USACE 1982). This study found that releases of petroleum-related hydrocarbons, raw natural gas, and polyethylene glycol could occur during accidents. The postulated accidents that could produce these releases were (1) loss of well control, (2) rig or barge capsizing, (3) gas-line breakage, and (4) glycol-line breakage (USACE 1982). The report concluded that occurrence of these accidents would be highly unlikely. Furthermore, the potential health risk associated with accidental release of di- or triethylene glycols, associated with trihalomethanes that may be formed during chlorination of a public drinking water supply, would not exceed the primary drinking water standards (USACE 1982).

The Lake Erie PEIS concludes that an accidental gaseous release from an explosion and fire at a gas treatment plant or from the rupture of an 8-in. (20-cm) gas flow line could have a potentially deleterious effect on the general public because of combustion products (USACE 1982). Although the specific impact of this type of event was not quantitatively assessed, it was expected that it would require residents to be evacuated.

In the absence of wind or rain, the rupture of an 8-in. flow (20-cm) line carrying H_2S gas would also require the evacuation of all people within 1,640 ft (500 m) of the break to avoid the toxic effects of the gas (USACE 1982). In addition, a larger area would probably be voluntarily evacuated by anyone in the area, to avoid the unpleasant smell of H_2S gas.

The extraction process raises significant concerns over public and occupational health and safety (Smith et al. 2002). Well blowouts are rare but can be quite serious. When the drill encounters an unusually pressurized zone or when equipment is removed from the hole, the

pressure exerted by the formation may rise to levels considerably higher than those exerted by the drilling or work-over fluid, causing such fluid to rise uncontrollably to the surface. Blowouts can completely destroy rigs and kill nearby workers. Likewise, explosions and leaks are known to have occurred in pipelines that transport fossil fuels (Smith et al. 2002).

Hydrogen sulfide, which may be released during the drilling process, is a highly toxic gas that can pose serious human health risks if present at sufficient concentrations (Smith et al. 2002). At a 1997 convention of the American Public Health Association, a number of scientists presented information about the dangers of "sour gas" exposure, which range from depression and extreme fatigue, to memory loss, brain damage, and death (Smith et al. 2002). Possible occupational exposure to H_2S for drill rig workers would also need to be monitored and mitigated. However, it should be noted that the presence and concentration of H_2S is formation-specific, that is, it is almost always spatially restricted to certain geological settings conducive to its subsurface and retention until accessed via drilling operations. These areas can be mapped by using well and seismic data with a relatively high degree of reliability

Drilling operations typically produce significant air emissions, including exhaust from diesel engines and turbines that power the drilling equipment, and from post-extraction treatment (Clark and Dutzik 2002). Pollutants from these sources are those commonly associated with combustion sources, including nitrogen oxides, particulates, ozone, and carbon monoxide. Each new well brings drilling rigs, gas compressors, generators, surface-disturbance machinery, such as earthmoving machines, and vehicular traffic (Smith et al. 2002).

Routine drilling wastes, such as drilling muds and cuttings, contain a variety of toxic chemicals that are known to be hazardous to human health (see Sections 2.2.1, 2.3, 3.4, and 3.5). If pollutants from oil and gas drilling build up in the food chain, people who consume fish from the Great Lakes could be at risk of health problems such as genetic defects and cancer. Routine discharges and accidental spills of toxic chemicals from drilling sites can also contaminate the water of Lake Erie, thus contaminating a primary drinking water source for millions of people (Clark 2003). From 2003 to 2008, the Great Lakes coastal population as a whole is expected to increase by approximately 650,000 people; the largest population increases are expected to occur in southern Michigan, Illinois, and Ohio (Crossett et al. 2004). Consequently, there is the potential for more people to be exposed to contaminants in drinking water from Lakes Michigan and Erie.

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7 SUMMARY AND CONCLUSIONS

7.1 EFFECTS OF ONSHORE AND OFFSHORE DEVELOPMENT

The Energy Policy Act of 2005 banned the issuance of Federal or State permits or leases on new oil and gas slant, directional, or offshore drilling in or under the Great Lakes. This study was conducted to identify potential environmental effects that could be uncured if such drilling were allowed in the US portion of the Great Lakes Basin. Currently, onshore oil and gas drilling and production, accessing oil and gas systems beneath the states but not beneath the Great Lake, occurs in all but two of the eight Basin states, as well as in the Canadian Province of Ontario (onshore and offshore drilling in Lake Erie). Any new onshore development of oil and gas systems beneath the Great Lakes would likely be conducted in a manner similar to what currently occurs in the Basin for other oil and gas systems, and may be expected to utilize existing infrastructure for the transport and refinement of the oil and gas extracted from beneath the Great Lakes. The primary environmental effects of accessing oil and gas systems beneath and adjacent to the Great Lakes would be associated with the following:

- The potential disturbance of ecological and/or cultural resources during exploration and the construction of the well site and its associated infrastructure;

- Exposure of biota, sensitive habitats, and areas important for tourism and recreation to accidental spills or releases; and, to a lesser extent,

- The visual and noise intrusion of oil and gas developments on areas that support recreation and tourism.

The greatest concerns are for accidental releases that may affect wetlands, unique habitats, fish, and aquatic birds. Spills may also affect recreational activities, cause consumption bans for fish and game, and affect land and water use. Impacts to these resources would also involve the loss of use while the spill is being addressed. With the exception of very large spills, impacts to land and water use for most spills may be expected to be localized and minor. However, depending on the location of a spill and the proximity of a water intake structure, short-term but significant impacts on public drinking water supplies may occur. These are the same spill-related concerns that exist for current oil and gas production activities in the Basin.

Offshore development may result in more environmental impacts and effects than onshore development because offshore wells would require both offshore and onshore infrastructure to collect and process the oil or natural gas. Thus, offshore development would involve a greater level of disturbance of both terrestrial and aquatic resources during construction. In addition, offshore spills (in open water) would be more difficult to contain and may affect a broader area (and thus more resources) than an onshore spill.

7.2 FACTORS THAT COULD LESSEN THE LIKELIHOOD AND MAGNITUDE OF POTENTIAL ENVIRONMENTAL EFFECTS

A number of factors may act to reduce or prevent some of the potential environmental effects identified for oil and gas development. For example, directional drilling (with multiple wells per drill site) would allow for a reduction in land disturbance and thus in the number of locations where habitat disturbance or an accidental spill may occur. While directional drilling sites are typically larger than any one single well site, the total combined area required for multiple well sites is larger than that required for a single directional drilling site accessing a similar number of oil or gas reservoirs. The use of directional drilling from onshore locations would eliminate the need for lake-bottom wells and offshore pipelines, thus eliminating the potential for accidental spills in offshore, open water areas.

The implementation of good engineering practices may also be expected to minimize or avoid many of the environmental effects identified for the construction phase of oil or gas development.

Existing regulations would greatly affect the siting of any wells targeting oil and gas deposits beneath the lakes, requiring avoidance of endangered species, recreational areas, drinking water supplies, wetlands, unique habitats, and other valued resources. Furthermore, existing state and Federal programs and requirements addressing spill prevention, reporting, and response would reduce the extent and magnitude of potential spills and associated environmental impacts and promote rapid containment and cleanup.

Finally, as directional drilling technology advances, it may be possible to access more oil and gas deposits than is currently possible from fewer well locations that are farther from sensitive areas. This would minimize the potential for locating wells and associated facilities in sensitive areas, and it would also limit the occurrence of accidental spills and releases to fewer locations, thereby potentially exposing fewer natural resources to spills.

7.3 UNCERTAINTIES AND DATA GAPS

The quantitative evaluation of environmental effects of onshore or offshore drilling in the Great Lakes can only be conducted at a site-specific level. This informational report provides a qualitative evaluation of the types of environmental effects that might occur within the Great Lakes Basin if the oil and gas systems beneath the lakes were explored and developed. Uncertainties associated with this qualitative evaluation are largely related to the limited information regarding the following:

- The actual abundance and distribution of oil and gas reserves beneath the US portion of the Great Lakes;
- The location of natural and cultural resources (especially underwater sites) in areas where oil and gas development may occur;

- The incidence and size of spills from current oil and gas wells and pipelines in each of the eight Great Lakes states;
- The response time of spill responders;
- The effectiveness of past spill cleanup operations, including recovery of ecological resources;
- Future advances in spill containment and cleanup procedures and methods; and
- Advances in directional drilling capabilities and technology.

The first of these uncertainties deals with the actual abundance and distribution of oil and gas reserves beneath the Great Lakes, as this will determine where oil and gas development may actually occur and which resources could be affected by the development of the reserves. The next uncertainty deals with the likelihood that well sites (and their associated infrastructure) will overlap with important ecological, cultural, and socioeconomic resources. Adverse environmental effects on these resources may be reduced as their locations are better defined and well and pipeline locations are better selected to avoid such resources to the extent possible or practicable.

The next four of these uncertainties deal with the likelihood of an accidental release occurring, how quickly the release would be contained, and how effective any cleanup would be. It can be safely assumed that as the incidence of spills decreases and the response time of responders decreases, the magnitude of any spill-related adverse effects should also decrease. The incidence of spills may decrease as drilling, pumping, storage, and transport technologies improve and as enhanced spill prevention programs and requirements are developed.

Finally, the last uncertainty deals with technological advances that would permit directional drilling to greater depths and distances from the wellhead, and in the number of wells or laterals that could originate from a single wellhead location. As technological advances are made, it may be possible to access oil and gas deposits beneath the lakes from much farther onshore locations, at locations farther removed from sensitive or valued onshore resources, and from fewer locations, thus reducing the extent and likelihood of disturbing valued resources.

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