**National Park Service**
**U.S. Department of the Interior**
**Water Resources Division**
**Fort Collins, Colorado**

# Assessment of Coastal Water Resources And Watershed Conditions at Pictured Rocks National Lakeshore

Technical Report NPS/NRWRD/NRTR-2006/361

**Cover photos:**
**Upper left, Arch at Chapel Rock**
**Upper right, AuSable Lighthouse**
**Lower left, Chapel Creek**
**Lower right, Legion Lake Bog**
**Photographs by Kristen Keteles**

# Assessment of Coastal Water Resources and Watershed Conditions at Pictured Rocks National Lakeshore

Technical Report NPS/NRWRD/NRTR-2006/361

Christine Mechenich
Center for Watershed Science and Education
College of Natural Resources
University of Wisconsin –Stevens Point
Stevens Point, WI 54481

George J. Kraft
Center for Watershed Science and Education
College of Natural Resources
University of Wisconsin –Stevens Point
Stevens Point, WI 54481

Stanley W. Szczytko
Center for Watershed Science and Education
College of Natural Resources
University of Wisconsin –Stevens Point
Stevens Point, WI 54481

David J. Mechenich
Center for Watershed Science and Education
College of Natural Resources
University of Wisconsin –Stevens Point
Stevens Point, WI 54481

This report was prepared under Task Order J238005086 of the Great Lakes Northern Forest Cooperative Ecosystems Studies Unit (agreement H6000C02000).

U.S. Department of the Interior
National Park Service

**Water Resources Division**
**Natural Resource Program Center**
1201 Oak Ridge Dr.
Fort Collins, CO  80525

The Natural Resource Publication series addresses natural resource topics that are of interest and applicability to a broad readership in the National Park Service and to others in the management of natural resources, including the scientific community, the public, and the NPS conservation and environmental constituencies. Manuscripts are peer-reviewed to ensure that the information is scientifically credible, technically accurate, appropriately written for the audience, and is designed and published in a professional manner.

The Natural Resource Technical Reports series is used to disseminate the peer-reviewed results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service's mission. The reports provide contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations. Current examples of such reports include the results of research that addresses natural resource management issues; natural resource inventory and monitoring activities; resource assessment reports; scientific literature reviews; and peer reviewed proceedings of technical workshops, conferences, or symposia.



Printed copies of reports in these series may be produced in a limited quantity and they are only available as long as the supply lasts. This report is also available from the Natural Resource Publications Management Web site (http://www.nature.nps.gov/publications/NRPM) on the Internet, or by sending a request to the address on the back cover.

Mechenich, C., G.J. Kraft, S.W. Szczytko, D.J. Mechenich. 2006. Assessment of Coastal Water Resources and Watershed Conditions at Pictured Rocks National Lakeshore, Wisconsin. Natural Resource Technical Report NPS/NRWRD/NRTR—2006/361. National Park Service, Fort Collins, Colorado.

NPS D-124, December 2006

# Contents

**Figures** 7

**Acknowledgements** 10

**Commonly Used Abbreviations** 10

**Executive Summary** 12

**Introduction and Park Description** 15
Size, Boundaries, Location, Climate, and Regional Setting 15
Key Features 15
Land Use and Vegetative Cover 20
Historic and Current Human Uses 21
Geology and Soils 24
General Hydrology and Water Budget 31

**Water Resources of Lake Superior** 34
Physical Characteristics 34
Biological Resources 35

**Water Resources of Inland Waters** 40
Physical and Chemical Characteristics 40
Biological Resources 44
Watersheds and Limnological Characteristics 47

**Assessment of Park Water Resources** 58
Sources of Pollutants 58
Surface Water Quality 72
Groundwater Quality, Quantity, and Use 82
Other Areas of Concern 87

**Conclusions** 96
Open Waters of Lake Superior 96
Inland Lakes 96
Streams 96

**Recommendations and Rationale** 99

**Works Cited** 102
Personal Communications 116

**Appendices** 118

# Figures

Figure 1. Location of Pictured Rocks National Lakeshore in the Upper Great Lakes region of the United States. 16

Figure 2. Land ownership in the shoreline zone and IBZ, Pictured Rocks National Lakeshore. 17

Figure 3. Land management and ownership in the Pictured Rocks area. 18

Figure 4. Key features and water resources of Pictured Rocks National Lakeshore. 19

Figure 5. Vegetative cover map for Pictured Rocks National Lakeshore. 22

Figure 6. IFMAP land cover for the Pictured Rocks area. 23

Figure 7. Municipal boundaries in the Pictured Rocks area. 25

Figure 8. Bedrock geology of the Pictured Rocks area. 26

Figure 9. Glacial landforms of the Pictured Rocks area. 27

Figure 10. Pleistocene and Holocene landforms in the Pictured Rocks area. 29

Figure 11. General soil association map (STATSGO) for the Pictured Rocks area. 30

Figure 12. Lake Superior bathymetry in the Pictured Rocks area. 32

Figure 13. Shoreline types for Pictured Rocks National Lakeshore. 33

Figure 14. National Wetlands Inventory for the Pictured Rocks area. 42

Figure 15. Areas of Alger County, MI where glacial deposits are the principal source of water to wells. 43

Figure 16. Watersheds for inland waters of Pictured Rocks National Lakeshore. 48

Figure 17. Sources of air emissions and locations of NPDES discharge permits in the Pictured Rocks area. 60

Figure 18. Lake Superior shipping lanes. 64

Figure 19. Shoreline sensitivity to spills classifications for Pictured Rocks National Lakeshore. 66

Figure 20. Locations of on-site waste disposal systems and vault toilets operated by Pictured Rocks National Lakeshore. 70

Figure 21. Total nitrogen for most recent sampling dates for waterbodies in the Pictured Rocks area. 77

Figure 22. Total phosphorus for most recent sampling dates for waterbodies in the Pictured Rocks area. 78

Figure 23. Alkalinity for most recent sampling dates for waterbodies in the Pictured Rocks area. 80

Figure 24. Exceedences of aquatic life and human health criteria in Pictured Rocks National Lakeshore. 81

Figure 25. Water supply wells in and near Pictured Rocks National Lakeshore. 84

Figure 26. Number of private household wells at various depths in Munising and Burt Townships near Pictured Rocks National Lakeshore. 85

Figure 27. Nitrate, VOC, and arsenic samples in the Pictured Rocks area. 86

Figure 28. Population of areas that border Pictured Rocks National Lakeshore, 1900-2003. 87

Figure 29. Numbers of visitors (in 100,000s) to Pictured Rocks National Lakeshore from 1995 to 2004. 90

## Tables

Table i. Water quality indicators and current and potential stressors of aquatic resources in Pictured Rocks National Lakeshore. 14

Table 1. NPS vegetation classifications for Pictured Rocks National Lakeshore shoreline zone and park (shoreline plus inland buffer zone). 20

Table 2. Land cover for Pictured Rocks National Lakeshore shoreline zone, park (shoreline plus inland buffer zone), and entire park watershed (shoreline plus inland buffer zone plus other lands within the Lake Superior watershed draining to the park). 21

Table 3. Soils of Pictured Rocks National Lakeshore. 28

Table 4. Lake Superior shoreline types, lengths, and USEPA shoreline sensitivity classifications. 34

Table 5. Classification of Lake Superior fisheries habitats by Lake Superior Technical Committee and U.S. Fish and Wildlife Service. 34

Table 6. Ecological roles of important Lake Superior fish species, including non-native species. 36

Table 7. Fish species and numbers identified in a survey of Lake Superior waters <9 m in depth in Pictured Rocks National Lakeshore, 2002. 37

Table 8. Selected physical, chemical, and biological characteristics of some inland lakes in Pictured Rocks National Lakeshore. 38

Table 9. Selected physical characteristics of named streams in Pictured Rocks National Lakeshore. 39

Table 10. Percentages of wetlands by National Wetlands Inventory system, subsystem, and class for Pictured Rocks National Lakeshore's shoreline zone, IBZ, and park as a whole. 41

Table 11. Sources of air emissions in Alger County, MI. 59

Table 12. Effluent characteristics for the City of Munising Wastewater Treatment Plant. 61

Table 13. Sources of water and composition of water discharges, Kimberly-Clark Corporation, (now Neenah Papers), Munising, MI. 62

Table 14. Parameters detected in wastewater, Kimberly-Clark Corporation (now Neenah Papers), Munising, MI. 62

Table 15. Routine water quality monitoring results, Kimberly-Clark Corporation (now Neenah Papers), Munising, MI. 63

Table 16. Locations of on-site waste disposal systems at Pictured Rocks National Lakeshore. 69

Table 17. Number of sampling dates for streams and inland lakes in Pictured Rocks National Lakeshore, 1949-2005. 74

Table 18. Total phosphorus, total nitrogen, nitrogen to phosphorus ratios, and most recent sampling dates for waterbodies in Pictured Rocks National Lakeshore. 76

Table 19. Total alkalinity and most recent sampling date for waterbodies in Pictured Rocks National Lakeshore. 79

Table 20. Cadmium levels and exceedences in streams, Pictured Rocks National Lakeshore. 82

Table 21. Number of people served by drinking water wells, and methods of wastewater disposal, in Pictured Rocks National Lakeshore. 83

Table 22. Activities of park visitors, Pictured Rocks National Lakeshore, July and August, 2000, and summer, 2001. 89

Table 23. Commercial harvest of Lake Superior fish from 1867-2000. 90

Table 24. Water quality indicators and current and potential stressors of aquatic resources in Pictured Rocks National Lakeshore. 97

Table 25. Crosswalk of report recommendations with the Vital Signs Monitoring program of the NPS Great Lakes Inventory and Monitoring Network. 98

## Appendices

Appendix A. Sources of data for base map and explanation of map terminology. 118

Appendix B. List of additional references. 118

Appendix C. National Wetlands Inventory classifications and acreages for Pictured Rocks National Lakeshore. 122

Appendix D. Classifications and scientific and common names of species listed in this report. 123

## Acknowledgements

We would like to thank the many people who assisted us in the preparation of this report. Many local experts provided information, including Doug Bovin, Munising City Manager; John Shauver, Munising Township Zoning Administrator; Mike Niemi, Munising Public Works Director; and Tom Moseley, LMASDHD sanitarian. MIDEQ staff were also very speedy and helpful in providing data and local information, including Laura DeGuire, Daniel Dell, Craig Fitzner, Margie Ring, Lindsey Ringuette, Carl Smith, Jeff Spencer, and especially William Taft. Ulf Gafvert of GLKN and Bruce Leutscher of PIRO provided valuable database and GIS information. Joan Elias of GLKN helped locate water quality data and information on Lake Superior habitat zones. Larry Hach and John Ochman of PIRO helped us understand IBZ oversight and the inner workings of the park's infrastructure.

Guidance and support throughout the project came from our primary contacts at NPS Water Resources Division, Mark Flora and Kristen Keteles, who also provided helpful comments to improve the draft report. Other useful review comments were provided by Jim Northup, PIRO; Barry Long, NPS Water Resources; Bill Route, GLKN; and Brenda LaFrancois and Jay Glase of the NPS Midwest Region. Our colleague Mike Hansen provided a detailed review of the Lake Superior fishery section. Finally, we would like to thank Lora Loope, PIRO aquatic ecologist, for graciously coordinating our tour of the park, providing information throughout the project, coordinating communications between us and other PIRO staff, and for her thoughtful and thorough review of our first draft.

## Commonly Used Abbreviations

| | |
|---|---|
| BP | before present |
| C | Celsius |
| CAAA | Clean Air Act Amendments |
| cm | centimeter |
| CUPPAD | Central Upper Peninsula Planning and Development Regional Commission |
| DO | dissolved oxygen |
| EPT | Ephemeroptera-Plecoptera-Trichoptera index |
| GLFC | Great Lakes Fishery Commission |
| ha | hectare |
| HC | hydrocarbons |
| IBZ | Inland Buffer Zone |
| IJC | International Joint Commission |
| kg | kilogram |
| km | kilometer |
| L | liter |
| LLC | limited liability company |
| LMASDHD | Luce-Mackinac-Alger-Schoolcraft District Health Department |
| LSBP | Lake Superior Binational Program |
| LSTC | Lake Superior Technical Committee |
| m | meter |
| $m^3 day^{-1}$ | cubic meters per day |
| $m^3 sec^{-1}$ | cubic meters per second |
| mg/L | milligram per liter (part per million) |
| mgd | million gallons per day |
| MIDEQ | Michigan Department of Environmental Quality |
| MIDNR | Michigan Department of Natural Resources |
| MNFI | Michigan Natural Features Inventory |
| NADP | National Atmospheric Deposition Program |
| NOAA | National Oceanic and Atmospheric Administration |
| $NO_x$ | nitrous oxides |

| | |
|---|---|
| NPDES | National Pollutant Discharge Elimination System |
| NPS | National Park Service |
| NWR | National Wildlife Refuge |
| PAH | polyaromatic hydrocarbon |
| PCB | polychlorinated biphenyl |
| PIRO | Pictured Rocks National Lakeshore |
| PM | particulate matter |
| TSI | Trophic State Index |
| g/L | microgram per liter (part per billion) |
| USDA NRCS | United States Department of Agriculture Natural Resources Conservation Service |
| USEPA | United States Environmental Protection Agency |
| USFWS | United States Fish and Wildlife Service |
| USGS | United States Geological Survey |
| VOC | volatile organic compound |
| WQI | Water Quality Index |

# Executive Summary

Pictured Rocks National Lakeshore (PIRO) was authorized as America's first national lakeshore by Public Law 89-668 on October 15, 1966, and it was formally established on October 6, 1972. PIRO is situated along the southern shore of Lake Superior in Alger County in Michigan's Upper Peninsula. It extends 62 kilometers (km) between Munising on the west end and Grand Marais on the east end, and is 4.8 km at its widest point. PIRO's boundary extends into Lake Superior out to 0.4 km perpendicular to shore.

The region is dominated by northern hardwood and mixed conifer forests. The average annual temperature is $5^{o}$ C, and the average annual precipitation is 85.9 centimeters (cm), 32% of which is in the form of snow during the winter months.

PIRO is unique among National Park Service (NPS) units because it includes an Inland Buffer Zone (IBZ) of 15,907 hectares (ha) owned by corporate, state, federal, and private entities. The IBZ was established to protect the watersheds of the 13,731 ha of the NPS Shoreline Zone (Fee Zone) while allowing timber harvesting and seasonal and permanent housing development that complies with local zoning regulations.

Lake Superior is the coldest, clearest, and cleanest of the Great Lakes, and 2,452 ha of its surface is included within PIRO's boundaries. The colorful 60-meter (m) sandstone cliffs that give PIRO its name rise along the Lake Superior shoreline for 19 km on PIRO's western end. East of the cliffs are 19 km of unspoiled sand and pebble beaches. At PIRO's eastern end, the Grand Sable Dunes formed as the prevailing winds reshaped ancient Lake Superior beaches. Among PIRO's significant cultural resources are several former Coast Guard facilities (the Munising Range Lights, Munising Coast Guard Station at Sand Point, Au Sable Coast Guard Station and Light, Grand Marais Coast Guard Station, and Grand Marais Harbor of Refuge) that help to preserve the area's maritime history.

PIRO has 14 named inland lakes, with surface areas ranging from 2 ha (Sevenmile Lake) to 310 ha (Beaver Lake). Four of these lakes (Section 36 Lake, Kingston Lake, and Upper and Lower Shoe Lakes) are located in the IBZ. Inland lakes are shallow, 3-6 m in depth, except for Beaver, Chapel, and Grand Sable Lakes. The water chemistry of PIRO lakes varies, but generally most can be classified as brown water, moderately productive alkaline lakes. Secchi transparency readings, a measurement of water quality and an indicator of productivity, generally range from 2-5 m.

PIRO also includes 19 named streams. Miners River is the longest and has the greatest discharge. Many first and second order low discharge streams drain directly to Lake Superior, some only seasonally. In general, PIRO streams are short and have steep gradients. Discharge is generally highest in the late spring and early summer. Beaver and Grand Sable Creeks originate in lakes, and Miners River flows through Miners Lake. A number of waterfalls are found within PIRO, including Munising, Miners, Mosquito, Little Mosquito, Bridalveil, Chapel, Spray, and Sable Falls. PIRO watersheds drain into Lake Superior, with the exception of the closed basin watersheds containing Legion, Section 36, and the Shoe Lakes, which are in the Lake Michigan drainage basin. PIRO's watersheds and their drainage patterns are determined mostly by the topography of underlying Cambrian rock and surficial Pleistocene and Holocene sediments.

PIRO is home to a number of rare plant species, including the federally threatened Pitcher's thistle (*Cirsium pitcheri*) and the state-endangered acute-leaved moonwort (*Botrychium acuminatum*). Grand Sable Dunes alone is home to ten species on Michigan Endangered Species or Species of Concern lists. Three state listed species are aquatic: autumnal water starwort (*Callitriche hermaphtroditica*), alternate-leaved water-milfoil (*Myriophyllum alterniflorum*) amd Farwell's water-milfoil (*Myriophyllum farwellii*). PIRO's mussel communities, although not listed on state or federal lists of species of concern, may become key remnant fauna within the next 10 to 15 years, as the expanding distribution of non-native zebra mussels (*Dreissena polymorpha*) leads to the extirpation of native mussels elsewhere.

Potential sources of pollution to PIRO are numerous and vary greatly in magnitude. Toxic organic contaminants, which are of particular concern in Lake Superior, may originate as air pollutants as far away as Mexico and Central America. Local sources of air pollutants are well-regulated, but the potential impact on PIRO of permitted local emissions is unknown. The pH of precipitation in Michigan's Upper Peninsula has increased somewhat since the 1980s, but acid precipitation is still a concern for those lakes with low to moderate buffering capacity.

Point sources of water pollution to Lake Superior near PIRO include the Munising municipal wastewater treatment plant and a Munising paper mill. Nonpoint sources include Great Lakes shipping activities, commercial tour boats and private boats, marinas, and stormwater discharges. Great Lakes cargo ships travel within 7 km of PIRO, and have the potential to accidentally spill cargoes or fuel, or discharge bilge water or ballast water that could contain exotic species. Munising and Grand Marais, which border PIRO on either end, discharge stormwater to the lake but are too small to be covered by USEPA stormwater regulations. Potential sources of water pollution to PIRO's inland water resources include on-site wastewater treatment systems, logging, and road building. PIRO staff oversight of development and logging activities in the IBZ has been a successful and essential method for protecting the park's inland waters.

PIRO's surface waters are generally of high quality. However, many inland waters exceed the criteria for total phosphorus for the ecoregion. Phosphorus sources are not evident on the land surface today, but may include sediment eroded from adjacent land during logging in the 1800s. Atmospheric deposition may also be increasing nitrogen levels. Only a few incidences of exceedences of human health or aquatic life criteria have been reported, and the most recent of those was in 1980. Limited groundwater sampling indicates generally good groundwater quality, although some arsenic has been detected in Alger County groundwater at levels below current drinking water quality standards.

Development and population pressures do not appear to be a major concern for PIRO at this time. Population in Michigan's Upper Peninsula is growing only slowly, and the IBZ allows for review of developments that might affect the park. The Shoe Lakes are the only lakes in the IBZ with potential for development. Visitor use is also projected to remain fairly stable over the next 10 years, although the completion of the paving of County Highway H-58 within Alger County may slightly increase park visitation and the proportion of visitors using recreational vehicles.

A number of exotic aquatic invasive species have been found in PIRO, including the sea lamprey (*Petromyzon marinus*), spiny waterflea (*Bythotrephes longimanus*), alewife (*Alosa pseudoharengus*), curly-leaf pondweed (*Potamogeton crispus*), and purple loosestrife (*Lythrum salicaria*). Others, such as the brown trout (*Salmo trutta*), splake (*Salvelinus fontinalis x namaycush*), steelhead (rainbow) trout (*Oncorhynchus mykiss*), pink salmon (*Oncorhynchus gorbuscha*), coho salmon (*Oncorhynchus kisutch*), Chinook salmon (*Oncorhynchus tshawytscha*), and rainbow smelt (*Osmerus mordax*), have been intentionally introduced. The effects of these introductions on park resources are largely unknown, but studies are beginning to address this serious issue. Purple loosestrife and curly-leaf pondweed are no longer believed to be present in PIRO.

Exotic species considered to be encroaching on PIRO include the zebra mussel, quagga mussel (*Dreissena bugensis*), Asian clam (*Corbicula fluminea*), fishhook waterflea (*Cercopagis pengoi*), Eurasian ruffe (*Gymnocephalus cernuus*), round goby (*Neogobius melanstomus*), the zooplankter Daphnia lumholtzi, the parasitic copepod Neoergasilus japonicus, Eurasian water-milfoil (*Myriophyllum spicatum*), rusty crayfish (*Orconectes rusticus*), white perch (*Morone americana*), threespine stickleback (*Gasterosteus aculeatus*), European frog-bit (*Hydrocharis morsus-ranae*), and flowering rush (*Butomus umbellatus*). Primary vectors for introducing exotic species to Lake Superior are the bilge and ballast water of commercial ships; for PIRO's inland waters, the main vector is recreational activity, including boating and bait bucket transfer. Climate change could also have major impacts on PIRO resources, both by altering the habitats that enable certain rare species to survive as well as by allowing exotic species to compete more successfully.

Other main anthropogenic threats and concerns to PIRO's surface waters include atmospheric deposition of contaminants (including acid deposition, organochlorides, and heavy metals, especially mercury), and sediment loading of streams. Lesser threats include water quality degradation from camping activities, septic systems, point source fuel emissions from boats and personal watercraft, and unsound logging and home building practices.

**Table i. Water quality indicators and current and potential stressors of aquatic resources in Pictured Rocks National Lakeshore.**

| Stressor or Environmental Indicator/Location | Lake Superior | Inland Lakes | Streams | Wetlands | Pictured Rocks escarpment | Grand Sable Dunes shoreline |
|---|---|---|---|---|---|---|
| **Water quality indicators** | | | | | | |
| Water clarity | OK | OK | OK | NA | NA | NA |
| Nutrients | PP | EP | EP | NA | NA | NA |
| Dissolved oxygen | OK | OK | OK | NA | NA | NA |
| Toxic contaminants | EP | PP | PP | PP | NA | NA |
| **Biological indicators** | | | | | | |
| Zooplankton populations | PP | OK | NA | NA | NA | NA |
| Fish consumption advisories | EP | EP (Hg) | PP (Hg) | NA | NA | NA |
| **Air quality** | | | | | | |
| Regional atmospheric deposition and air pollution | EP | EP (Hg) | PP | PP | OK | OK |
| Local air pollution sources | OK | PP | PP | PP | OK | OK |
| **Water quality** | | | | | | |
| Wastewater discharges covered by NPDES permits | OK | NA | NA | NA | NA | NA |
| Stormwater | PP | PP (PAHs) | PP (PAHs) | PP (PAHs) | NA | NA |
| Agriculture | OK | OK | OK | OK | NA | NA |
| Landfills | OK | OK | OK | OK | NA | NA |
| Septic systems | OK | OK | PP | PP | NA | NA |
| Road building | OK | PP | PP | PP | NA | NA |
| Logging | OK | PP | PP | PP | NA | NA |
| Commercial boating | PP | NA | NA | NA | PP | PP |
| Recreational boating | PP | PP | PP | NA | OK | OK |
| **Invasive species** | | | | | | |
| Ballast water discharges | PP | NA | NA | NA | NA | NA |
| Recreational boating | OK | PP | NA | NA | OK | OK |
| Bait bucket transfer | PP | PP | PP | NA | NA | NA |
| **Development and use** | | | | | | |
| Visitor use intensity | OK | PP | PP | PP | PP | PP |
| Residential development | OK | PP | PP | PP | NA | NA |
| Commercial fishery | OK | NA | NA | NA | NA | NA |
| **Global climate change** | PP | PP | PP | PP | PP | PP |

**Definitions: EP= existing problem; PP = potential problem; OK= no detectable problem**

**shaded =limited data; NA= not applicable.**

# Introduction and Park Description

### Size, Boundaries, Location, Climate, and Regional Setting

Pictured Rocks National Lakeshore (PIRO) is located along the south shore of Lake Superior in Michigan's Upper Peninsula (Figure 1). It encompasses 62 kilometers (km) of shoreline from its western gateway at the city of Munising to its eastern gateway at Grand Marais (LaFrancois and Glase 2005), and is 4.8 km wide at its widest point.

PIRO's 27,467 land hectares (ha) are divided into a "shoreline zone" and an "inland buffer zone" (IBZ) (Figure 1). The shoreline zone includes 13,731 ha of land and inland waters. Except for 8.1 ha of State of Michigan land east of Grand Sable Lake, it is federally owned. (PIRO, Lora Loope, Aquatic Ecologist, pers. comm. 2006). The shoreline zone includes inland lakes, streams, waterfalls, wetlands, and other valuable resources. It also extends 0.4 km into Lake Superior, accounting for an additional 3,954 ha of water surface.

The 15,907 ha IBZ is unique among National Park Service (NPS) areas. It was legislatively established to allow continued timber harvesting and residential use, so long as they are compatible with the preservation and recreational use of the resources that occur within the shoreline zone, and follow zoning ordinances of Munising and Burt Townships. Current landholders within the IBZ include the ForestLand Group, LLC (7,082 ha), the State of Michigan (5,630 ha), private landowners (2,462 ha), and the NPS (732 ha) (Figure 2) (NPS 2004b). Some of the IBZ is surrounded by actively managed Lake Superior State Forest (Figure 3). In this report, general references to "PIRO" or "the park" will include both the shoreline zone and the IBZ.

PIRO is located in the physiographic province called the Interior Lowlands of the United States (de Blij 1993). Thus, its landscape is influenced both by the exposed sedimentary bedrock of the Cambrian and Ordovician periods millions of years ago, and by the relatively recent glacial advances and retreats of the Pleistocene epoch. PIRO's General Management Plan names the topographic relief and associated vegetation related to the bedrock geology and glacial landforms as one of PIRO's significant features. The boundaries of the park generally follow the watershed divide created by the bedrock formations, glacial moraines, and other topographic features in the park. The shoreline zone is entirely within the Lake Superior drainage basin except for the Legion Lake area, where 166 ha are in the headwaters of the Lake Michigan drainage basin. Part of the IBZ, consisting of 1,030 ha in the area of the Shoe Lakes and Section 36 Lake, are also in the Lake Michigan drainage basin, where the IBZ boundary follows County Highway H-58. Together, these 1,196 ha make up about 4% of PIRO's total area (Figure 4).

In the Koppen climate classification system, PIRO is classified as Dfb, also known as the humid continental climate (de Blij 1993). Summers are moderately warm, winters are cold, and the climate is moist all year round. Lake Superior has a significant local effect on climate; the "lake effect" increases cloudiness and snowfall during fall and winter, keeps temperatures cooler during late spring and early summer, and warms temperatures during late fall and early winter. However, the lake effect ceases when the lake freezes over. At Munising, recorded temperatures have ranged from 39°C to -40°C (Michigan State Climatologists Office n.d.). From 1961-1990, the average maximum temperature ranged from -4°C in the coldest month, January, to 24°C in the warmest month, July, and the average annual temperature was 5.0° C (NCDC 2005). From 1950-51 to 1979-80, the average annual precipitation was 88.6 centimeters (cm), and the average seasonal snowfall was 374.4 cm (Michigan State Climatologists Office n.d.). Thirty-two percent of the total annual precipitation is in the form of snow.

### Key Features

Approximately 2,451 ha of Lake Superior surface waters are included within the boundary of PIRO. Colorful 60-meter (m) sandstone cliffs, which give PIRO its name, rise along the Lake Superior shoreline for 19 km on PIRO's western end. East of the cliffs are 19 km of unspoiled sand and pebble beaches. At PIRO's eastern end, the Grand Sable Dunes formed as the prevailing winds reshaped ancient Lake Superior beaches. PIRO's significant cultural resources include several former Coast Guard facilities (the Munising Range Lights, Munising Coast Guard Station at Sand Point, Au Sable Coast Guard Station and Light, Grand Marais Coast Guard Station, and the Grand Marais Harbor of Refuge) that help to preserve the area's maritime history (NPS 2003). The nearly 300 square km Alger Underwater Diving Preserve, administered by the Michigan Department of Natural

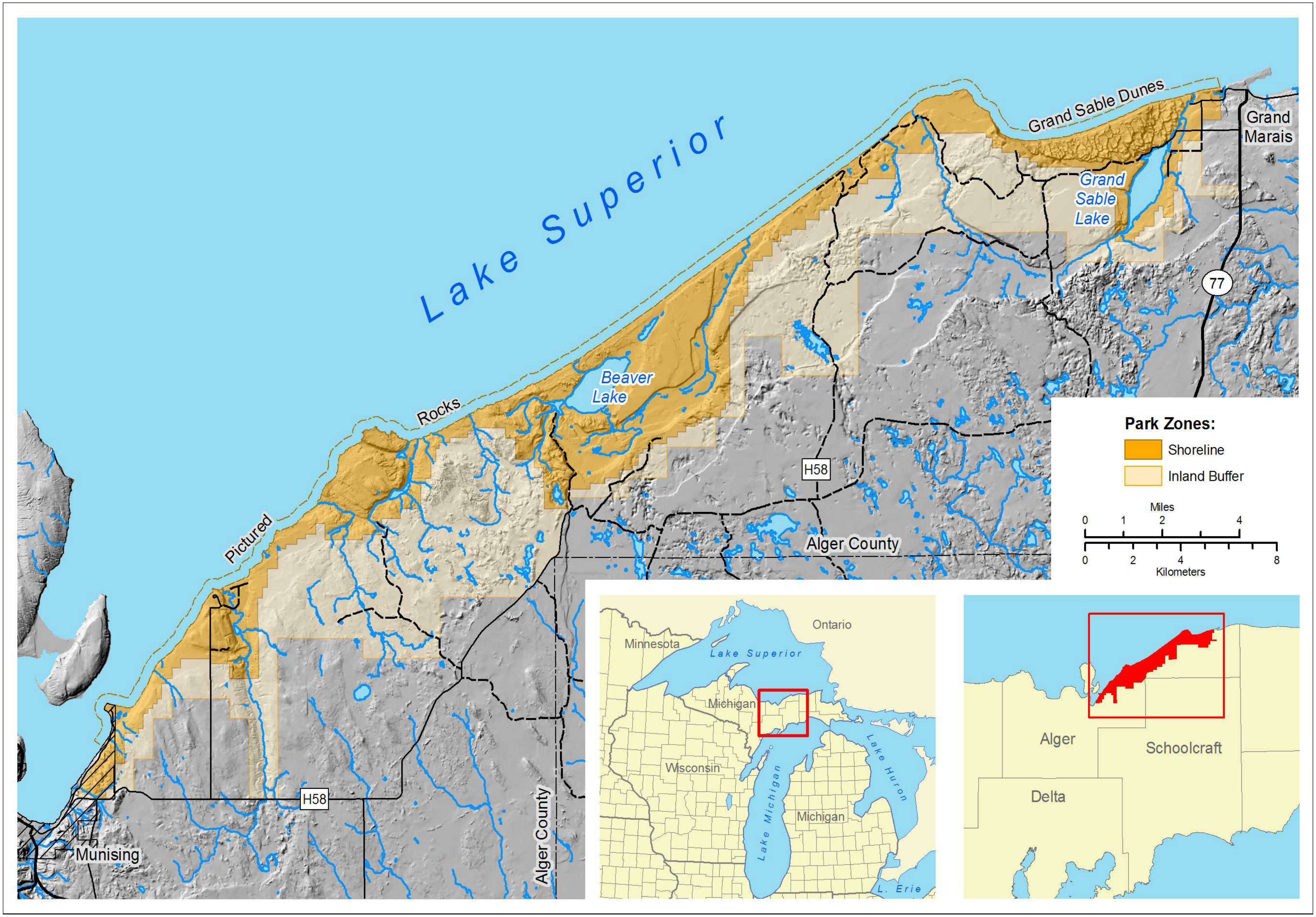


Figure 1. Location of Pictured Rocks National Lakeshore in the upper Great Lakes region of the United States.

(Source: See Appendix A)

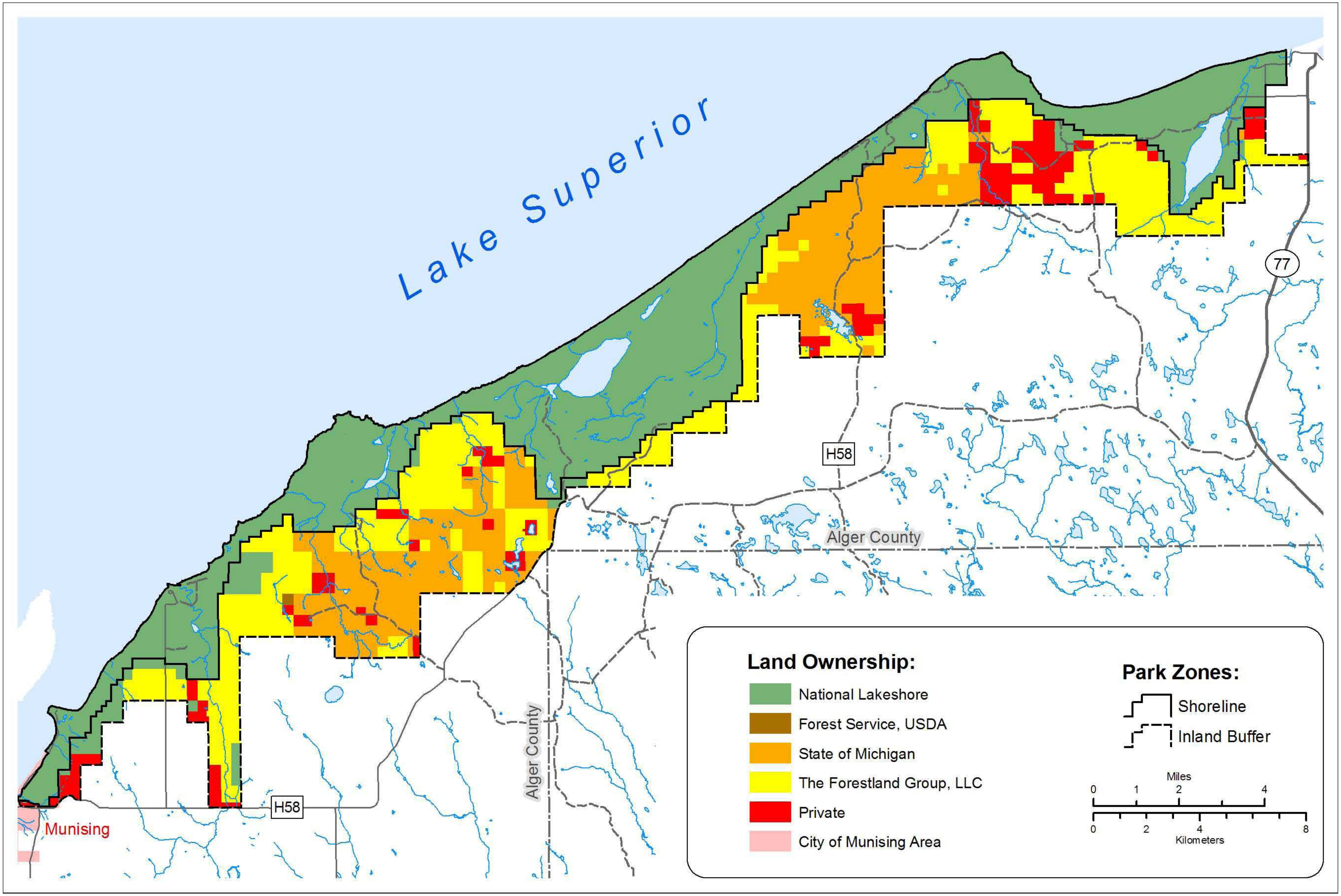


Figure 2. Land ownership in the shoreline zone and IBZ, Pictured Rocks National Lakeshore.
(Source: NPS 2006)

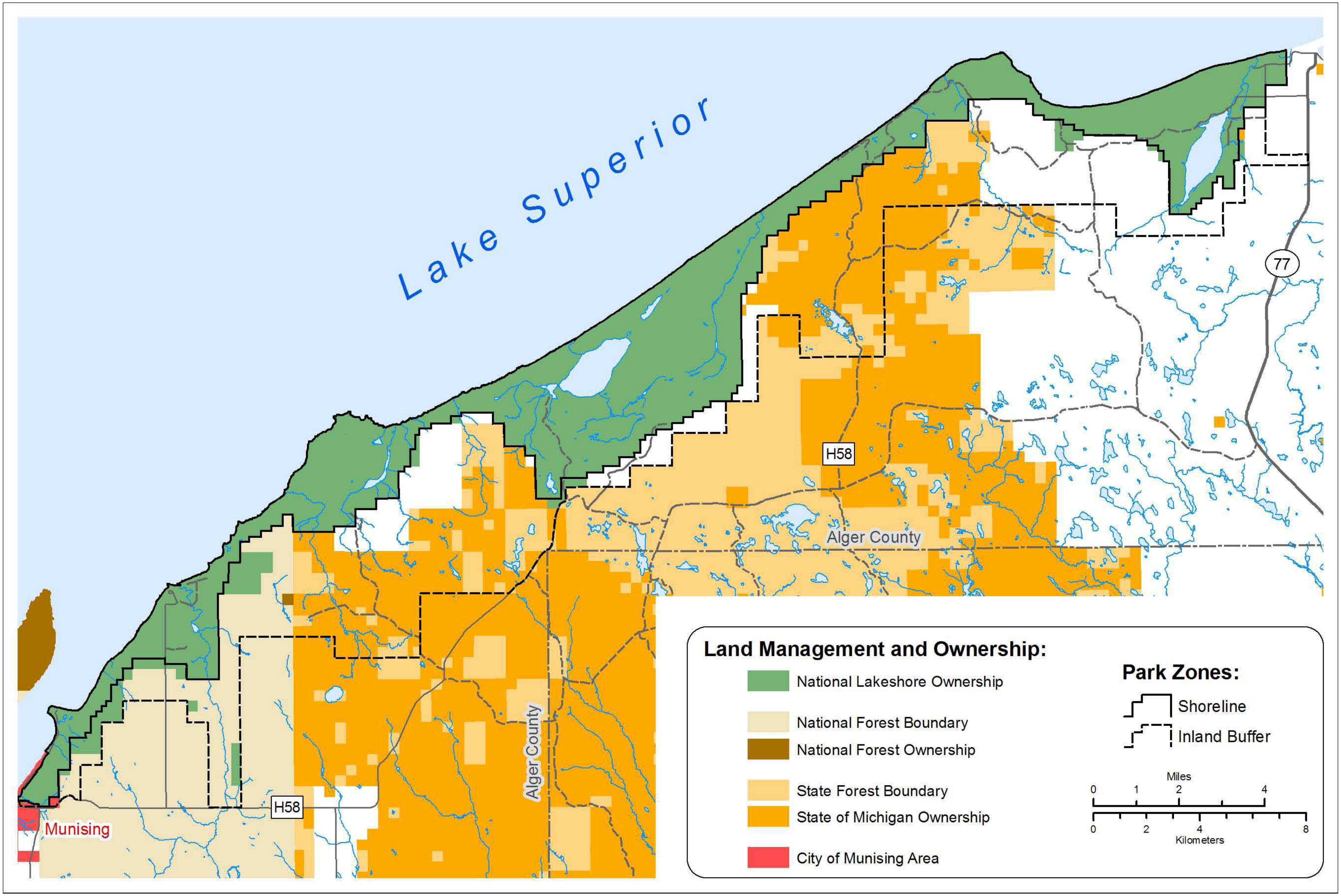


Figure 3. Land management and ownership in the Pictured Rocks area.

(Source: MIDNR 2001; State Forest Boundary after MIDNR 2005a; USDA - Forest Service 2004; NPS 2006)

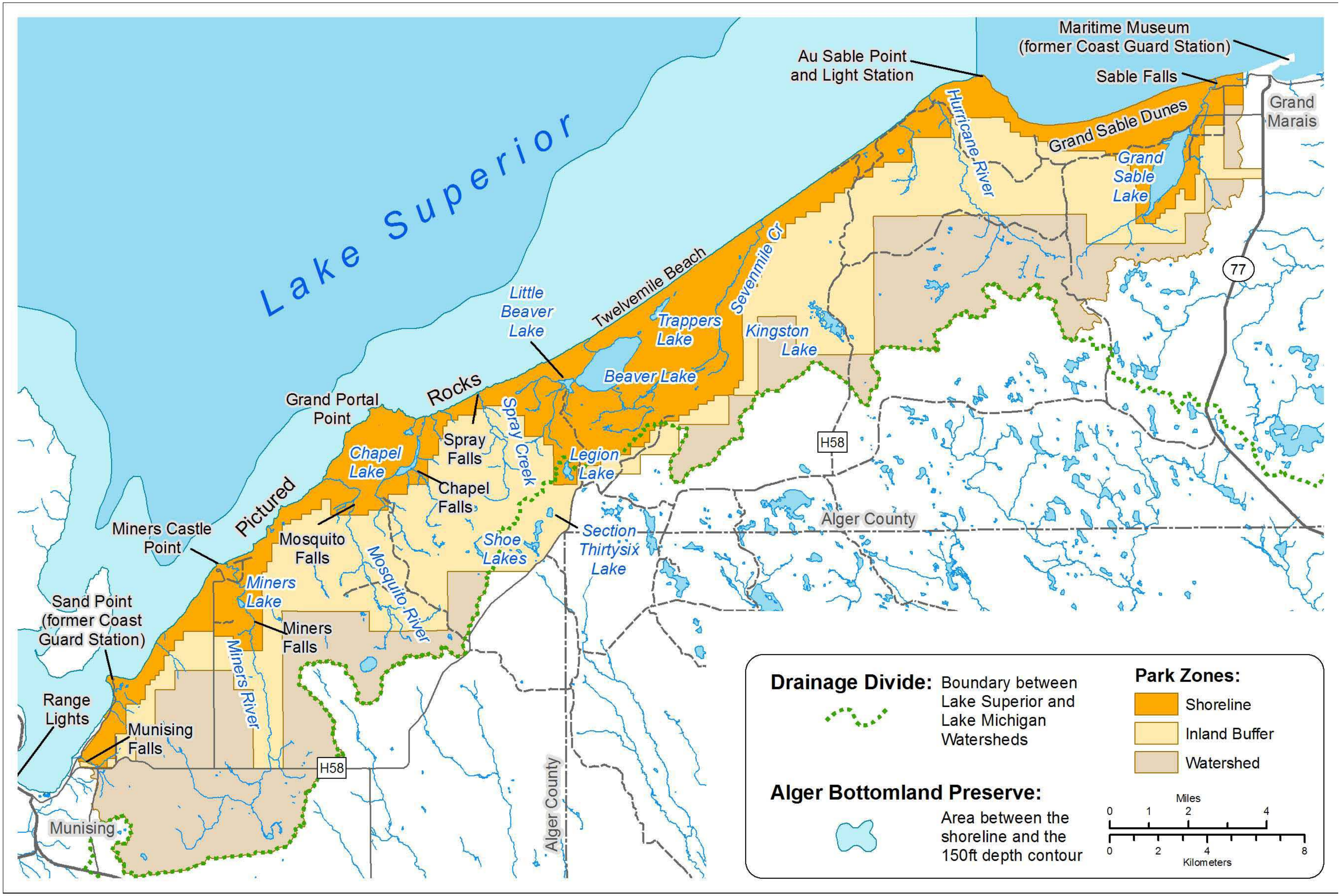


Figure 4. Key features and water resources of Pictured Rocks National Lakeshore.

(Source: Preserve - State of Michigan 1979; depth contour derived from NOAA 2004b, 2004c; Watershed Zone and Divide derived from MIDEQ 1998)

Resources (MIDNR), protects the shipwrecks and other underwater resources of the area. The preserve includes the water and bottomlands of Lake Superior from AuSable Point to AuTrain Point between the shoreline and the 45-m depth contour level (Figure 4) (State of Michigan 1979).

Fourteen named inland lakes ranging in size from 2 ha to over 300 ha, numerous beaver ponds and wetlands, and 19 named streams, many of which include rapids, cascades, and waterfalls, are important resources as well (Figure 4). Waterfalls within PIRO include Munising, Miners, Mosquito, Little Mosquito, Bridalveil, Chapel, Spray, and Sable Falls (NPS 2003).

**Land Use and Vegetative Cover**

In addition to PIRO's Draft Resource Management Plan (NPS 2003), two sources were used to assess the land use and vegetative cover of the park and its surrounding watershed area: the NPS Vegetation Classifications (2005a) and the State of Michigan Integrated Forest Monitoring Assessment and Prescription map (IFMAP) (MIDNR 2003) ( Table 1, Table 2, Figure 5, Figure 6). Land use and vegetative cover maps provide somewhat comparable information in the case of a mostly undeveloped watershed such as the PIRO watershed.

In the shoreline zone, upland forests comprise 71-79% of the land cover. Deciduous forests comprise nearly two-thirds of the forested areas. In PIRO as a whole, the percentage of land in upland forest is even greater – 75-87%. The IBZ is not intensively developed ( Table 1, Table 2), and it lacks the open areas of beach and dunes found within the shoreline zone.

Much of PIRO's upland northern hardwood forest is relatively young because of past logging. Two major white pine logging booms occurred in PIRO around 1880 and 1890. Through the 1930s, the upland hardwoods also

**Table 1. NPS vegetation classifications for Pictured Rocks National Lakeshore shoreline zone and park (shoreline plus inland buffer zone) (NPS 2005a).**

| NPS Vegetation Class | | Shoreline Zone Hectares | Shoreline Zone Percent | Park Hectares | Park Percent |
|---|---|---|---|---|---|
| Sand | | 182.2 | 1.5 | 183.9 | 0.7 |
| Dune Plant Community | | 604.8 | 5.0 | 604.8 | 2.2 |
| Cleared Area/Non Forest | | 5.9 | 0.0 | 97.6 | 0.4 |
| | All Open Areas | 793.0 | 6.5 | 886.3 | 3.2 |
| Sugar Maple | | 1061.6 | 8.8 | 3179.8 | 11.6 |
| Red Maple | | 214.5 | 1.8 | 260.4 | 0.9 |
| Maple/Hardwoods | | 4948.9 | 40.8 | 12617.2 | 45.9 |
| Aspen/Birch | | 17.6 | 0.1 | 186.4 | 0.7 |
| All Deciduous Forest | | 6242.6 | 51.5 | 16243.8 | 59.1 |
| Red Pine | | 104.2 | 0.9 | 661.9 | 2.4 |
| Red/White Pine | | 404.4 | 3.3 | 1466.6 | 5.3 |
| Jack Pine | | 241.8 | 2.0 | 485.3 | 1.8 |
| Red/White/Jack Pine | | 41.1 | 0.3 | 41.1 | 0.1 |
| Hemlock | | 62.0 | 0.5 | 66.0 | 0.2 |
| Cedar | | 677.8 | 5.6 | 1788.2 | 6.5 |
| All Conifer Forest | | 1531.3 | 12.6 | 4509.1 | 16.4 |
| Hardwood/Conifer | | 1841.8 | 15.2 | 3092.0 | 11.3 |
| | All Forest Areas | 9615.8 | 79.3 | 23844.8 | 86.8 |
| Wetland Conifer | | 858.0 | 7.1 | 1570.0 | 5.7 |
| Wetland Shrub | | 108.5 | 0.9 | 348.0 | 1.3 |
| Wetland Shrub-Marsh | | 17.7 | 0.1 | 17.7 | 0.1 |
| Wetland Shrub-Bog | | 14.4 | 0.1 | 18.5 | 0.1 |
| | All Wetlands | 998.7 | 8.3 | 1954.3 | 7.1 |
| Inland Water | | 720.3 | 5.9 | 781.7 | 2.8 |
| | Total | 12127.8 | 100.0 | 27467.0 | 100.0 |

were harvested. The forest regrowth within the area that would become PIRO was once again harvested in the 1950s and 1960s for pulpwood (NPS 2004b).

Wetlands cover 8-13% of the shoreline zone and 7-14% of the park as a whole, consisting of scattered small patches of wetter habitat on upland benches and in poorly drained topographic lows (NPS 2003). The land cover map indicates that less than 1% of the shoreline zone, and of the park as a whole, consists of roads, parking lots, and other developed areas.

**Historic and Current Human Uses**

People have lived in the PIRO area since the last retreat of the glaciers. Archaic and Woodland Indians made their summer homes along its shore. Later, an Ojibwa village was located on Grand Island, just west of PIRO. Ojibwa burial grounds are located at Sand Point and Grand Sable Dunes (Karamanski 1995; NPS 2004b).

Pierre Esprit Radisson was the first known European visitor to PIRO, in 1658 (Karamanski 1995). However, there was little interest in settling the remote area until the mineral deposits of

**Table 2. Land cover for Pictured Rocks National Lakeshore shoreline zone, park (shoreline plus inland buffer zone), and entire park watershed (shoreline plus inland buffer zone plus other lands within the Lake Superior watershed draining to the park) (MIDNR 2003).**

| | Shoreline Zone | | Park | | Watershed | |
|---|---|---|---|---|---|---|
| **IFMAP Land Use Class** | **Hectares** | **Percent** | **Hectares** | **Percent** | **Hectares** | **Percent** |
| Urban-low intensity | 1.1 | 0.01 | 3.0 | 0.01 | 14.1 | 0.03 |
| Urban-high intensity | 1.3 | 0.01 | 2.8 | 0.01 | 4.3 | 0.01 |
| Urban-road/parking | 45.5 | 0.38 | 129.3 | 0.47 | 211.3 | 0.52 |
| All Urban | 48.0 | 0.40 | 135.1 | 0.49 | 229.8 | 0.57 |
| Ag-non-vegetated farmland | 0.0 | 0.00 | 0 | 0.00 | 3.8 | 0.01 |
| Ag-forage crops | 1.1 | 0.01 | 1.1 | 0.00 | 49.3 | 0.12 |
| All Ag | 1.1 | 0.01 | 1.1 | 0.00 | 53.1 | 0.13 |
| Upland Open-herbaceous | 432.1 | 3.56 | 523.9 | 1.91 | 788.0 | 1.94 |
| Upland Open-shrub/low density trees | 122.4 | 1.01 | 954.9 | 3.48 | 1435.7 | 3.54 |
| Upland Open-parks/golf courses | 0.0 | 0.00 | 1.0 | 0.00 | 37.8 | 0.09 |
| All Upland Open | 554.5 | 4.57 | 1479.8 | 5.39 | 2261.5 | 5.57 |
| Upland Forest-northern hardwoods | 6004.0 | 49.48 | 15131.3 | 55.11 | 22323.0 | 54.98 |
| Upland Forest-oak types | 11.2 | 0.09 | 72.6 | 0.26 | 145.9 | 0.36 |
| Upland Forest-aspen types | 744.0 | 6.13 | 1350.7 | 4.92 | 1906.1 | 4.69 |
| Upland Forest-mixed deciduous | 104.0 | 0.86 | 247.9 | 0.90 | 465.8 | 1.15 |
| Upland Forest-pine types | 1088.7 | 8.97 | 2336.2 | 8.51 | 3074.0 | 7.57 |
| Upland Forest-other conifers | 36.6 | 0.30 | 150.0 | 0.55 | 257.3 | 0.63 |
| Upland Forest-mixed conifers | 322.5 | 2.66 | 732.7 | 2.67 | 1016.3 | 2.50 |
| Upland Forest-mixed | 308.8 | 2.54 | 602.4 | 2.19 | 812.2 | 2.00 |
| All Upland Forest | 8619.9 | 71.03 | 20623.8 | 75.11 | 30000.5 | 73.89 |
| Inland Water | 851.2 | 7.01 | 936.3 | 3.41 | 1014.4 | 2.50 |
| Wetlands-deciduous forest | 179.4 | 1.48 | 695.7 | 2.53 | 1220.0 | 3.00 |
| Wetlands-coniferous forest | 924.1 | 7.61 | 1813.9 | 6.61 | 3332.3 | 8.21 |
| Wetlands-mixed forest | 35.1 | 0.29 | 82.7 | 0.30 | 135.5 | 0.33 |
| Wetlands-floating aquatic | 17.4 | 0.14 | 25.7 | 0.09 | 39.1 | 0.10 |
| Wetlands-shrub | 323.1 | 2.66 | 944.1 | 3.44 | 1388.8 | 3.42 |
| Wetlands-emergent | 1.5 | 0.01 | 4.4 | 0.02 | 18.9 | 0.05 |
| Wetlands-mixed non-forest | 120.9 | 1.00 | 247.5 | 0.90 | 433.2 | 1.07 |
| All Wetlands | 1601.3 | 13.20 | 3814.1 | 13.89 | 6567.6 | 16.18 |
| Bare/Sparse-sand/soil | 196.4 | 1.62 | 202.7 | 0.74 | 206.9 | 0.51 |
| Bare/Sparse-exposed rock | 21.3 | 0.18 | 21.3 | 0.08 | 21.3 | 0.05 |
| Bare/Sparse-other | 241.6 | 1.99 | 242.3 | 0.88 | 245.2 | 0.60 |
| All Bare/Sparse | 459.4 | 3.79 | 466.3 | 1.70 | 473.5 | 1.17 |
| Totals | 12135.3 | | 27456.5 | | 40600.4 | |

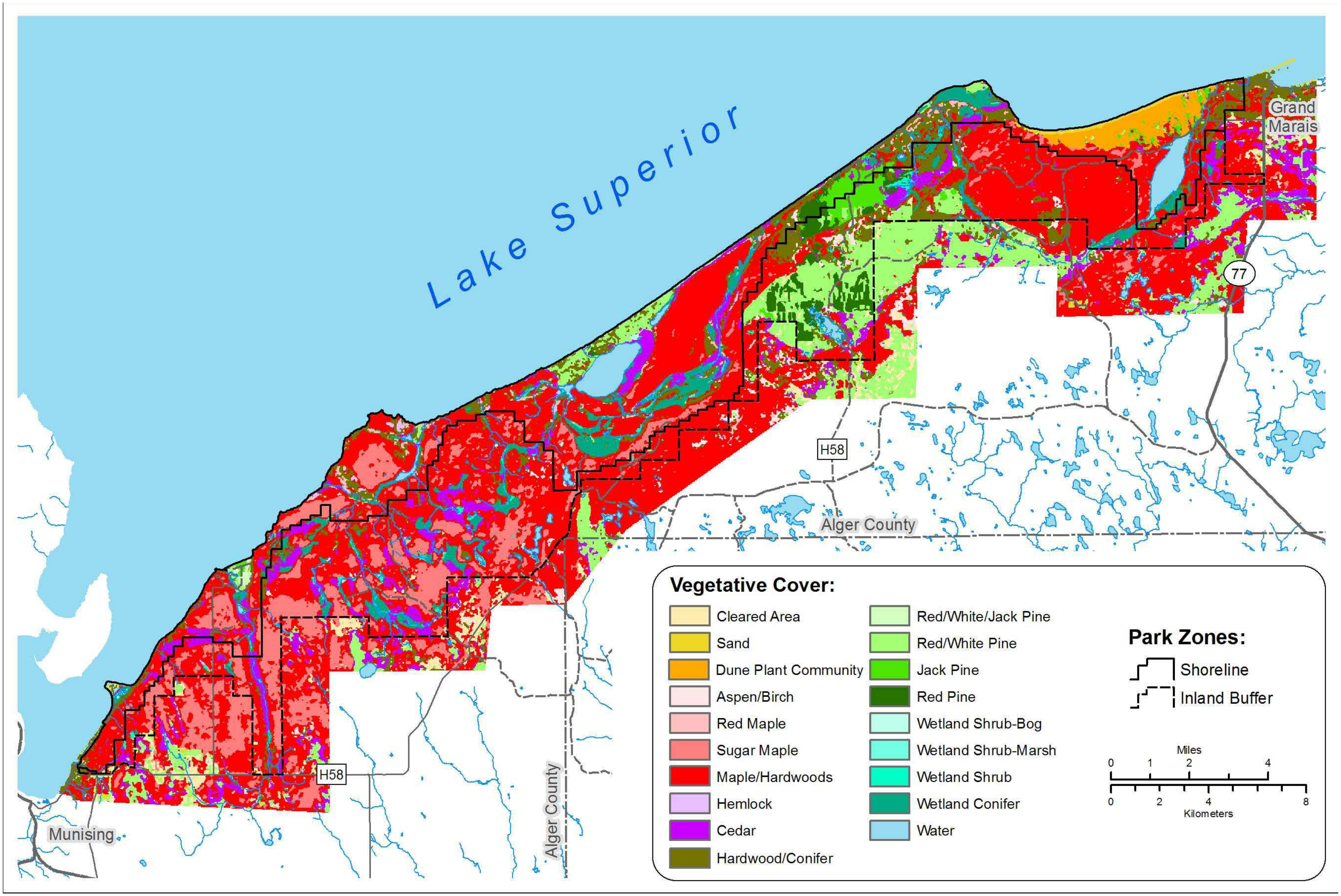


Figure 5. Vegetative cover map for Pictured Rocks National Lakeshore.
(Source: NPS 2005a)

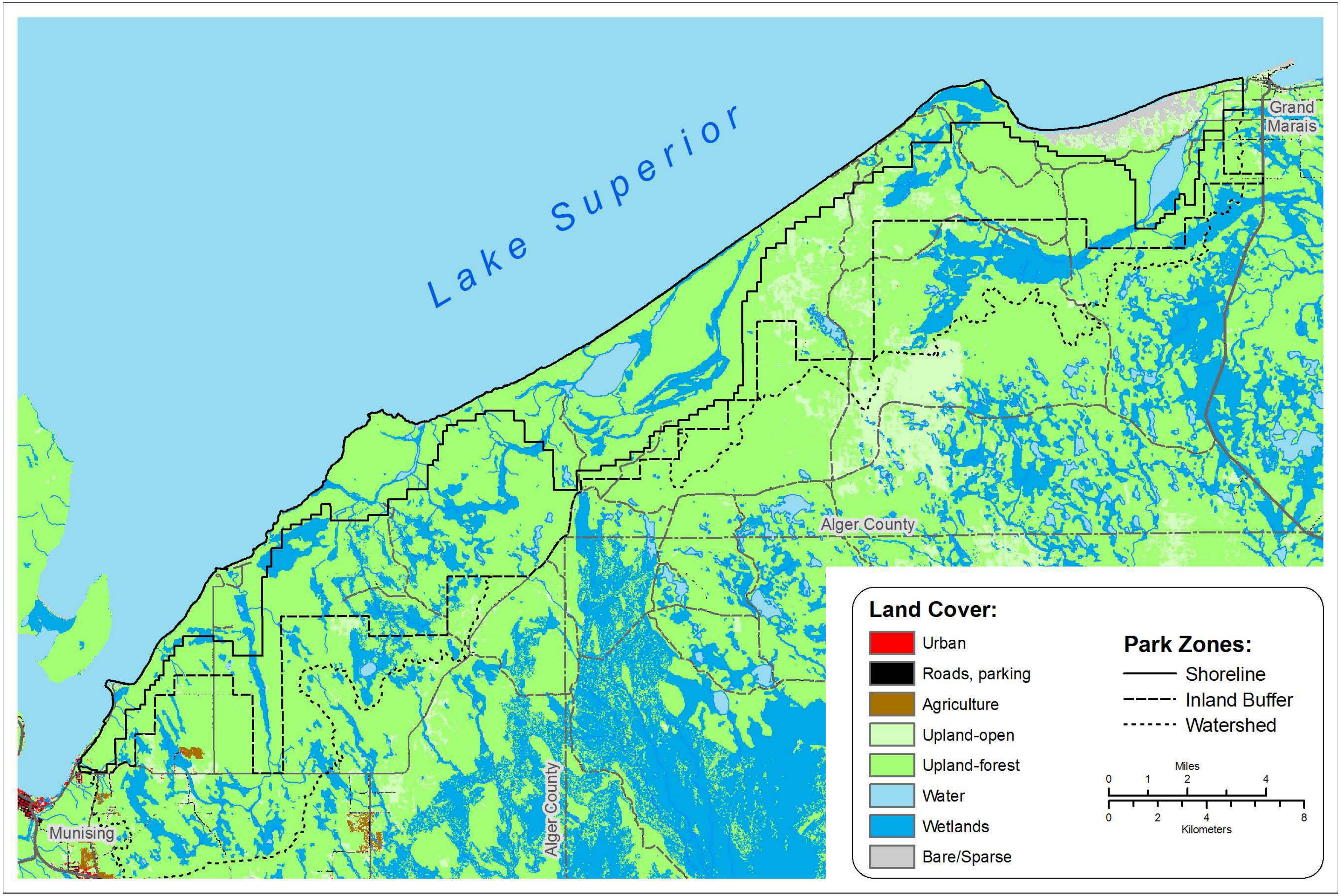


Figure 6. IFMAP land cover for the Pictured Rocks area.

(Source: MIDNR 2003)

Michigan's Upper Peninsula were discovered in the 1820s. Shortly thereafter, loggers arrived to begin harvesting the white pine forests. The first attempt to promote recreational use of the area came in 1850, when the Munising Company built a tourist hotel on the mainland just opposite Grand Island. However, it experienced little success.

Commercial ship traffic began on Lake Superior in the 1840s and 1850s. Because of the lake's dangerous cliffs and reefs and frequent storms, light stations were established at Au Sable in 1874 and Grand Marais Harbor in 1897, and U.S. Coast Guard motor lifeboat stations were later established at Munising and Grand Marais (NPS 2004b).

In 1900, the Cleveland-Cliffs Iron Company purchased Grand Island, and the company's founder developed the island as a private retreat. From this beginning, he went on to build an impressive and popular vacation resort, the Hotel Williams. However, the resort went into decline during the Great Depression and was closed some time before 1950 (Karamanski 1995).

Also in the early 1900s, a few families established subsistence farms in the area, but poor soils and short growing seasons made farming difficult (NPS 2004b). In the World War II era, PIRO had some scattered family fishing and hunting camps, and a fair-sized corporate hunting and fishing camp in the Beaver Lake Basin, owned by the Michigan-Wisconsin Pipeline Company (NPS 2004b). However, PIRO was a largely unused and unappreciated recreational resource. Roads were poor, and the area was still recovering from the logging and burning of the late 19th century. The Pictured Rocks themselves could be seen only from Lake Superior.

During 1957-58, the PIRO area was identified as being suitable for inclusion in the National Park System. On October 15, 1966, Public Law 89-668 authorized PIRO as America's first national lakeshore, and it was formally established on October 6, 1972 (NPS 2004a). During FY 2004, PIRO had 380,217 recreation visits. Approximately 50 percent of PIRO's total visitation occurs in July and August. Most of those visitors are drive-through day users who limit their visits to automobile-accessible points of interest, but hiking and backpacking are also very popular (NPS 2003).

In 2000, 9,862 people lived in Munising, at PIRO's western edge, 3,125 lived in Munising Township to the south and west of PIRO, and an additional 480 people lived in Burt Township (including the unincorporated community of Grand Marais) on its southern and eastern border (Figure 7). An additional 3,718 people live outside these communities in the remainder of Alger County (U.S. Census Bureau 2005). The county's major employers include the Alger Maximum Security Prison, with 400 employees; the Kimberly Clark Corporation, with 370 employees; and Timber Products Company, with 300 employees (Alger County Chamber of Commerce n.d.). In addition, an estimate of the importance of the tourist industry can be gained from the 2002 Economic Census lists, where four establishments are listed under "Arts, Entertainment and Recreation" and 41 under "Accomodations and Food Services" for a total of 370 paid employees (U.S. Census Bureau 2005).

**Geology and Soils**

The present character of PIRO is largely the product of both its recent glacial history and its more ancient bedrock depositional past. PIRO contains rocks of Precambrian, Cambrian, Ordovician, Pleistocene, and Holocene ages. Because PIRO lies along the northwestern edge of the Michigan Basin, the bedding of its sedimentary rocks deposited in post-Precambrian time dips to the southeast (Vanlier 1963; NPS 2005b). A more recent erosional surface dips to the north, so the bedrock nearest the surface is oldest in the north and becomes progressively younger to the south.

PIRO is underlain by deeply buried unnamed Precambrian igneous and metamorphic rocks covered by the Precambrian Jacobsville Formation (Figure 8). The Jacobsville is a well-cemented, medium-grained, red and reddish brown, nonfossiliferous sandstone (Handy and Twenter 1985). The thickness of the Jacobsville ranges from zero in the southern part of Alger County to 300 m along the county's Lake Superior shoreline (Vanlier 1963). In PIRO, it crops out only at a few locations in the far north, including east of Hurricane River campground, at Au Sable Point, and in the gorge at Sable Falls (NPS 2003).

Lying uncomformably atop the Jacobsville, and separated from it by millions of years of geologic time, is the Cambrian-age Munising Sandstone, which is 45-60 m thick depending on the location (Handy and Twenter 1985). It has three

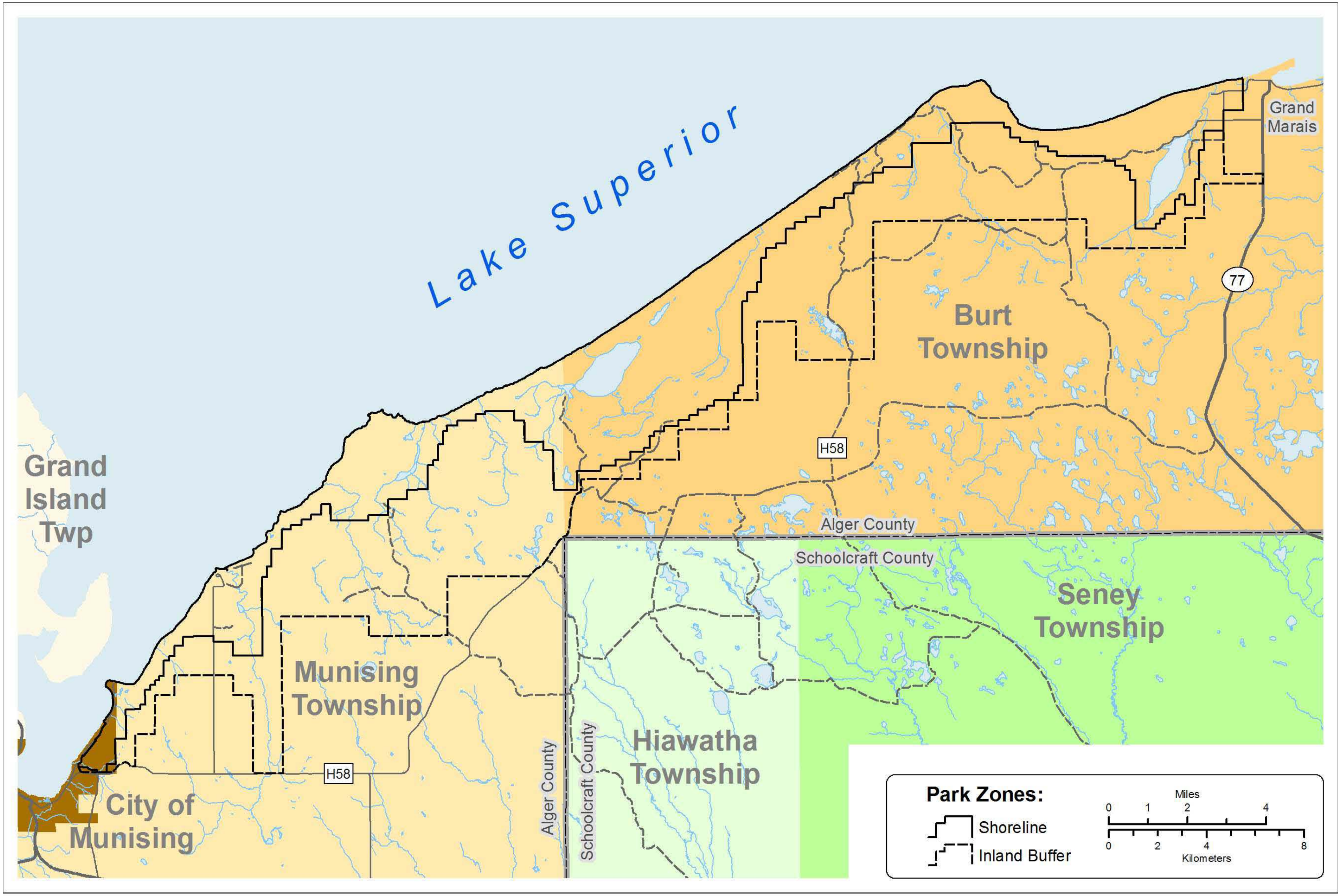


Figure 7. Municipal boundaries in the Pictured Rocks area.
(Source: Michigan Center for Geographic Information 2005)

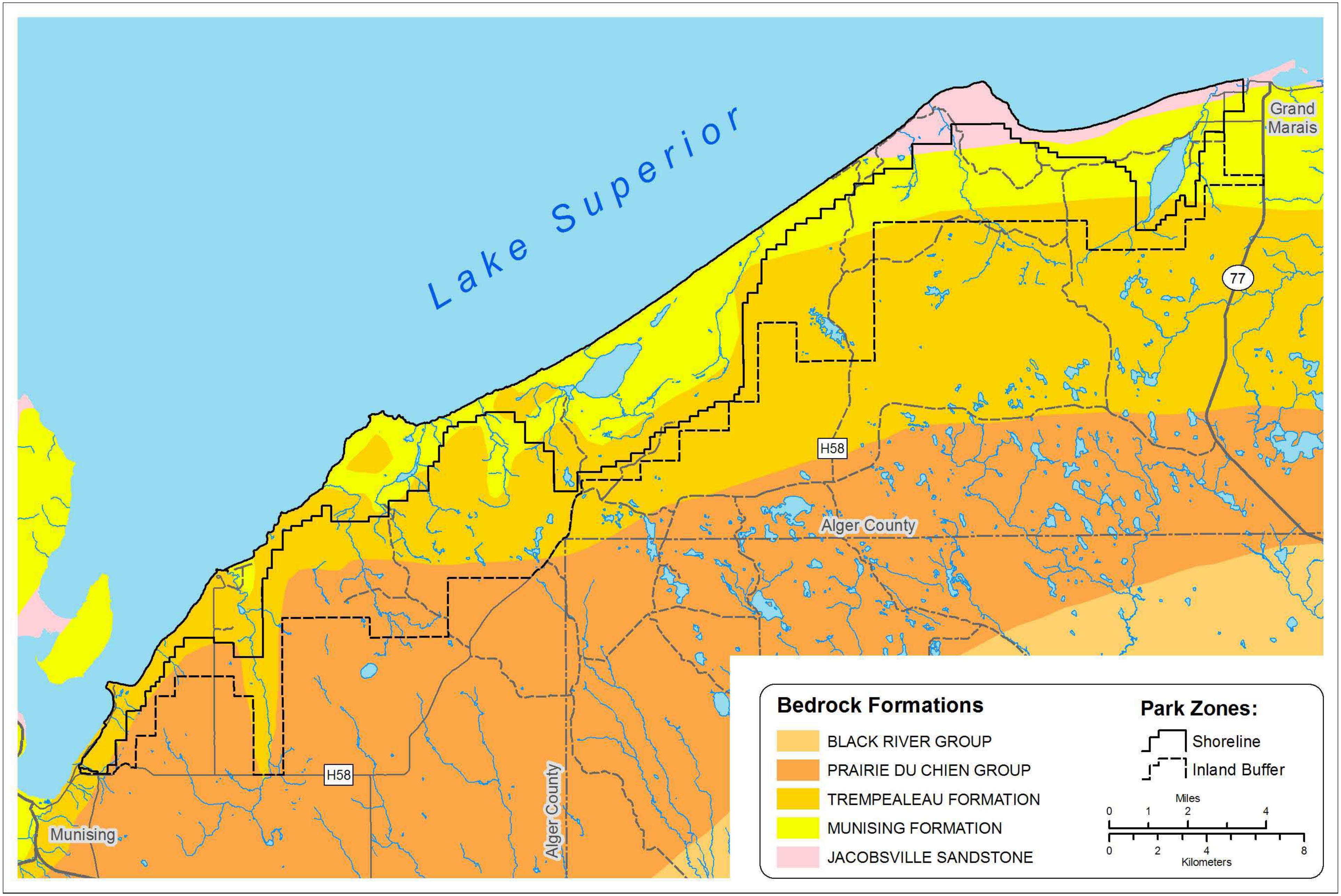


Figure 8. Bedrock geology of the Pictured Rocks area.
(Source: MIDEQ Geologic Survey Division 1987)

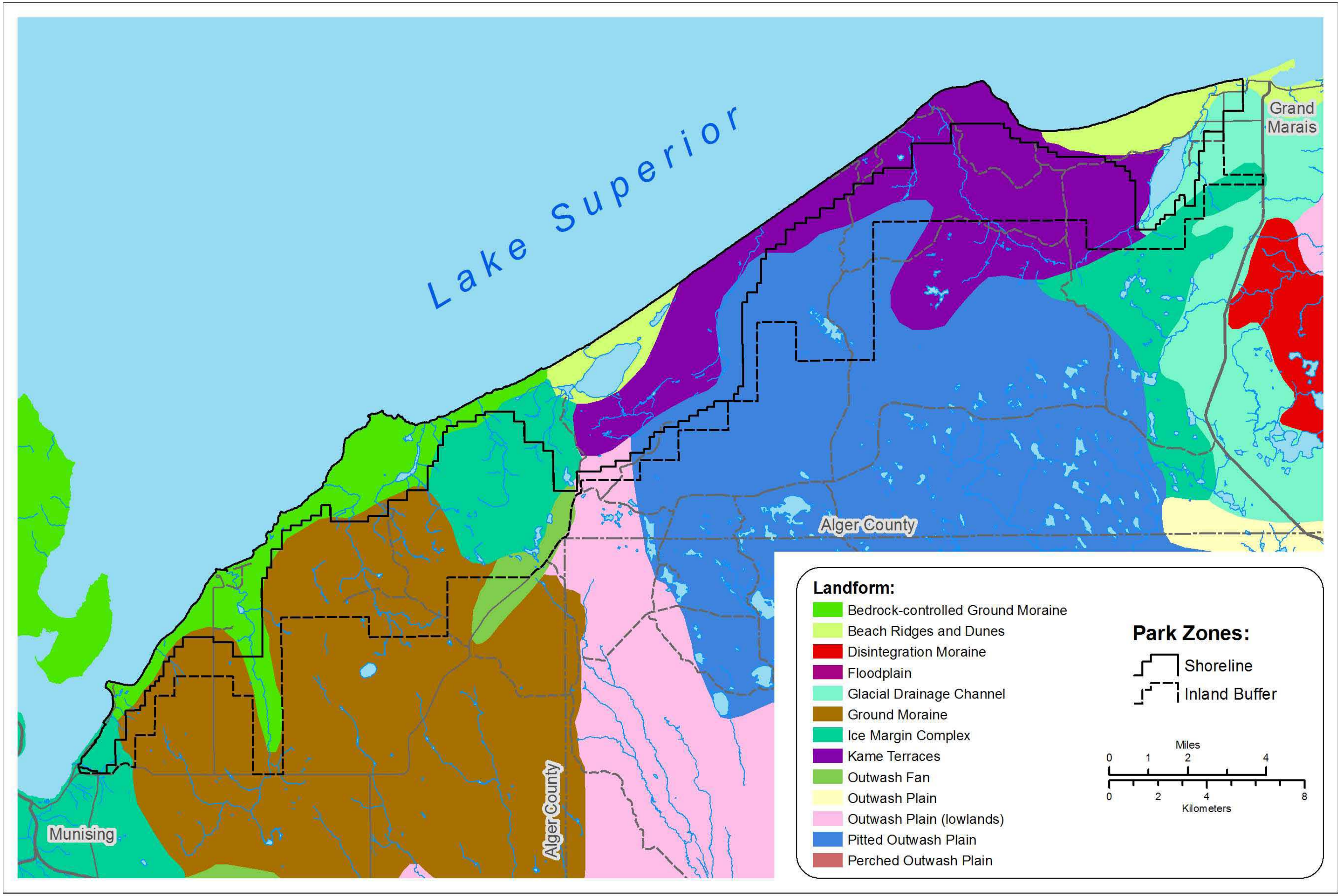


Figure 9. Glacial landforms of the Pictured Rocks area.
(Source: After Jerome 2005)

distinct members; from oldest to youngest, they are the Basal Conglomerate, which is up to 4 m thick; the 12-18 m thick Chapel Rock member, in which many caves are formed in outcrops, and the up to 42 m thick Miners Castle member, which forms the colorful sloping cliffs of Pictured Rocks (Rose 1997).

The Prairie du Chien group and Trempealeau formations of the Early Ordovician period lie above the Munising Sandstone (Handy and Twenter 1985). They are from 15-70 m thick. In the western half of the Pictured Rocks, the Miners Castle member of the Munising Sandstone is capped by a resistant dolomitic sandstone called the Au Train formation of the Prairie du Chien group. The differential erosion of the Au Train and the underlying Miners Castle formations has produced wave-cut features in the Pictured Rocks, many waterfalls in PIRO's interior, the waterfalls that enter Lake Superior, and a steep escarpment just south of Beaver Lake (Hamblin 1958, 1961; Handy and Twenter 1985).

The Black River and Trenton limestones of the middle Ordovician period are present in southwestern Alger County outside the area covered by our base map (Figure 8). Handy and Twenter (1985) show a small area of Black River limestone in the headwaters of the Miners River, but the Michigan Geological Survey (MIDEQ 1987) does not.

Much more recently, during the Pleistocene epoch, PIRO was affected by the advance and retreat of four glaciers during the last continental glaciation, the Wisconsin stage. The last major glacial advance, the Marquette, occurred about 10,000 years BP (Jerome 2005). Melting of glacial ice created streams that carried millions of tons of rock debris to the south of Lake Superior, creating glacial features that can be seen in PIRO today. These include ice margin complexes, kame terraces, outwash fans, and pitted outwash plains (Figure 9). To the west of this outwash area, the glacial deposits consist of ground moraines. The thickness of glacial deposits in PIRO ranges from 0-60 m or more (Handy and Twenter 1985).

Glacial drainage channels were carved into the Munising Sandstone about 9,600 years BP, and can be seen today at Chapel Creek, Mosquito River, and Beaver Basin (NPS 2003). Loope (2004) summarized the work of numerous authors (Hughes 1968; Carey 1993; Blewett 1994; Schwenner 2003) to describe the location of these channels, which included one at the southern edge of Beaver Basin, where Hyde Lake, Sevenmile Lake, and Sevenmile Creek are currently located, and another that occupied two contemporary watersheds and included Hurricane River, Rhody Creek, Grand Sable Lake, and Sable Creek. The Hurricane River and the lower portion of the Mosquito River both now flow in the opposite directions than they did when they were formed by glacial meltwaters (Loope 2004).

Other PIRO lakes also formed during the Pleistocene. Legion, Section 36, the Shoe Lakes, and Kingston Lake are glacial kettle lakes, formed by the melting of large blocks of ice fragmented from the retreating glacier. Elongate Chapel Lake was likely formed by a large plunge pool in a glacial meltwater channel (Loope 2004).

**Table 3. Soils of Pictured Rocks National Lakeshore (NPS 2003)**

| Soil type | Characteristics | Location in park |
|---|---|---|
| Upland loam | Underlain by gravels and stony clays; generally well drained and moderately productive | Southwestern part of shoreline zone |
| Plains sands | Level to slightly rolling terrain; well drained and low in fertility | Kingston Plains, southeastern and southcentral portions of IBZ |
| Sandy loams and sands | Stony; underlain by leached sands; some local clays in subsoil | High, hilly upland areas in the eastern sections of PIRO, in the western portion of Beaver Basin, and southwest of Sand Point |
| Upland stony loams and sands | Poorly developed profile; bedrock near surface; many clay inclusions | Rolling terrain from Beaver Lake to Sand Point. |
| Lakeshore sands, gravels and stones | Excessively dry | Sand Point and extensively along the northern shore of PIRO from Miners Beach to Sable Creek. |
| Swamp and wetland soils | Almost permanently waterlogged | Bogs, marshes, and in narrow floodplains along major stream channels. |
| Organic mucks and peats | May be up to ten feet deep | |

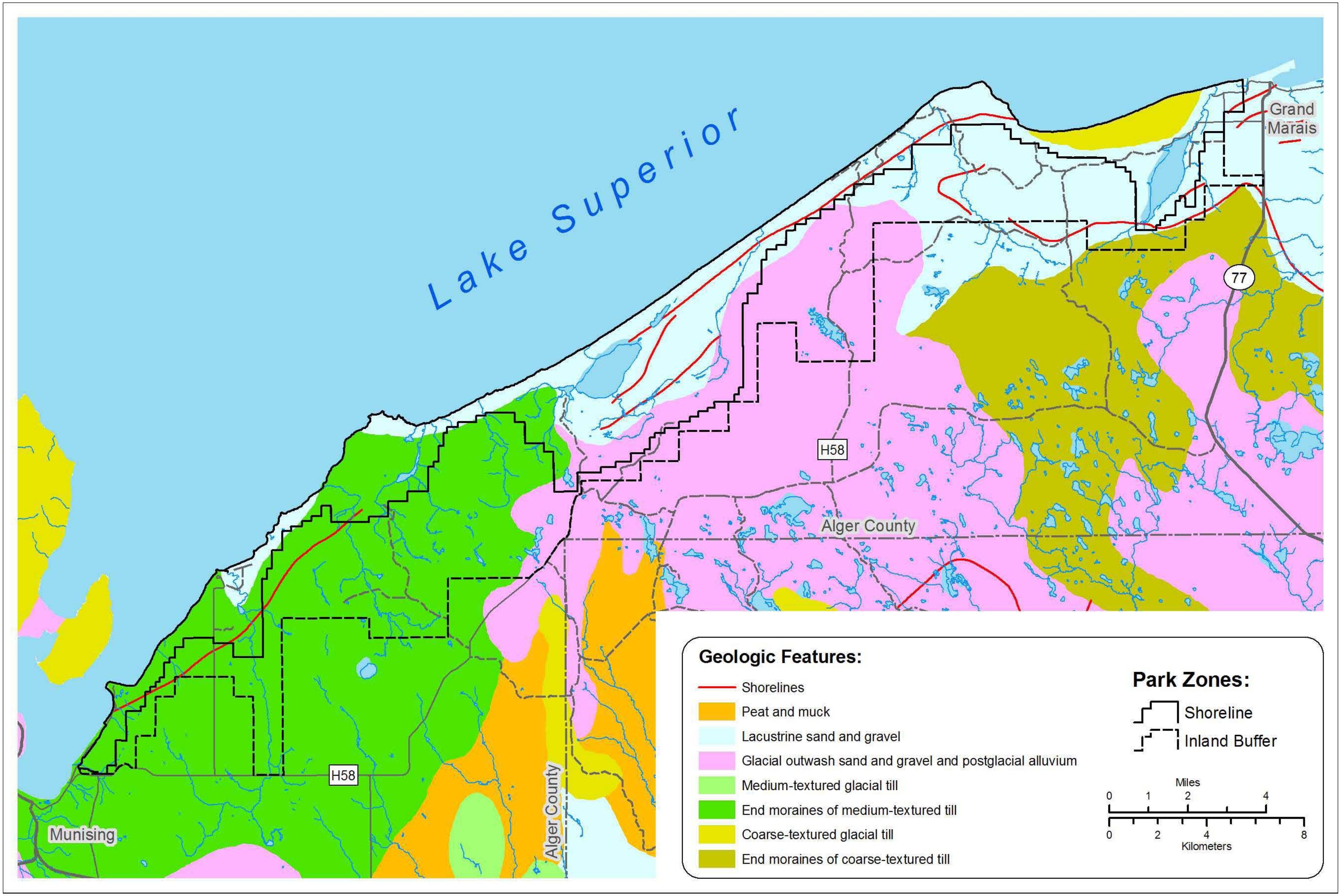


Figure 10. Pleistocene and Holocene landforms in the Pictured Rocks area.

(Source: MNFI and MIDNR 1998)

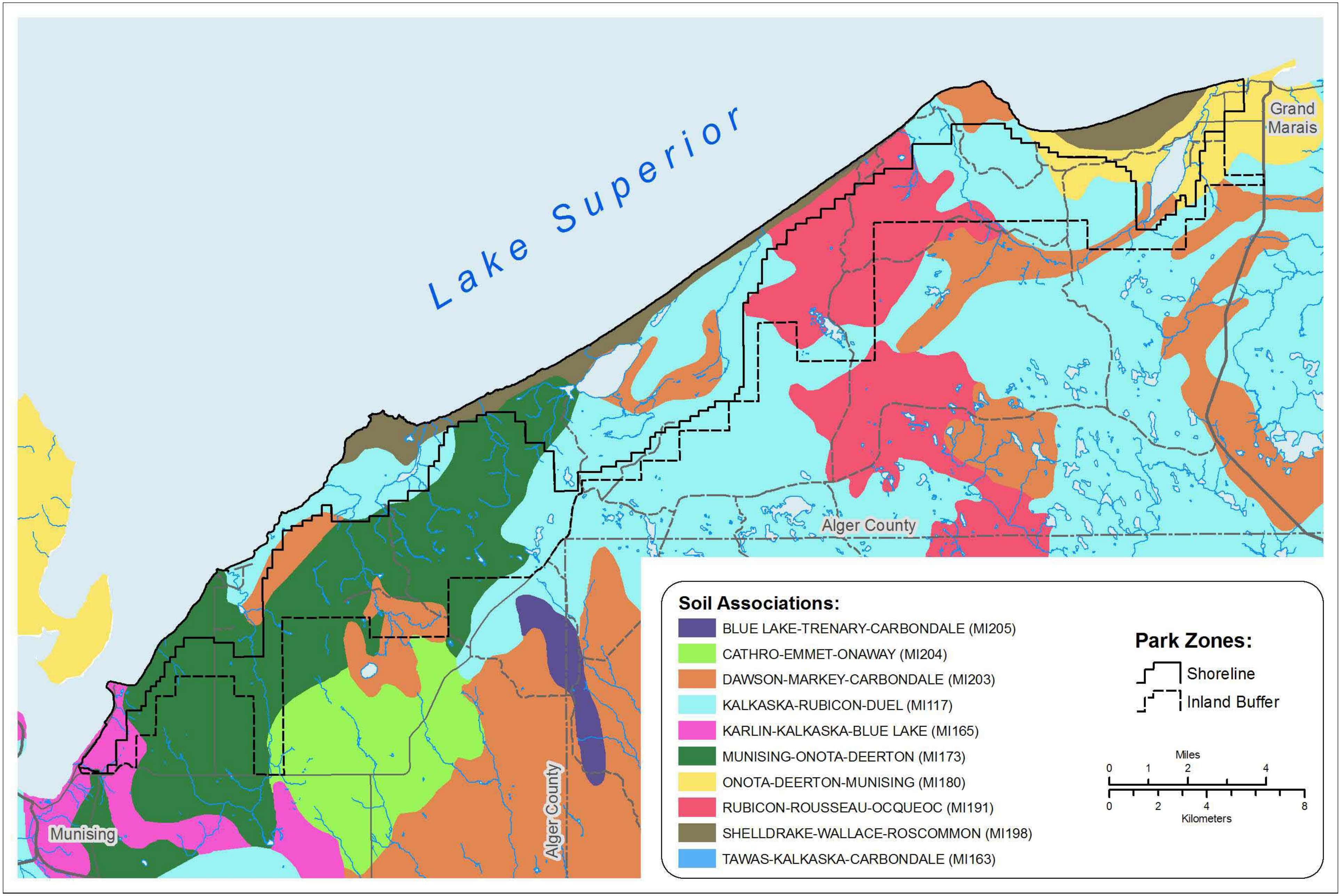


Figure 11. General soil association map (STATSGO) for the Pictured Rocks area.

(Source: USDA NRCS 1994)

Isostatic rebound occurred after the glaciers' retreat during the Holocene, causing a general uplifting of the landscape (Flint 1957). Around 6,000 BP, Lake Nipissing, one of the ancestral lakes of Lake Superior, was 12-14 m higher than today (Flint 1957). Waves carved some of PIRO's most famous features, such as Chapel Rock and Miners Castle, during that time. The Grand Sable Banks, originally deposited by glacial meltwaters, were destabilized by the high water and reworked by wind to form the Grand Sable Dunes (NPS 2005b). This high period of Lake Superior inundated Miners and Beaver Basins, as well as Sand Point (Loope 2004), and thus Beaver, Trappers, Little Beaver, Chapel, Little Chapel, and Miners Lakes were all once embayments of Lake Nipissing (NPS 2005c). As Lake Nipissing's water level dropped over a 1,600 year period, lake currents created a "corrugated plain" of parallel beach ridges which can be seen near Au Sable Point and on Sand Point (NPS 2005c), and which created Miners, Little Beaver, Beaver, and Trappers Lakes (Loope 2004).

Grand Sable Lake and the current channel of Sable Creek also formed at this time when dune dams blocked the ancestral channel, creating the lake and rerouting the creek downstream from Grand Sable Lake several times (Loope et al. 2001). Wind and water continue to work to create beach ridges and dunes along the Lake Superior shoreline, and water has created small areas of recent alluvial deposits in the floodplains of present-day streams.

The Michigan Quaternary Geology map shows that the major surficial deposits in the park include lacustrine sand and gravel, glacial outwash sand and gravel, postglacial alluvium, and end moraines of medium-textured till (Figure 10) (MNFI and MIDNR 1998). The State Soil Geographic (STATSGO) data base for Michigan includes seven major soil associations within PIRO's boundaries (Figure 11) (USDA NRCS 1994). According to PIRO's Aquatic Monitoring Plan, the Kalkaska sand and the Rubicon sand comprise the greatest percentage of the soils of PIRO (Loope 2004). Other common soils include various loamy sands, sandy loams, and the Chippeny, Carbondale, Lupton, and Rifle mucks and peats (Table 3). A new soil survey, including an electronic version of a soils map, is currently in progress for Alger County (Schwenner 2003).

**General Hydrology and Water Budget**

No specific water budget has been completed for PIRO, but a number of studies provide general insight on the budget and park hydrology. Bennett (1978) proposed a Lake Superior basin budget, with inputs of direct precipitation (69.6 cm) and land drainage (65.86 cm), and outputs of evaporation (47.0 cm) and outflow through the St. Mary's River (88.29 cm). Similarly, Holtschlag and Nicholas (1998) proposed that Lake Superior's water input is dominated (56%) by direct input from precipitation. Another 11% enters through surface runoff and 33% arrives indirectly as groundwater discharge, which is defined as the groundwater component of streamflow. For gaged streams in Michigan's Upper Peninsula that flow into Lake Superior, from 74-89% of flow could be attributed to groundwater discharge (Holtschlag and Nicholas 1998).

Alger County's annual water budget has been estimated to average an input of 86 cm of precipitation, and outputs of 15 cm of groundwater runoff and 71 cm of surface runoff and evapotranspiration (Vanlier 1963). For some park watersheds perched directly on bedrock, surface runoff is a significant component of the water budget. Loope (2004) synthesized several data sources to indicate that some watersheds respond rapidly to heavy and/or prolonged rainfall and to annual snowmelt. On the other hand, on the areally extensive sandy areas of the Kingston and Wetmore Plains, up to 41 cm of groundwater recharge occurs, and the other 46 cm returns to the atmosphere through evapotranspiration, leaving large areas with no significant surface runoff (Vanlier 1963).

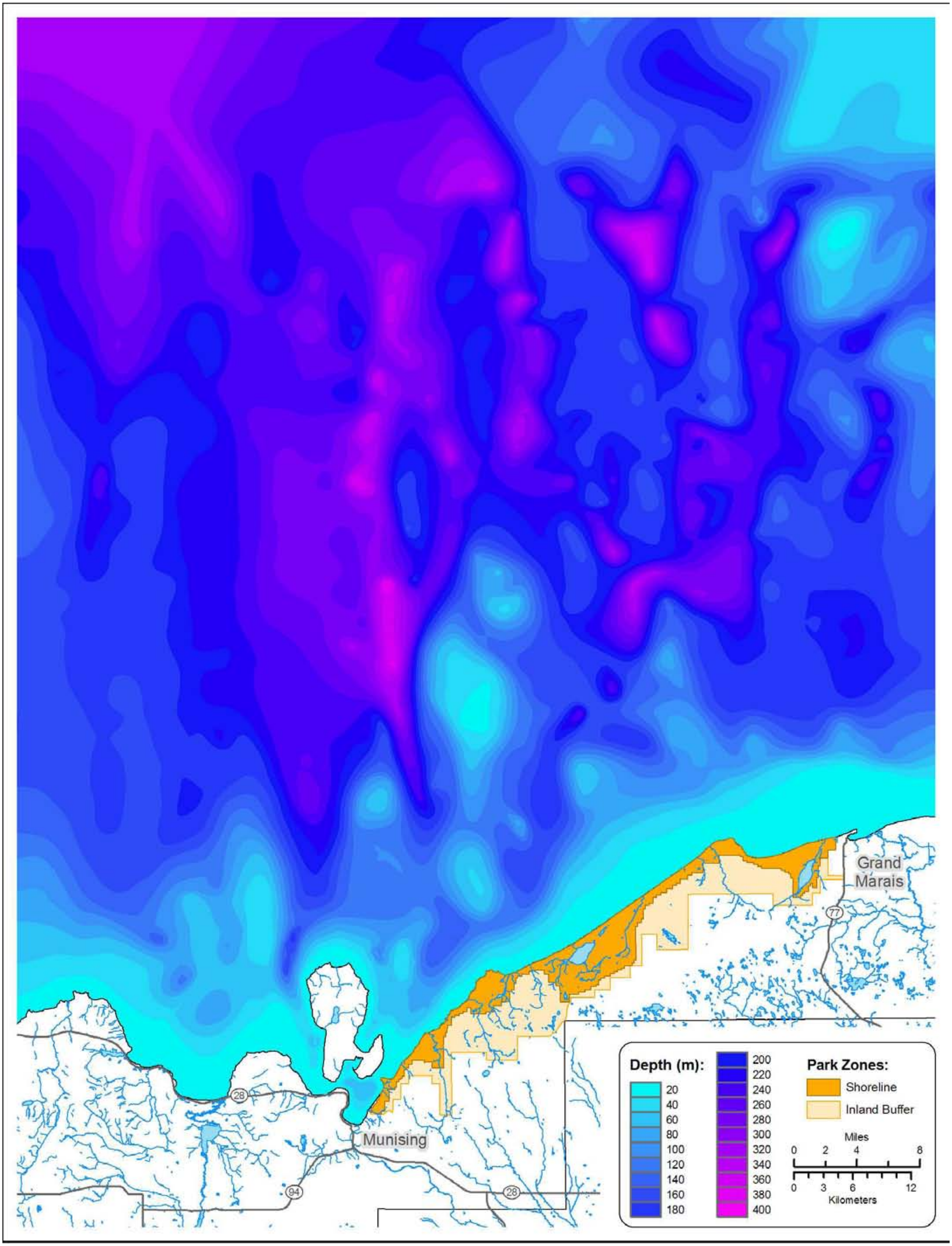


Figure 12. Lake Superior bathymetry in the Pictured Rocks area.
(Source: derived from NOAA 2004a, 2004b, 2004c, 2005)

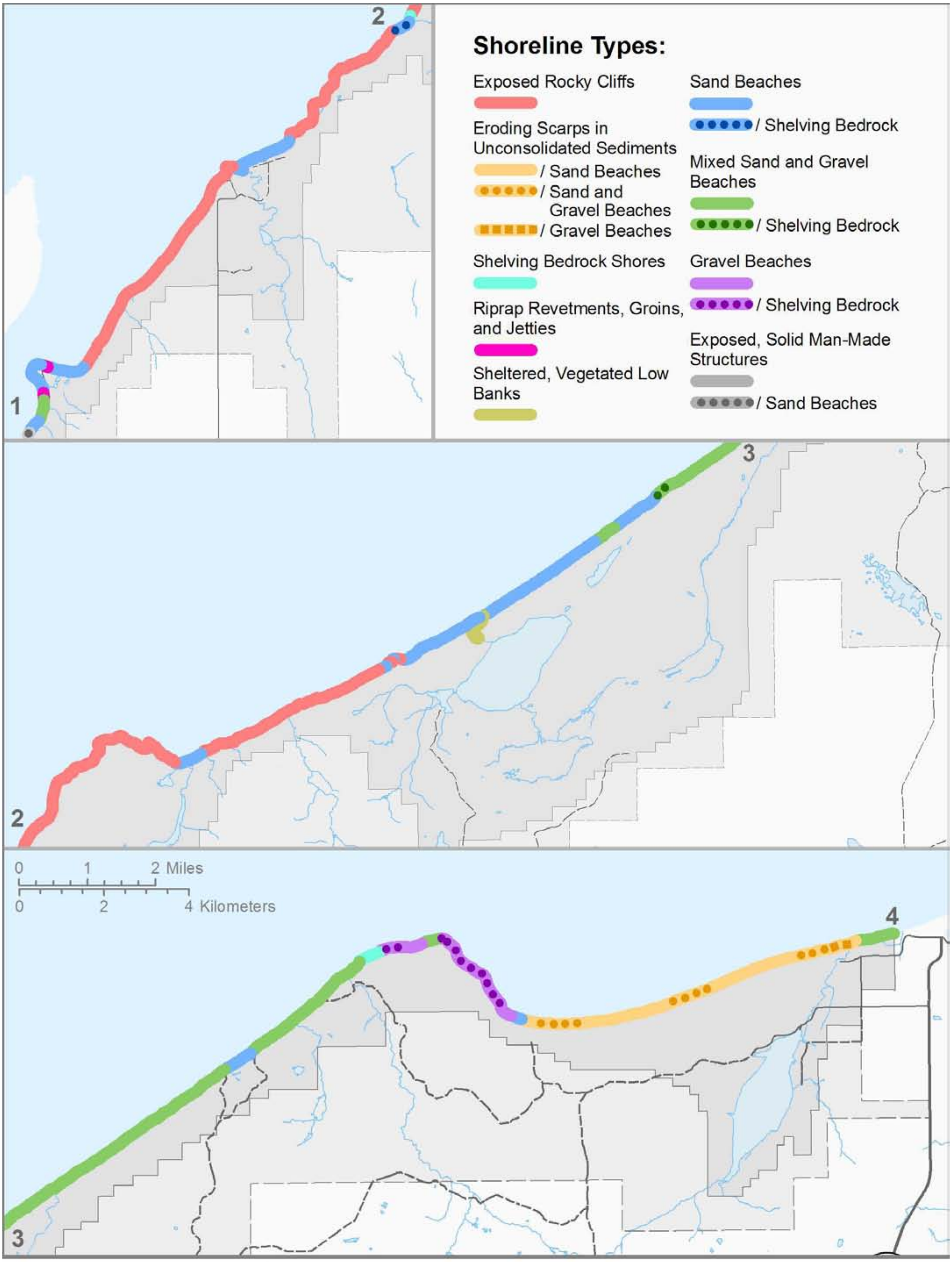


Figure 13. Shoreline types for Pictured Rocks National Lakeshore.
(Source: USEPA Region 5 2000)

Table 4. Lake Superior shoreline types, lengths, and USEPA shoreline sensitivity classification (USEPA Region 5 2000).

| Shoreline Type | Number of Kilometers | NOAA ESI Shoreline | EPA Shoreline Sensitivity Classification |
|---|---|---|---|
| Exposed Rocky Cliffs | 21.24 | 1A | Low |
| Exposed, Solid Man-made Structures | 0.03 | 1B | Low |
| Shelving Bedrock Shores | 0.66 | 2 | Low |
| Riprap Revetments, Groins and Jetties | 0.35 | 6B | Low |
| **Subtotal for Low Sensitivity** | **22.28** | | |
| Exposed, Solid Man-made Structures/Sand Beaches | 0.06 | 1B/4 | Low-Medium |
| Eroding Scarps in Unconsolidated Sediments/Sand Beaches | 4.71 | 3/4 | Low-Medium |
| Eroding Scarps in Unconsolidated Sediments/ Mixed Sand and Gravel Beaches | 2.96 | 3/5 | Low-Medium |
| Eroding Scarps in Unconsolidated Sediments/ Gravel Beaches | 0.56 | 3/6A | Low-Medium |
| Sand Beaches | 12.62 | 4 | Low-Medium |
| Sand Beaches/Shelving Bedrock Shores | 0.46 | 4/2 | Low-Medium |
| Mixed Sand and Gravel Beaches | 14.06 | 5 | Low-Medium |
| Mixed Sand and Gravel Beaches/Shelving Bedrock Shores | 0.32 | 5/2 | Low-Medium |
| Gravel Beaches | 0.61 | 6A | Low-Medium |
| Gravel Beaches/Shelving Bedrock Shores | 3.13 | 6A/2 | Low-Medium |
| **Subtotal for Low-Medium Sensitivity** | **39.48** | | |
| Sheltered, Vegetated Low Banks | 1.38 | 9A | Medium-High |
| **Total** | **63.14** | | |

# Water Resources of Lake Superior

**Physical Characteristics**

Lake Superior has the greatest surface area of any freshwater lake in the world. The lake is 563 km long and 257 km wide, and its shoreline length is 4,800 km, including islands. Its volume is 12,100 km$^3$, 10% of the world's freshwater (USEPA and Government of Canada 1995).

Lake Superior's mean depth is 147 m, and its current level at approximately 183 m above sea level was established approximately 2,000 years ago (LSBP 2006). PIRO's offshore waters are relatively shallow (40 m or less), although a number of deep troughs with north-south orientation can be found farther north (LSBP 2000) (Figure 12). The deepest point of Lake Superior (405 m) lies about 56 km north of PIRO (NPS 1996).

Lake Superior has both epilimnetic and hypolimnetic currents, which flow counterclockwise, or from west to east in the PIRO vicinity (LSBP 2000). Overall, currents are strongest on the south side (Matheson and Munawar 1978). Current speeds are small and uniform with depth in the spring. As temperatures warm, currents accelerate in the epilimnion, reaching a maximum in early September, while currents decelerate in the hypolimnion, reaching a minimum in August (Bennett 1978). Fall mixing again makes the current speeds homogeneous (Lam 1978), and they decelerate and continue to flow through the winter (LSBP 2000). Lake Superior experiences seiches, which are internal gravity waves that form in response to wind or to changes in barometric pressure (LSBP 2000). Because of

Table 5. Classification of Lake Superior fisheries habitats by Lake Superior Technical Committee (LSBP 2000) and U.S. Fish and Wildlife Service (Newman 2003).

| Depth | Lake Superior Technical Committee | U.S. Fish and Wildlife Service |
|---|---|---|
| **Less than 9 meters** | | Nearshore |
| **10 meters or less** | "subset" of Nearshore | |
| **9-73 meters** | | Inshore |
| **Less than 80 meters** | Nearshore | |
| **Greater than 73 meters** | | Offshore |
| **Greater than 80 meters** | Offshore | |

the prevailing wind direction, PIRO has some of the highest wave exposure of any location on the lake (World Wildlife Fund Canada 1997).

PIRO's Lake Superior shoreline is a product of sedimentary rock deposition during the Cambrian era, 570-500 million years ago, and events during the Pleistocene and Holocene epochs of the last 10,000 years (LSBP 2000; Jerome 2005). In 1993, the National Oceanic and Atmospheric Administration (NOAA) identified and mapped 15 shoreline types in PIRO as part of a United States Environmental Protection Agency (USEPA) assessment of shoreline vulnerability to oil spills (Figure 13) (USEPA Region 5 2000). PIRO's shoreline types can be roughly described as rocky cliffs or bedrock shores (35%), human-made structures (1%), or sand, sand and gravel, or gravel beaches (63%) (Table 4). In addition, the mouth of Beaver Creek was specially classified as vegetated low to steep banks and mud flats (Table 4) (USEPA Region 5 2000). This classification differs from slightly, but substantially agrees with, that proposed by Newman (2003) who described PIRO's shoreline as 5.55 km of embayment with sandy substrate (9%), 37.56 km of predominantly sandy beach (60%), 16.45 km of cliff face (26%), and 3.01 km of large boulder shoals (5%).

For purposes of describing aquatic communities, the U.S. Fish and Wildlife Service (USFWS) divides Lake Superior waters into three zones based on depth: a "nearshore" where waters are <9 m in depth, an "inshore" of 9-73 m depth, and an "offshore" of >73 m depth (Newman 2003). An alternative, but similar classification has been proposed by the Lake Superior Technical Committee (LSTC), which defines a "nearshore" where waters are <80 m in depth (including both USFWS's "nearshore" and "inshore") and an "offshore" of >80 m depth (LSBP 2000). The LSTC also segregates a subset of the nearshore habitat in which the entire water column is subject to seasonal warming and cooling at about the 10 m depth, but does not give it a specific name (Table 5) (LSBP 2000).subject to seasonal warming and cooling at about the 10 m depth, but does not give it a specific name (Table 5) (LSBP 2000).

**Biological Resources**

*Aquatic and Shoreline Vegetation*

Lake Superior has been classified as an ultra-oligotrophic lake because of its low nutrient levels and cold temperatures (LSBP 2006). Consistent with this, Lake Superior generally has little to no aquatic vegetation (NPS 2002). Additional factors that limit aquatic vegetation specifically at PIRO include the frequent onshore winds and high wave exposure, the configuration of the shoreline, which includes sheer sandstone cliffs and unstable dunes, and the sandy composition of the shoreline substrates offshore of the beaches (NPS 2002).

Along the cliffs, the water depth is at least 1 m, and there is no submerged, floating, or emergent vegetation. Short sloping cliff bases along shorelines infrequently support terrestrial species such as butterwort (*Pinguicula vulgaris*), bird's eye primrose (*Primula mistassinica*), green alder (*Alnus viridis ssp. crispa*), mountain alder (*Alnus incana ssp. rugosa*), willow (*Salix spp.*), Labrador tea (*Ledum groenlandicum*), showy mountain ash (*Sorbus decora*), and two species of blueberries (*Vaccinium spp.*) (NPS 2002). The beaches and dunes support plant communities made up mainly of grasses and forbs. Above the wave line, Sand Point, Miners Beach, Chapel Beach, Twelvemile Beach, and Grand Sable Dunes have substantial vegetative cover, which includes slender wheat grass [*Agropyron trachycaulum* (now *Elymus trachycaulus*)], beach grass (*Ammophilia brevigulata brevigulata*), Canada wild rye (*Elymus canadensis*), beach wild wormwood (*Artemisia campestris var. caudata*), horsetails (*Equisetum spp.*), beach pea (*Lathyrus japonicus var. maritimus*), common evening primrose (*Oenothera biennis*), and sand cherry (*Prunus pumila*) (NPS 2002). Grand Sable Dunes is also home to the Pitcher's thistle (*Cirsium pitcheri*), which is on both the federal and state list of threatened species, and acute-leaved moonwort (*Botrychium acuminatum*) on the State Endangered Species list. Five species are found on the list of State Threatened species [calypso orchid (*Calypso bulbosa*), Lake Huron tansy (*Tanacetum huronense*), and three species of *Botrychium*]. An additional five Grand Sable Dunes species appear on the list of State Species of Concern [dune grass (*Elymus* (now *Leymus*) mollis), blue wild-rye (*Elymus glaucus*), ram's head orchid (*Cypripedium arietinum*), stitchwort (*Stellaria longipes*) and Douglas' hawthorn (*Crataegus douglasii*)] (NPS 2003).

*Phytoplankton, Zooplankton, Aquatic Invertebrates, and Benthos*

Both the zooplankton and phytoplankton communities of Lake Superior within the PIRO boundary are indicative of the lake's oligotrophic condition. Samples collected in summer 1970 at eight lake sites contained mainly diatoms, with some chrysomonads and one genus of green algae (Limnetics, Inc. 1970). Lake-wide, approximately 300 phytoplankton species are present (LSBP 2000). Phytoflagellates (including cryptomonads, chrysomonads, and dinoflagellates) comprise approximately 35 percent of the species, while diatoms comprise 31 percent and green algae comprise 22 percent (Munawar and Munawar 1978). In 1973, diatoms and phytoflagellates, especially cryptomonads and chrysomonads, contributed most of the lake-wide phytoplankton biomass. No clear seasonal trends were observed (Munawar and Munawar 1978). A 1998 study similarly found the lake dominated by cryptophytes, diatoms, and chrysophytes, and concluded that the results "suggest the lake has changed little in the past 20 years" (Barbiero and Tuchman 2001). However, Barbiero and Tuchman did find a difference in species composition between spring and summer. Species composition differs little between nearshore and offshore waters in the PIRO vicinity (Munawar and Munawar 1978).

In the open waters of Lake Superior, large calenoid copepods dominate the zooplankton community, with little change detected from the early 1960s to 1998 (Barbiero et al. 2001). Along the lake's southern and eastern shore, major embayments and inshore areas such as PIRO's have zooplankton communities dominated by herbivorous filter feeders such as cladocera and smaller diaptomid copepods. In spring and summer, these communities are dominated by calanoid copepod nauplii and copepodites, and in fall, experience a peak of calanoid adults, cladocerans, and cyclopoid copepods (Watson and Wilson 1978). Zooplankton samples collected in the Lake Superior waters of PIRO in 1970 contained twelve species and were dominated by the calenoid copepod *Diaptomus sicilis* (also called *Leptodiaptomus sicilis*) (Limnetics, Inc. 1970). Two large-bodied zooplankters, *Mysis relicta* and *Diporeia affinis*, are major components of the original Lake Superior food web (GLFC 2001).

Aquatic invertebrates of Lake Superior have not been surveyed at PIRO, but their numbers and diversity along the Lake Superior shoreline are expected to be low and generally associated with creek mouths and wetlands (NPS 2002). Benthos samples collected in 1970 were mainly clean sand and contained no benthos, except for a sample from Munising Bay, which contained two unidentified oligochaetes and a snail species (Limnetics, Inc. 1970).

*Fish*

A comprehensive survey of the lakewide fish communities of Lake Superior was conducted by Lawrie (1978). Seventy-three fish species belonging to 18 families are known to have occurred in the whole of Lake Superior and its tributaries during the 20th century (Lawrie 1978). They can be classified according to the trophic level they occupy as adults (Table 6) (GLFC 2001). The original Lake Superior food web of the offshore and nearshore open waters was simple: lake herring (*Coregonus artedii*) fed on zooplankton and were in turn eaten by lake trout (*Salvelinus namaycush*), and deepwater ciscoes (*Coregonus spp.*) and deepwater sculpin (*Myoxocephalus thompsoni*) were the primary prey of siscowet lake trout in the offshore zone (GLFC 2001). In addition, coaster brook trout (*Salvelinus fontinalis*) lived part of their life in the lake, but returned to tributary streams to spawn in early autumn (Trout Unlimited 2005). Today, lake herring, bloater (*Coregonus hoyi*), and the non-native rainbow smelt (Osmerus mordax) are the three important planktivores on zooplankton or phytoplankton. Kiyi (*Coregonus kiyi*), lake whitefish (*Coregonus clupeaformis*), brook trout, ninespine stickleback (*Pungitius pungitius*), slimy sculpin (*Cottus cognatus*), deepwater sculpin,

**Table 6. Ecological roles of important Lake Superior fish species, including (*non-native species) (from GLFC 2001).**

| Planktivores<br>Diet predominantly zooplankton or phytoplankton | Benthivores<br>Diet predominantly macroinvertebrates | Piscivores<br>Diet predominantly fish |
|---|---|---|
| Lake herring | Kiyi | Coho salmon* |
| Bloater (deepwater ciscoes) | Lake whitefish | Chinook salmon* |
| Rainbow smelt * | Brook trout | Sea lamprey* |
| | Ninespine stickleback | Lake trout |
| | Slimy sculpin | Rainbow trout* |
| | Deepwater sculpin | Brown trout* |
| | Lake sturgeon | Burbot |
| | | Walleye |

and lake sturgeon (*Acipenser fulvescens*) are benthivores on macroinvertebrates. Three native species [lake trout, burbot (*Lota lota*), and walleye (*Sander vitreus*)] and five introduced species [coho salmon (*Oncorhynchus kisutch*), Chinook salmon (*Oncorhynchus tshawytscha*), rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), and sea lamprey (*Petromyzon marinus*)] feed mainly on other fish (GLFC 2001).

Fish species can also be classified according to the habitat they generally occupy. About 77% of Lake Superior consists of offshore (>80 m) habitat. Fish species in this community consist of pelagic adult lean lake trout, siscowet lake trout, burbot, Pacific salmon, sea lamprey, deepwater ciscoes, lake herring, and deepwater sculpins. The remaining 23% nearshore habitat contains a larger fish community that includes lean lake trout, siscowet lake trout, humper lake trout, burbot, Pacific salmon, brown trout, lake herring, lake whitefish, round whitefish (*Prosopium cylindraceum*), rainbow smelt, lake sturgeon, ninespine sticklebacks, pygmy whitefish (*P. coulteri*), deepwater ciscoes, slimy and deepwater sculpins, trout perch (*Percopsis omiscomaycus*), and longnose (*Catostomus catostomus*) and white suckers (*C. commersoni*) (GLFC 2001). In addition, Lake Superior fish such as walleye, brook trout, burbot, lake sturgeon, Pacific salmon, longnose and white suckers, redhorse suckers (*Moxostoma* spp.), mottled sculpin (*Cottus bairdii*), bullheads (*Ictalurus* spp.), sea lamprey, and many species of minnows depend on spending all or part of their lives in tributaries.

Studies on Lake Superior fisheries within PIRO are rather limited. Edsall (1960) studied whitefish in nearby Munising Bay (outside PIRO) and provided some data on age and

**Table 7. Fish species and numbers identified in a survey of Lake Superior waters <9 m in depth in Pictured Rocks National Lakeshore, 2002. *Species noted for the first time (Newman 2003).**

| Common name | Scientific name | Number |
|---|---|---|
| Longnose sucker | *Catostomus catostomus* | 535 |
| *Trout-perch | *Percopsis omiscomaycus* | 245 |
| Rainbow trout (steelhead) | *Oncorhynchus mykiss* | 210 |
| *Lake chub | *Couesius plumbeus* | 197 |
| White sucker | *Catostomus commersoni* | 101 |
| Longnose dace | *Rhinichthys cataractae* | 79 |
| Round whitefish | *Prosopium cylindraceum* | 70 |
| *Ninespine stickleback | *Pungitius pungitius* | 65 |
| Logperch | *Percina caprodes* | 60 |
| Yellow perch | *Perca flavescens* | 42 |
| Slimy sculpin | *Cottus cognatus* | 31 |
| Splake (brook trout x lake trout) | *Salvelinus fontinalis x namaycush* | 14 |
| Coho salmon | *Oncorhynchus kisutch* | 13 |
| Lake whitefish | *Coregonus clupeaformis* | 11 |
| Alewife | *Alosa pseudoharengus* | 9 |
| Burbot | *Lota lota* | 9 |
| Emerald shiner | *Notropis atherinoides* | 6 |
| Spottail shiner | *Notropis hudsonius* | 6 |
| Johnny darter | *Etheostoma nigrum* | 5 |
| Mottled sculpin | *Cottus bairdii* | 4 |
| Walleye | *Sander vitreus* | 4 |
| Brook stickleback | *Culaea inconstans* | 4 |
| Northern pike | *Esox lucius* | 1 |
| Pink salmon | *Oncorhynchus gorbuscha* | 1 |
| Lake herring | *Coregonus artedii* | 1 |
| Chinook salmon | *Oncorhynchus tshawytscha* | 1 |
| Brook trout | *Salvelinus fontinalis* | 1 |
| Blacknose shiner | *Notropis heterolepis* | 1 |
| Pumpkinseed | *Lepomis gibbosus* | 1 |

Table 8. Selected physical, chemical and biological characteristics of some inland lakes in Pictured Rocks National Lakeshore (Humphreys and Colby 1965; Doepke 1972; Kamke 1987; Loope 1998a).

| Lake | Surface area (ha) | Maximum depth (m) | Mean depth (m) | Shoreline length (m) | DO (mg/L) | TSI | Stratification | Secchi transparency (m) |
|---|---|---|---|---|---|---|---|---|
| Beaver | 309.6 | 13.1 | 6.7 | 7704 | orthograde to anoxic in hypolimnion | 40-47 | cold polymictic, | 3.2 |
| Grand Sable | 306.8 | 20.1 | 9.9 | 9920 | abundant at all times of year | 20-54 | dimictic thermocline 4-7 m | 3.1-3.7 |
| Kingston (IBZ) | 101.2 | 9.8 | | | | | | |
| Chapel | 30.5 | 43.9 | 14.9 | 4224 | deepest 18 m anaerobic | 35-46 | meromictic | 2.5 |
| Trappers | 20.3 | 1.9 | 1.7 | 2400 | | 37-42 | none | bottom |
| Little Beaver | 16.2 | 6.5 | 3.3 | | anoxic hypolimnion in summer months | 45-53 | dimictic | 1.4-2 |
| Legion (IBZ) | 13.8 | | 10-13 | | metalimnetic maximum, decreasing markedly toward bottom | | dimictic | 7-8.5 |
| Upper Shoe (IBZ) | 12.5 | | | | | | | |
| Lower Shoe (IBZ) | 8.5 | | | | | | | |
| Miners | 5.3 | 4.0 | 2.0 | 950.9 | orthograde to low in hypolimnion | 37-44 | partial | 2.7 |
| Section 36 (IBZ) | 4.9 | 3.7 | | | | | | |
| Little Chapel | 2.4 | | | | | 46 | | |
| Sevenmile | 1.94 | | | | | | | |
| Hyde | 0.77 | | | | | | | |

**Table 9. Selected physical characteristics of named streams in Pictured Rocks National Lakeshore (Handy and Twenter 1985; Michigan DNR Watershed Council 2000).**

| Stream | Length (km) | Watershed | Watershed area (ha) | Discharge ($m^3sec^{-1}$) |
|---|---|---|---|---|
| Munising Falls Creek | 2.35-2.5 | Munising Falls Creek | 502 | 0.028-0.119 |
| Miners River | 13.4 | Miners River | 6,863-7,044 | 0.356-3.030 |
| Mosquito River | 8.5 | Mosquito River | 3,418-3,600 | 0.107-1.087 |
| Chapel Creek | 5.3 | Chapel Creek | 2,188-2,486 | 0.059-0.609 |
| Section 34 Creek | 2.5 | Chapel Creek | | 0.128 |
| Spray Creek | 5.6 | Spray Creek | 1,846-1,580 | 0.096-0.390 |
| Beaver Creek | 1 | Beaver Creek | 2,694-3,962 | 0.518-1.127 |
| Lowney Creek | 3.1 | Beaver Creek | | |
| Arsenault Creek | 1.7 | Beaver Creek | | |
| Little Beaver Creek | 2.9 | Beaver Creek | | |
| Bills Creek | 1.3 | Beaver Creek | | |
| Sevenmile Creek | 2.5 | Sevenmile Creek | 2,103 | 0.439-0.694 |
| Sullivan Creek | 6.9 | Sullivan Creek | 1,885 | 0.068-0.210 |
| Hurricane River | 5.6 | Hurricane River | 3,548 | 0.269-0.844 |
| Sable Creek | 3.2 | Sable Creek | 3,263-5,024 | 0.079-1.246 |
| Towes Creek | 3.6 | Sable Creek | | |
| Rhody Creek | 4.5 | Sable Creek | | |
| DeMull Creek | 2.0 | Sable Creek | | |

growth. The MIDNR estimated that up to 30 species of fish in 17 families occur in Lake Superior waters adjacent to PIRO (NPS 2002). Newman (2003) compiled data from several sources to create a list of 52 species recorded from nearshore (<9 m depth) waters of Lake Superior, but found only 29 species in PIRO in 2002, including nine not previously documented (Table 7). He collected 210 non-native rainbow trout, but only one native brook trout. Not found were lake sturgeon, shorthead redhorse, pygmy whitefish, common carp (*Cyprinus carpio*), or the amphibian mud puppy (*Necturus maculosus*), which are known to occur in nearshore waters elsewhere in the lake. Newman stated that habitat diversity was low and could not sustain all species for an extended period of time. The greatest fish diversity occurred in the embayment of South Bay and around the rocky point around Au Sable Point; medium diversity occurred along the cliff faces of the Pictured Rocks, and low diversity was found along the beaches (Newman 2003). The nearshore zone of PIRO is considered important spawning habitat for round whitefish, lake whitefish, and lake trout, which are commercially important species (LSBP 2000).

Within PIRO, several attempts have been made to return native Lake Superior fish to their habitats. In the 1980s, the extirpated arctic grayling (*Thymallus arcticus*) was unsuccessfully re-introduced in Section 34 Creek and Spray Creek (NPS 2003). Baker et al. (1999) developed an action plan for restoring coaster brook trout to PIRO, evaluated potential impediments to coaster brook trout rehabilitation efforts such as harvest, habitat, and genetics, and recommended three streams for coaster brook trout reintroduction. Coaster brook trout were experimentally re-introduced in the Mosquito and Hurricane Rivers and Sevenmile Creek five times during 1997–2003, in concert with a Lake Superior-wide restoration program initiated by the Great Lakes Fishery Commission (NPS 2003). Currently several research projects are being conducted by Northern Michigan University involving coaster migrations from PIRO streams into Lake Superior and their return (NPS 2003). PIRO staff have expressed concern about the MIDNR's proposal to stock 25,000 yearling coho salmon in the Anna River each year from 2002-2008, because of the closeness of the river to PIRO and the potential for competition between coho salmon and coasters (NPS 2003).

## Water Resources of Inland Waters

**Physical and Chemical Characteristics**

*Inland Lakes*

The 14 named inland lakes within PIRO's shoreline zone and IBZ range in size from several hectares to over 300 (Table 8). Bog lowlands are associated with several of the lakes and are common within the area. The larger inland lakes within PIRO include Grand Sable, Beaver, Little Beaver, Chapel, Little Chapel, Miners, Trappers, Legion, Kingston, and the Shoe Lakes. Most of these lakes are shallow (3-6 m), except for Beaver, Chapel, and Grand Sable Lakes, and have Secchi transparency readings from 2-5 m. The water chemistry of PIRO lakes can vary widely, but generally most lakes can be classified as brown water, moderately productive alkaline lakes.

*Streams*

Miners River, PIRO's longest stream, has an average discharge at the mouth of 1.3 cubic meters/second ($m^3sec^{-1}$) in June, falling to 0.6 $m^3sec^{-1}$ in late summer and autumn. Hurricane and Mosquito Rivers have similar spring and early summer discharges around 0.5 $m^3sec^{-1}$, although the Mosquito River's discharge drops more quickly as the summer progresses (NPS 2003). Other PIRO streams, including Munising, Chapel, Section 34, Spray, Sevenmile, Beaver, Rhody, Sullivan, and Sable Creeks, are shorter and discharge less water (Table 9). Beaver and Sable Creeks have less seasonal fluctuation, and higher temperatures from July until late fall, since they flow from lakes (NPS 2003). Current hydrography does not delineate many first order streams with small watersheds and short distances to Lake Superior.

Water levels in streams that are perched above bedrock are very flashy and are responsive to heavy rainfall and snowmelt (Stottlemyer and Rutkowski 1990; Boyle et al. 1999). Stream discharge can double in several hours after heavy rains, and seasonal variation can be as high as a factor of 10 (Handy and Twenter 1985). Some streams are intermittent annually, with no flow connecting standing water pools above beaver ponds. Except for the Hurricane River and Sullivan Creek, the streams have relatively steep gradients. Most contain many riffles, and some have knickpoints (waterfalls) at severe drops over the Cambrian Sandstone bedrock. Only Miners River is suitable for canoeing, and woody debris makes even that difficult. All named PIRO streams are second order streams except for the Mosquito River, which is third order (NPS 2003). Stottlemyer (1982a) indicated that the upper portions of the first order streams are able to quickly neutralize acidic precipitation.

Stream substrates are generally composed of cobble/gravel, sand, and bedrock. Pools are usually formed due to the hydraulic action of flowing water on submerged structures, with some the result of scouring at meander bends. The depositional substrate occurring in reduced flow areas is mostly mud, silt, or both (NPS 2003). The most productive substrate for the invertebrate organisms that form the base of the food chain is a mixture of cobble and rubble, including some organics

*Wetlands*

Estimates vary as to the percent of PIRO that is covered by wetlands. The shoreland zone is estimated to be 8% (NPS 2005a), 13% (MIDNR 2003), and 18% (USFWS 1994) wetlands, while the park as a whole is estimated to be 7%, 14%, and 16% wetlands by the same sources, respectively. The National Wetlands Inventory map for PIRO shows the location of wetlands within the park (Figure 14). Palustrine wetlands are more common (67.2%) than lacustrine ones (32.9%), and of palustrine wetlands, most are forested (Table 10). A complete listing of wetland acreages by National Wetlands Inventory system, subsystem, class, and subclass is included as Appendix C.

**Table 10. Percentages of wetlands by National Wetlands Inventory system, subsystem, and class for Pictured Rocks National Lakeshore's shoreline zone, IBZ, and park as a whole (USFWS 1994).**

| System | Subsystem | Class | Shore | IBZ | Park |
|---|---|---|---|---|---|
| Lacustrine | | | 32.9% | 4.7% | 19.3% |
| | Littoral | | 4.8% | 0% | 2.5% |
| | Limnetic | | 28.0% | 4.7% | 16.8% |
| Palustrine | | | 67.2% | 95.3% | 80.7% |
| | | Emergent | 0.9% | 3.2% | 2.0% |
| | | Forested | 60.1% | 85.4% | 72.2% |
| | | Scrub-Shrub | 4.7% | 5.2% | 4.9% |
| | | Unconsolidated Bottom | 1.5% | 1.5% | 1.5% |

Four major bog areas have been identified within PIRO: at Sand Point, northeast of Beaver Lake, around Legion Lake, and east of Twelvemile Beach campground. Most bogs that occur within PIRO are filled-in lake beds that have a Sphagnum spp. base with leatherleaf (*Chamaedaphne calyculata*), bog rosemary (*Andromeda glaucophylla*), bog laurel (*Kalmia polifolia*), and cranberries (*Vaccinium macrocarpon, V. oxycoccos*), as well as several species of orchids. The best examples of marshes in PIRO are found around Miners and Little Chapel Lakes (NPS 2003).

*Vernal Pools*

Vernal pools are small, temporary pools that are common in PIRO during and following snowmelt. They provide a direct linkage between the terrestrial and aquatic habitats, since many species utilize both ecosystems during their life cycle (Williams 1996). Vernal pools provide important habitat and cover for amphibians, invertebrates, and some mammals at a critical time in their life cycles. Rare species, as well as more than 550 species of multi-cellular animals (including microcrustaceans, aquatic insects, reptiles, birds, and mammals), have been reported to occur in vernal pools (Colburn 2004), and many have adapted unique survival strategies designed to ensure success in these highly variable habitats (Batzer et al. 2004).

Little is known about the distribution or ecology of PIRO's vernal pools, although aerial photographic studies show that they are abundant

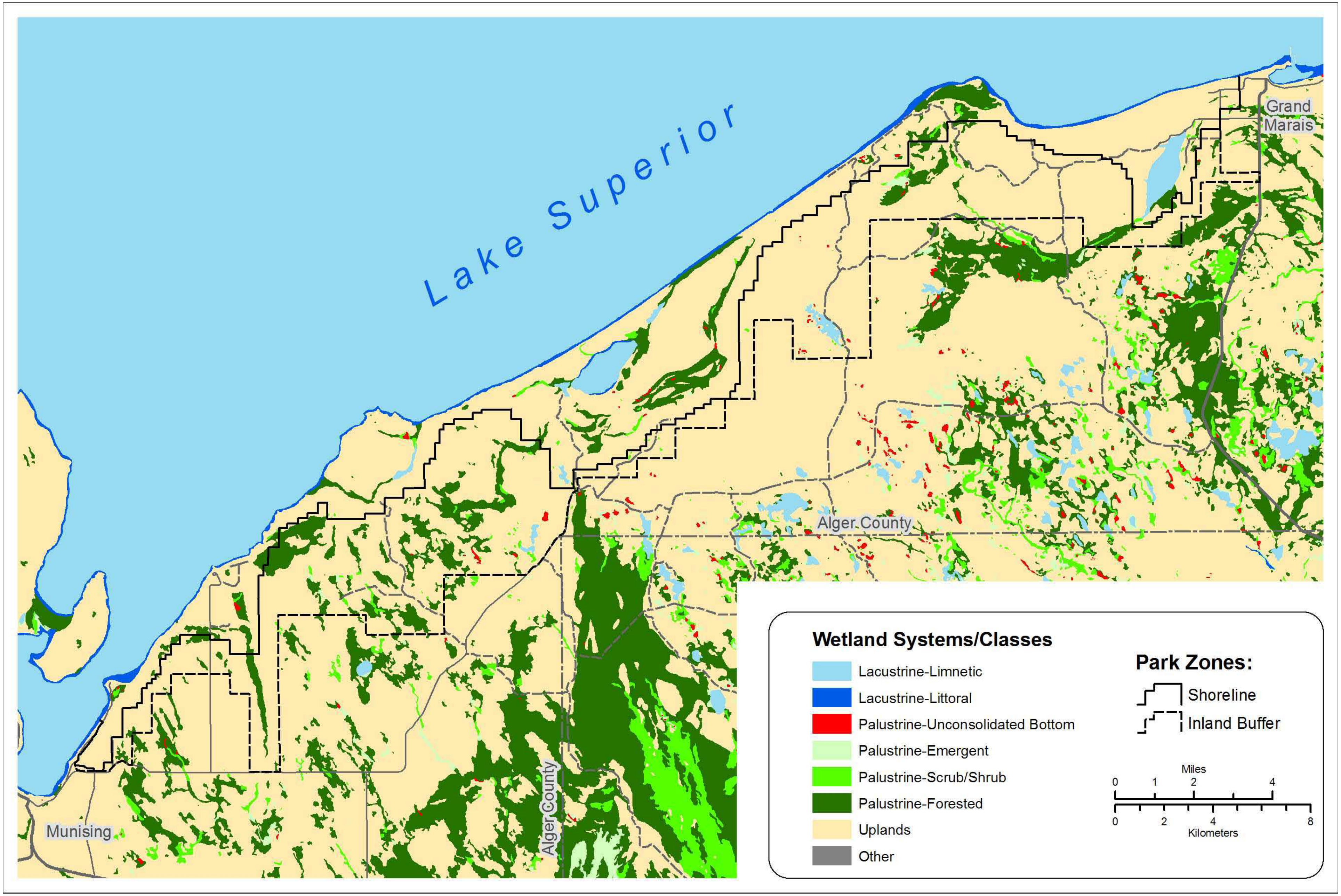


Figure 14. National Wetlands Inventory for the Pictured Rocks area.
(Source: USFWS 1994)

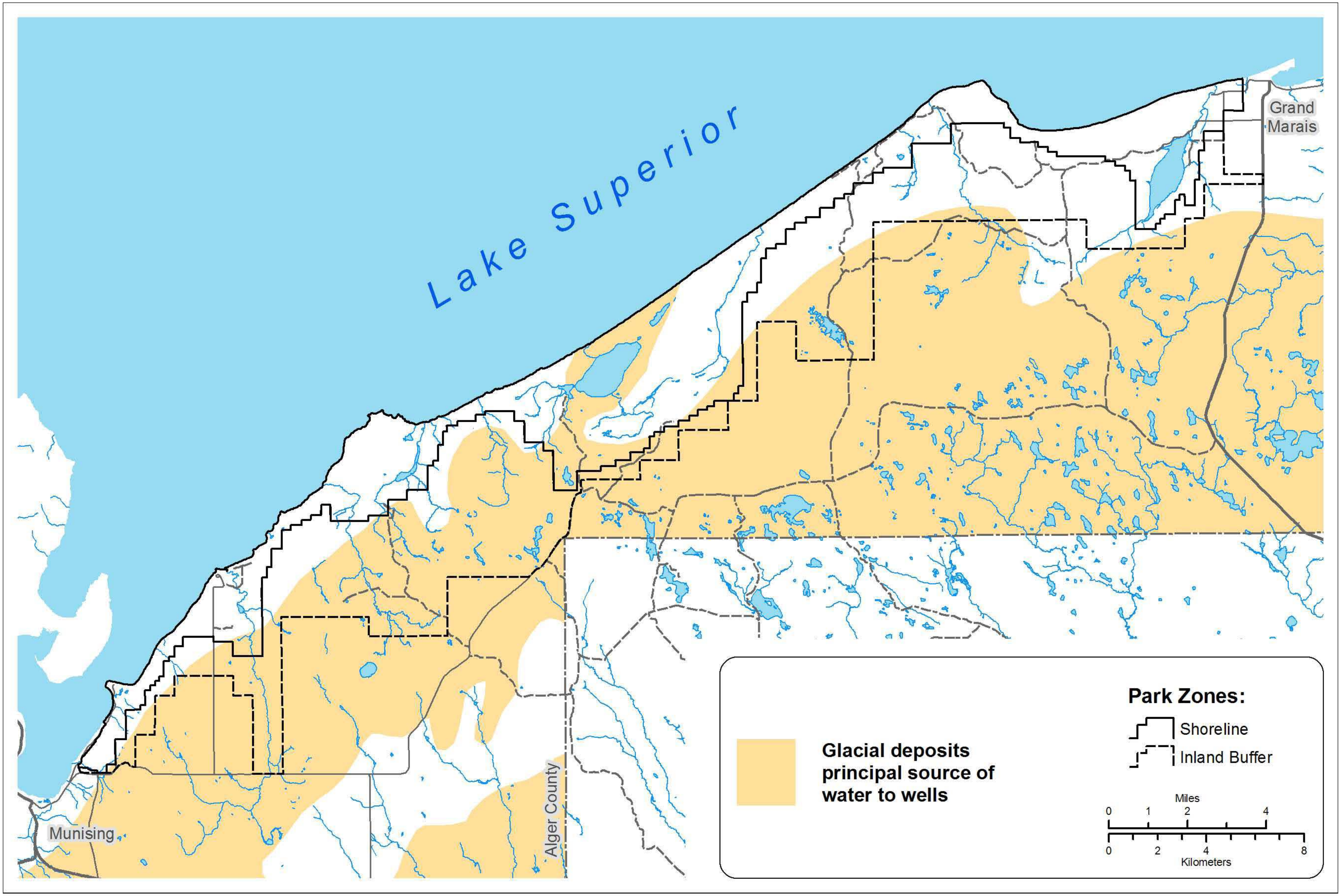


Figure 15. Areas of Alger County, Michigan where glacial deposits are the principal source of water to wells.
(Source: After Vanlier 1963)

(LaFrancois 2006). Casper (2005) found that vernal pools in PIRO support fish-intolerant fairy shrimp (*Eubranchipus* sp.), and may provide breeding habitat for the spotted, blue-spotted, and four-toed salamanders, as well as the wood frog and northern spring peeper. DeBruyn (1997) reported that female black bears (*Ursus americanus*) and their cubs feed extensively on the young sprouting plants of vernal pools near PIRO.

The greatest threats to vernal pools in PIRO appear to be invasive species, climate change, hydrologic modifications to surface and groundwater, and disturbance from logging and road construction and maintenance activities within the watershed (LaFrancois 2006). The protection of vernal pool habitat is critical to ensure continued reproductive success of PIRO's frogs and salamanders (Casper 2005). Widespread amphibian declines have been observed where vernal pools have been degraded (Reaser 2000) and might also be expected with degradation of PIRO's vernal pools.

*Groundwater*

Groundwater is an important conduit for the transport of water off the landscape and into Lake Superior and its tributaries. For Lake Superior as a whole, an estimated 75% of terrestrially originating lake water originates as groundwater (Holtschlag and Nicholas 1998). For Michigan Upper Peninsula tributaries to Lake Superior, 74-90% of the flow of gaged streams was attributable to groundwater discharge (Holtschlag and Nicholas 1998).

Aquifers in the vicinity of PIRO include the glacial drift, the Trenton and Black River limestones, the Prairie du Chien group and Trempealeau formation (also known as undifferentiated Ordovician and Cambrian dolomite and sandstone), the Munising Sandstone, and the Jacobsville Sandstone (Vanlier 1963; Handy and Twenter 1985). All PIRO aquifers derive their water directly or indirectly from precipitation.

Glacial drift in PIRO ranges from 0-60 m thick, but the distribution of its thickness and where it is saturated are not precisely mapped. The map of Vanlier (1963) (Figure 14) shows that the drift is not a principal source of water to wells in much of PIRO, but this certainly underestimates the importance of the drift to PIRO hydrology. The specific capacity of the drift aquifer has been estimated to range from 18-250 $m^2 day^{-1}$ (Handy and Twenter 1985), with the outwash of the Wetmore and Kingston plains being the most permeable sediment in PIRO's vicinity (Vanlier 1963). Potential well yields there are estimated at hundreds to thousands of liters per minute.

The Black River and Trenton limestones are important water sources in the southwestern part of Alger County (Vanlier 1963), but not for PIRO (Handy and Twenter 1985). Below the Black River and Trenton limestones, the Prairie du Chien group and Trempealeau formation are sometimes considered a distinct aquifer (Handy and Twenter 1985) and included in the Munising Sandstone aquifer as "undifferentiated rocks of the Ordovician and Cambrian periods" (Vanlier 1963). Little is known about the water-yielding characteristics of this aquifer (Handy and Twenter 1985).

The Munising Sandstone is one of the principal aquifers in the Upper Peninsula (Handy and Twenter 1985), but few wells in the PIRO area make use of it because shallower aquifers are available. Its specific capacity is approximately 18 $m^2 day^{-1}$, and it is generally capable of yielding 20-60 liters per minute to wells (Handy and Twenter 1985). The Jacobsville underlies all of Alger County, and is important along Lake Superior as the only source of water to wells (Vanlier 1963). It is a well-cemented sandstone with low primary permeability, but where it is exposed or near the surface, it is extensively fractured and so has a higher secondary permeability. Its specific capacity is the lowest of the aquifers in PIRO at 1.8-18 $m^2 day^{-1}$.

**Biological Resources**

*Phytoplankton*

Fifty-one taxa of blue green algae (Cyanophyta), dinoflagellates (Pyrrhophyta), yellow brown algae (Chrysophyta), diatoms (Bacillariophyta), and green algae (Chlorophyta) have been collected from inland lakes within PIRO. The diatoms *Asterionella formosa*, *Fragilaria intermedia*, *Aulacoseira islandica*, and *Tabellaria fenestrate*, and the blue-green algae *Aphanizomenon flos-aquae*, *Aphanocapsa rivularia*, *Chroococcus limneticus*, and *Lyngbya birgei* represent the major taxa in most lakes. Legion Lake, a softwater lake, supports the filamentous green alga *Bulbochaete* sp., *Batrachospermum* sp., a unique red alga, is found in Chapel Creek, Section 34 Creek, Little Beaver Creek, and Mosquito River. *Ulothrix* and *Spirogyra*, filamentous green algae which can grow strands up to several meters, can be found in streams with bedrock substrate such as near the mouth of the Mosquito River. Attached diatoms (Bacillariophyta) are common in most streams (NPS 2003).

*Zooplankton*

The zooplankton communities of PIRO lakes vary among the lakes and with depth and season. Thirty-five taxa of cladocerans (waterfleas), 11 species of calanoid and cyclopoid copepods (aquatic crustaceans), and two genera of rotifers (aquatic invertebrates) are known to occur in eight lakes within PIRO. These communities tend to be dominated by a few species including one cladoceran species, one calanoid copepod species, and one cyclopoid copepod species. The cladocerans *Bosmina longirostris*, *Eurycercus lamellatus, Daphnia galeata mendotae, Holopedium gibberum*, and *Pseudochydorus globosus*; the calanoid copepods *Skistodiaptomus oregonensis* and *Epischura lacustris*; the cyclopoid copepods *Cyclops vernalis* and *Diacyclops bicuspidatus thomasi*; and rotifers of the genus *Keratella* are the dominant zooplankton in PIRO lakes (NPS 2003).

*Aquatic Macrophytes*

The aquatic macrophyte communities of PIRO are poorly known (LaFrancois and Glase 2005), since most available information is from surveys conducted for limited time periods on a limited number of lakes (e.g. Doepke 1972; Crispin et al. 1984; Kamke 1987). Doepke (1972) found nine species of aquatic macrophytes in Beaver Lake, 16 species in Little Beaver Lake, and 20 species in Grand Sable Lake. Crispin et al. (1984) conducted a higher plant survey of PIRO and found two species of special concern, the water starwort (*Callitriche hermaphroditica*) and the alternate flower water-milfoil (*Myriophyllum alterniflorum*), but not the previously reported state-threatened species Farwell's milfoil (*Myriophyllum farwellii*) or the bog aster (*Aster nemoralis*), and they recommended additional studies. Kamke (1987) found pond-lilies (Nuphar sp.) and bladderworts (*Utricularia* sp.) in Miners and Chapel Lakes, horsetails in Miners, Chapel, and Grand Sable Lakes, water-milfoils (*Myriophyllum* sp.) in Miners, Beaver, and Grand Sable Lakes, pondweed (*Potamogeton* spp.) in Chapel, Beaver, and Grand Sable Lakes, coon's tail (*Ceratophyllum demersum*) in Chapel Lake, water plantain (*Alisma* sp.) in Beaver Lake, and Canadian waterweed (*Anacharis* sp.) in Grand Sable Lake. Essentially no information is available for the aquatic macrophyte communities in PIRO bogs, wetlands, vernal pools, or streams. Future efforts are needed to characterize these communities in light of the potential effects of global climate change and invasive species.

*Macroinvertebrates*

The benthic (bottom dwelling) invertebrate diversity of the inland lakes is high, and 108 taxa have been collected. Major taxa include Hemiptera (water bugs), Coleoptera (water beetles), Trichoptera (caddisflies), Lepidoptera (butterflies), Odonata (dragonflies and damselflies), Ephemeroptera (mayflies), Megaloptera (fishflies and alderflies), Diptera (true flies), Oligochaeta (aquatic earthworms), Hirudinea (leeches), Tardigrada (water bears), Amphipoda (side swimmers), Ostracoda (seed shrimp), Isopoda (aquatic sow bugs), Gastropoda (snails and limpets), Pelecypoda (clams), Decapoda (crayfish), Porifera (freshwater sponges), and Bryozoa (moss animalcules). Littoral zones generally have the highest diversity, in part because of greater substrate diversity and available niche space, while profundal zones are dominated by midge larvae (NPS 2003).

One hundred seventy-three taxa of aquatic macroinvertebrates have been collected from PIRO streams and rivers, including Hemiptera, Coleoptera, Trichoptera, Plecoptera, Odonata, Ephemeroptera, Megaloptera, Diptera, Oligochaeta, Amphipoda, Hirudinea, Gastropoda, and Decapoda. Three riffle beetles (Coleoptera, Elmidae), *Macronychus glabratus, Optioservus fastiditus*, and *Stenelmis crenata*, were collected in the mid -1990s and represent new records for Alger County, MI. Porifera, Coelenterata (hydra), Bryozoa (moss animalcules), and Turbellaria (planaria) are also commonly collected (NPS 2003).

Boyle et al. (1999) studied six lakes (Beaver, Chapel, Legion, Grand Sable, Miners, and Section 36 Lakes) and five streams (Mosquito, Miners, Hurricane Rivers and Sevenmile and Sullivan Creeks) in PIRO to determine human impacts of activities such as road building and timber harvest. They established a statistically significant link between substrate size (sand/silt, gravel, and cobble) and variations in the community structure of the benthic macroinvertebrate community in the Mosquito, Miners and Hurricane Rivers.

### *Mussels*

Nichols et al. (2001) surveyed the unionid mussel populations in PIRO and found generally healthy, stable communities in Beaver, Little Beaver, Trappers, and Kingston Lakes, composed of multiple year classes and exhibiting successful recruitment. However, Grand Sable Lake's community, which has several species found nowhere else in the park, is on the verge of extirpation. In all lakes, clams colonized areas above the hypolimnion, and unionid densities were therefore related to the available shallow littoral area above the thermocline. Overall, the species richness of unionid communities within PIRO was low but fairly typical of other lake populations in the Midwest. Unionids do not occur in PIRO streams, most likely due to the severe winter low temperatures and lack of soft substrates typically used for burrowing. The maximum density of clams in PIRO was $3.37/m^2$, much lower than the maximum density of clams Nichols et al. (2001) found in Isle Royale lakes ($33/m^2$). Reasons for the lower densities at PIRO were unclear because of a lack of historical unionid density data. They also found that female *Lampsilis* spp. had a shorter life span in PIRO than in other areas within their geographic range.

Nichols et al. (2001) further concluded that zebra mussel (*Dreissena polymorpha*) populations within the Great Lakes Basin are probably the largest factor in reducing the diversity of mussel communities and indicated that within 10-15 years the communities in PIRO may become key remnant fauna. They stated that exotic species such as the zebra mussel and round goby (*Neogobius melanstomus*) are the greatest threat to unionid populations in PIRO and recommended that Big Beaver, Kingston, and Little Beaver Lakes be surveyed every 10 years.

### *Herptiles*

A 2004 inventory of reptiles and amphibians in PIRO confirmed the presence of 17 species (five salamanders, five frogs and toads, three turtles, and four snakes). Five species of salamanders were found, including the spotted salamander (*Ambystoma laterale*), blue-spotted salamander (*Ambystoma maculatum*), four-toed salamander (*Hemidactylium scutatum*), eastern newt (*Notophthalmus viridescens*), and red-backed salamander (*Plethodon cinereus*). Five frog and toad species were found, including the American toad (*Bufo americanus americanus*), eastern gray treefrog (*Hyla versicolor*), northern spring peeper (*Pseudacris crucifer crucifer*), green frog (*Rana clamitans melanota*), and wood frog (*Rana sylvatica*). Three turtles were present, including the eastern snapping turtle (*Chelydra serpentina serpentina*), painted turtle (*Chrysemys picta*), and accidental occasional wood turtles (*Glyptemys insculpta*). Four snakes are also present, including northern watersnake (*Nerodia sipedon sipedon*), smooth greensnake (*Opheodrys vernalis*), northern red-bellied snake (*Storeria occipitomaculata occipitomaculata*), and eastern gartersnake (*Thamnophis sirtalis sirtalis*). Another four herptile species [common mudpuppy (*Necturus maculosus maculosus*), northern leopard frog (*Rana pipiens*), mink frog (*Rana septentrionalis*), and northern ring-necked snake (*Diadophis punctatus edwardsii*)] were likely present, but unconfirmed (Casper 2005). Natural openings, such as the sandscapes at Sand Point and Chapel Beach, are important to smooth greensnakes and to pregnant snakes of all species. The shrub wetlands with moss hummocks on Sand Point are important habitat for four-toed salamanders. Sand Point also appears to provide good habitat for northern leopard frogs, even though none were found in the 2004 inventory (Casper 2005).

### *Fish*

The streams and lakes within PIRO do not support large populations of fish because of their relatively low productivity; however, some populations of trout and cool water game fish do occur. Smallmouth bass (*Micropterus dolomieu*), northern pike, walleye, yellow perch, and non-native rainbow smelt are the major cool water game species found within PIRO, while brook trout, lake trout, and non-native rainbow trout or steelhead are the major cold water fish species found (NPS 2003).

Most PIRO fish studies have included information on species present, age and growth statistics and relative abundance (Doepke 1972; Gruhn 1976; Grim 1990a, 1990b). Gerovac and Whitman (1995) studied nine streams, a channel connecting Beaver and Little Beaver Lakes, and four lakes within PIRO boundaries. They found a total of 19 different fish species, but because they used only seining as a method of capture, they probably did not collect all species present. Boyle et al. (1999) collected 11 species in five PIRO streams using electroshocking gear. A comprehensive fisheries literature review and personal interviews of local residents by Vogel (2000) is an important resource for information on historic changes, stocking, and species presence.

Newman (2005) conducted a larger fish survey of Chapel, Spray, and Sable Creeks and two unnamed tributaries, Trappers, Chapel, Hyde, and Grand Sable Lakes, and six unnamed PIRO ponds, concentrating on species that were likely to occur but not previously documented. Using gill nets, Windermere nets, and backpack electrofishing gear, 595 fish from 21 species were captured. The only species new to PIRO was the western blacknose dace (*Rhinichthys atratulus*). Seven other species whose geographic ranges include PIRO were not collected and most likely do not occur in PIRO. They are the brassy minnow (*Hybognathus hankinsoni*), silver lamprey (*Icthyomyzon unicuspis*), yellow bullhead (*Ictalurus natalis*), silver redhorse (*Moxostoma anisurum*), shorthead redhorse (*Moxostoma macrolepidotum*), mimic shiner (*Notropis volucellus*), and pearl dace (*Semotilus margarita*). Rainbow trout found upstream from Chapel Lake may be a land-locked reproducing population due to the bedrock cascade waterfall at the mouth of the stream.

**Watersheds and Limnological Characteristics**

PIRO fully or partially contains 14 watersheds designated by the MIDEQ (1998) (Figure 16). However, some of these large-scale watersheds contain more than one distinct waterbody or drainage area. This report follows other researchers (Handy and Twenter 1985; MIDNR Watershed Council 2000) and discusses 14 significant watersheds and subwatershed areas. From west to east, they are the Munising Falls watershed, the Sand Point watershed, the Miners River watershed, the Mosquito River watershed, the Little Chapel Lake watershed, the Chapel Creek watershed, the Spray Creek watershed, the Beaver watershed, the Sevenmile Creek watershed, the Twelvemile Bog and Pond area, the Sullivan Creek watershed, the Hurricane River watershed, and the Sable watershed, all of which drain to Lake Superior, and the Legion-Section 36-Shoe Lakes area, whose watershed drains to Lake Michigan. In addition, there are many small (85 ha or less) unnamed watersheds within the shoreline zone. These small creeks often have wetland headwaters and perennial flow, but no lentic habitats, and are not discussed in detail here. The discussion that follows is largely based on PIRO's Draft Aquatic Monitoring Plan (Loope 2004). Stream lengths were calculated from the Michigan Geographic Framework and NPS 1:24000 hydrography coverages (Michigan Center for Geographic Information 2005; NPS 2005f).

*Munising Falls Area*

The Munising Falls area at PIRO's western end is considered part of a larger watershed by the MIDEQ (1998) (Figure 16), but has been separately delineated as 502 ha by Handy and Twenter (1985). The 2.35-2.5 km Munising Falls Creek originates in marshes both within and outside PIRO, and flows northwest to join Lake Superior at Munising Falls. Recorded discharges range from 0.03 $m^3sec^{-1}$ (August 1981) to 0.12 $m^3sec^{-1}$ (June 1979) (Handy and Twenter 1985). Sea lamprey are known to spawn in this creek (Smith et al. 1974).

Other unnamed streams that enter Lake Superior between Munising and the Miners River watershed include a 4.4 km stream at Munising, a 1.2 km stream east of Munising, a southern stream that is apparently intermittent, and a permanent stream west of the Miners River, which is 2.7 km and is forked from the south for ca. 1/3 of its length.

*Sand Point Area*

Waters in the Sand Point area originate on top of an escarpment and flow seasonally to the low areas of Sand Point. Three main seasonally fluctuating beaver ponds and associated wetlands occur in the lower reaches that drain into Lake Superior via 2 outlets. One of these outlets occurs on the southwest end of the Sand Point swimming beach and the other is near the escarpment near the northeast portion of Sand Point (Loope 2004).

*Miners River Watershed and Miners Lake*

The Miners River watershed is PIRO's largest, between 6,863 ha and 7,044 ha (Handy and Twenter 1985; MIDNR Watershed Council 2000), and includes the Miners River and Miners Lake, a fluviatile pond. The 13.4 km Miners River, PIRO's longest, originates outside the IBZ in a 0.2 ha pond and several wetlands. Approximately 3.2 river km, as well as an unnamed 2.3 km northwest tributary, lie outside the IBZ. At Miners Lake, a small unnamed tributary from the east, and a small groundwater-fed rivulet from the higher bedrock to the west, are important cold water sources during the summer (Loope 2004). The river exits the lake at its northeast end and follows a highly meandering 2.9 km path to Lake Superior east of Miners Castle. Observed discharges at the mouth ranged from 0.36 $m^3\ sec^{-1}$ in August to a maximum of 3.0 $m^3\ sec^{-1}$ in April (Handy and Twenter 1985).

Most waters in the watershed are brown-

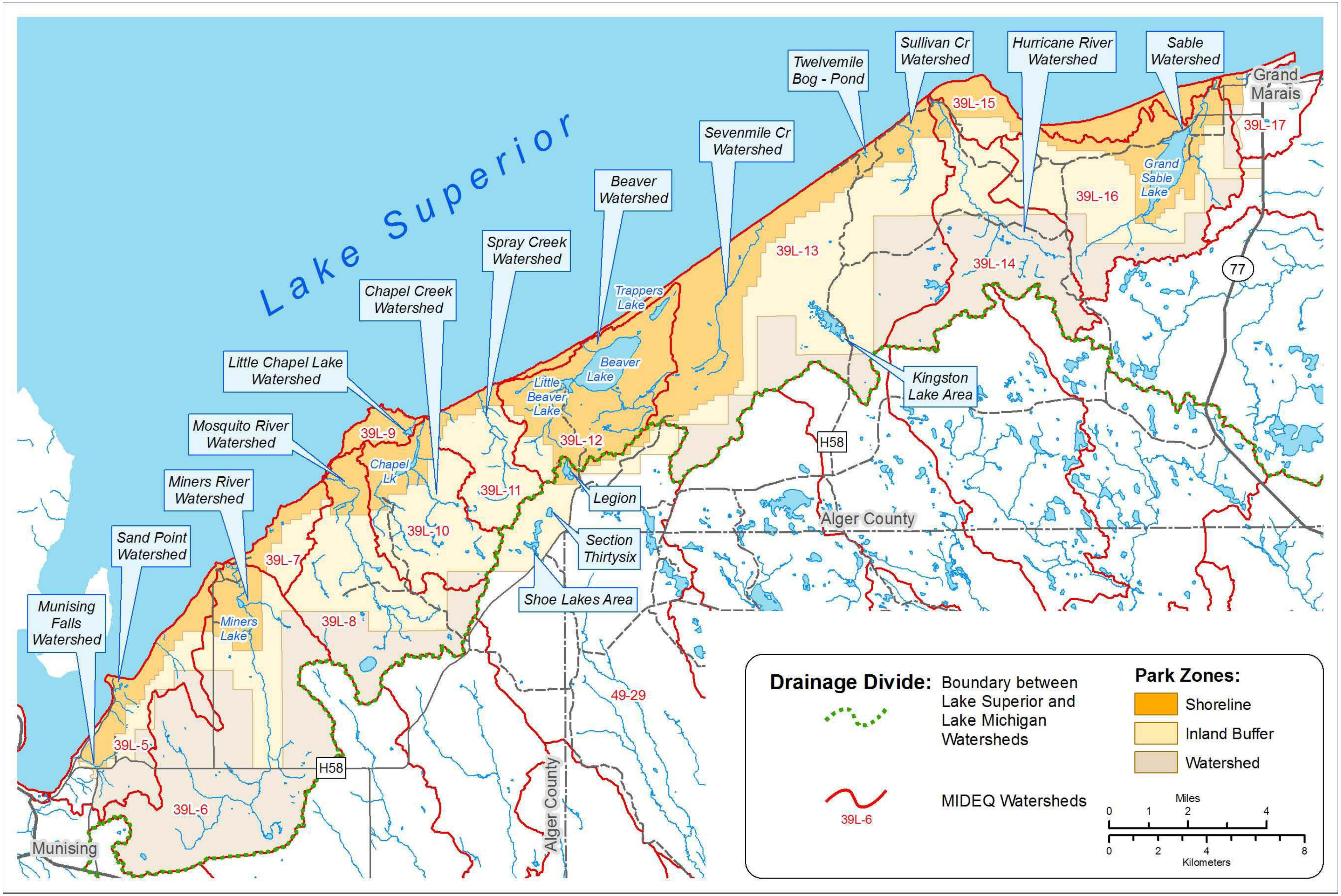


Figure 16. Watersheds for inland waters of Pictured Rocks National Lakeshore.

(Source: MIDEQ 1998)

stained with tannic and humic acids. Miners River habitat conditions are excellent, with acceptable macroinvertebrate populations and Ephemeroptera-Plecoptera-Trichoptera index (EPT) percentages above 60% (MIDEQ 2005b). Sea lamprey spawn in the river up to a control dam, downstream from Miners Lake, that prevents further upstream progress (Loope 2004).

Teardrop-shaped Miners Lake, a former embayment of Lake Nipissing (Farrand and Drexler 1985) is between 4.6-5.3 ha (Humphreys and Colby 1965; Kamke 1987), with a maximum depth of 4.0 m and a mean depth of 1.9 m. Its shoreline length is 950.9 m, and its volume is 89,956 $m^3$ (Kamke 1987). It stratifies only partially in summer. Motorized boat traffic, although not restricted, is negated by the lake's distance of 0.8 km along a hiking trail from a parking lot (Loope 1998a). Along the river, even canoe access is made difficulty by large woody debris and shallow water.

Dissolved oxygen (DO) levels of 4 mg/L or less were observed in the lower hypolimnion of Miners Lake in October 1983 and May 1994 (Loope 1998a). Orthograde DO profiles occurred in October 1983 and May 1985 (Kamke 1987). Average Secchi transparency depths were 2.7 m (Kamke 1987; Loope 1998a). Total nitrogen levels ranged from 0.2-0.5 mg/L, and total phosphorus levels were less than 0.05 mg/L, during the midsummers of 1994-1996 (Boyle et al. 1999). Downstream of the lake, specific conductance, bicarbonate, calcium, magnesium, barium, and manganese increased in the Miners River, while color decreased (Handy and Twenter 1985).

Miners Lake has lower chlorophyll a values than Grand Sable, Beaver, or Chapel Lakes (1.4-4.3 mg $m^{-3}$), but has the highest Trophic State Index (TSI) (Carlson 1977) value of the four (Kamke 1987). Lake productivity is sequestered in higher aquatic plants. Miners Lake is between the mesotrophic and early eutrophic stages, based on its high eplimnetic to hypolimnetic ratio, the abundance of aquatic macrophytes, high nutrient levels, and low levels of decomposed organic sediment (Kamke 1987). Data collected by Elias (2006) in summer 2005 indicate that Miners Lake is mesotrophic, based on TSI values of 37 (chlorophyll a), 47 (Secchi), and 44 (total phosphorus).

Major species of zooplankton observed in Miners Lake include the calanoid *Skistodiaptomus oregonensis*, the cyclopoid *Diacyclops bicuspidatus thomasi*, and the cladocerans *Bosmina longirostris* and *Daphnia galeata mendotae* (Kamke 1987). Major species of aquatic macrophytes include horsetails, pond-lilies, bladderworts, and water-milfoils (Kamke 1987). Among PIRO's lakes, mare's tail (*Hippurus vulgaris*) is known only from Miners Lake. In 1970, the benthic community of Miners Lake was reported to contain only oligochaetes and the snail *Lymnaea palustris* (Limnetics Inc. 1970). However, Kamke (1987) found 25 genera in 14 families and 9 orders of macroinvertebrates, made up mainly of Coleoptera, Ephemeroptera, and Chrionomidae, but also including *Sphaerium* sp. (clams), *Valvata* sp. (snail), and *Hyalella azteca* and *Gammarus lacustris* (scuds) in the littoral zone. Leeches are also common in the lake (Loope 1998a).

*Mosquito River Watershed*

The Mosquito River watershed is between 3,418 ha and 3,600 ha (Handy and Twenter 1985, MIDNR Watershed Council 2000). The Mosquito River is a brown water 8.5 km river that originates and has most of its river miles within the IBZ. Four unnamed tributaries join the Mosquito River: a 0.8 km northeast tributary, a lower eastern 3.3 km tributary, a southern 1.1 km tributary, and a 2.5 km southwest tributary. Beaver ponds on two tributaries provide the only lentic habitat within the watershed (Loope 2004). The Mosquito River flows over bedrock in several locations, including at Mosquito Falls, ca. 2.36 km from Lake Superior. Observed discharges at the river's mouth range from 0.11 $m^3sec^{-1}$ (August 1981) to 1.09 $m^3sec^{-1}$ (June 1979) (Handy and Twenter 1985).

Gruhn (1976) sampled the entire mainstem of the Mosquito River and some tributaries and described habitat characteristics. Fisheries data were limited, but rainbow trout, brook trout, and some forage fish were found. Mullen (1988) monitored streamflow and water quality for a study on the potential effects of timber harvest on the Mosquito River, and concluded that small winter harvests (<15% cover removed) did not have a significant effect on the river.

The MIDEQ (2005b) found good habitat conditions in its assessment of the Mosquito River. Macroinvertebrate populations were acceptable, with EPT percentages above 40%. In 1997, coaster brook trout were first reintroduced to the river (NPS 2003). Sreenivasan and Leonard (2003) found significant differences in length, weight, and condition factor between migrant and resident brook trout, with migrating brook trout being significantly larger. Sea lamprey occur in the Mosquito River, and treatment with a lampricide (granular Bayer 73) began in 1958 (Loope 2004).

*Little Chapel Watershed and Little Chapel Lake*
The 363 ha Little Chapel watershed (MIDNR Watershed Council 2000) lies in a former glacial meltwater channel (Blewett 1994) and includes 2.4 ha Little Chapel Lake and an unnamed 677 m tributary which feeds it on the southwest end (Humphreys and Colby 1965; Loope 1998a). The lake drains to Lake Superior via an unnamed temporary stream at the west end of Chapel Beach, generally only during snowmelt and spring runoff.

Little Chapel Lake, located just to the north of Chapel Lake, is a former bay of Lake Nipissing which became isolated when lake levels dropped (Farrand and Drexler 1985) and is now slowly filling in with aquatic vegetation (Limnetics, Inc. 1970). Access to this lake with sampling equipment is difficult (Loope 1998a), and information about it is limited to some general information provided by Humphrey and Colby (1965) and a single set of samples collected by Limnetics, Inc. (1970). The pH was 6.8 and calcium, magnesium, specific conductivity, and total dissolved solids were low. Total phosphorus, nitrate nitrogen, and organic nitrogen were 0.06, <0.005, and 0.70 mg/L respectively. A single sample collected by an unknown method in fall 1970 contained no benthos (Limnetics, Inc. 1970). One zooplankton sample contained 12 species, 11 of which were cladocerans. The diversity and density of cladocerans was greater than in most of the larger, deeper lakes, and the species collected were different from those collected in other small PIRO lakes (Limnetics, Inc. 1970). One phytoplankton sample contained 16 species of algae, including diatoms, yellow-brown, green, and blue-green algae. A TSI of 46 places the lake within the “good” water quality classification range (Loope 1998a).

*Chapel Creek Watershed and Chapel Lake*
The 2,188 -2,486 ha Chapel watershed (Handy and Twenter 1985; MIDNR Watershed Council 2000) includes Chapel Creek, Section 34 Creek, and Chapel Lake. Observed discharges at the mouth of Chapel Creek range from 0.06 $m^3sec^{-1}$ (August 1981) to 0.61 $m^3sec^{-1}$ (April 1981) (Handy and Twenter 1985). Mean discharges are 0.32 $m^3sec^{-1}$ in early summer and 0.16 $m^3sec^{-1}$ in late summer and early fall (Boyle et al. 1999).

Chapel Lake, with a surface area of 23.8 to 30.5 ha (Humphreys and Colby 1965; Limnetics, Inc. 1970; Kamke 1987), is a dark brown water lake with an elongate shape. It likely formed as a large plunge pool in a glacial meltwater channel that flowed from west to east, and represents a remnant of a Lake Nipissing bay (Hughes 1968). Its maximum and mean depth are 43.9 and 14.9 m respectively, and its shoreline length and lake volume are 4,224 m and 4,558,975 $m^3$ (Kamke 1987). It is fed by Chapel Creek, Section 34 Creek, and seepage, and its level is partially controlled by a beaver dam at the north end. The average discharge of Section 34 Creek into Chapel Lake is 0.128 $m^3sec^{-1}$ (Loope 2004). Chapel Creek drains the lake and discharges into Lake Superior approximately 1 km downgradient.

The lake is naturally split by depth into an elongate, relatively shallow (< 6m) northern basin and an oval, southern basin about 43 m deep, extending into the Jacobsville sandstone. Because of the southern basin’s morphometry, its protection from the wind by steep banks, and biogenic processes, it is meromictic (Kamke 1987). The deepest 18 m of water (the monomolimnion) is cold, dense, and anoxic. A chemocline at 25-30 m creates a density gradient that prevents the monomolimnion from mixing with the mixolimnion during spring and fall turnovers (Kamke 1987). Excessive levels of sulfate and high alkalinity were found in the monomolimnion, and iron, magnesium, and total hardness values were 2000%, 1820%, and 260% higher, respectively, than surface values. Conductivity, carbon dioxide, color, turbidity, silica, and manganese also increased substantially in this layer. Interestingly, high levels of hydrogen sulfide, mercury, lead, aluminum, and zinc did not occur. Kamke (1987) suggested that the lack of hydrogen sulfide was due to the absence of sulfur bacteria in the sediments because of the cold water. During July and October 1983 and May 1984, waters > 20 m deep were anoxic, and during the other sampling periods had DO levels below 6 mg/L. The profundal zone contained what appeared to be sapropel sediment, based on color and smell. Sapropel is a shiny black sediment formed under intense anaerobic conditions, usually containing FeS and $H_2S$, and typical of meromictic lakes (Cole 1983).

Kamke (1987) reported a mean Secchi transparency of 2.5 m for Chapel Lake, and the mean pH values at the surface, mid-depth, and bottom were 7.5, 7.1, and 6.9, respectively. Handy and Twenter (1985) reported a range of pH values between 7.6 – 7.9, total dissolved solids from 69 – 131 mg/L, and specific conductance from 193 – 205 µS/cm from 1979 – 1981. Based on total hardness values of 71-150 mg/L, Chapel Lake is a moderately-hard to hard water lake (Handy and Twenter 1985; Kamke 1987). Kamke (1987) reported an average alkalinity of 135 mg/L $CaCO_3$ from 1983-1985, but Handy and Twenter (1985) found lower values of 56 – 98 mg/L $CaCO_3$ in their earlier study. The mean surface values for TKN (0.51 mg/L), total phosphorus (0.017 mg/L), and reactive phosphorus (0.011 mg/L) were the second highest of the four lakes Kamke (1987) studied within PIRO (with mean values determined from the mixolimnion). Data collected by Elias (2006) in summer 2005 indicate that Chapel Lake is mesotrophic, based on TSI values of 41 (chlorophyll a), 42 (Secchi), and 35 (total phosphorus).

Where Section 34 and Chapel Creeks enter Chapel Lake, organic sediments support a littoral zone with limited aquatic macrophyte growth (Kamke 1987). The shallow northern end supports emergent and submergent aquatic macrophytes including broadleaf cattail (*Typha latifolia*), coon's tail, several species of *Potamogeton*, eelgrasses (*Vallisneria* sp.), pond-lilies, horsetails, and *Scirpus* sp. (Kamke 1987; Loope 1998a). Coon's tail growth was extensive in the shallow northern basin during summer (Kamke 1987). Farwell's water-milfoil, a State of Michigan threatened species, is also found (Crispin et al. 1984).

Thirteen genera of zooplankton and seven genera of phytoplankton are reported from Chapel Lake. However, these are the result of a very small number of field samples, and the actual number is likely much higher for both groups (Limnetics, Inc. 1970; Kamke 1987; Loope 1998a). In his sampling of four PIRO lakes, Kamke (1987) found the calanoid *Epischura lacustris* and the cyclopoid *Cyclops scutifer* only in Chapel Lake. The rare shrimp *Mysis relicta* is also found in Chapel Lake (Loope 2004).

Forty-five taxa of benthic organisms have been reported to occur in the lake, but the profundal zone is dominated by midge larvae (Limnetics, Inc. 1970; Kamke 1987). Interesting fauna found in the lake include the bryozoan *Pectinatella magnifica* (on submerged logs) and the typical stream riffle beetle (*Dubiraphia* sp.) (Kamke 1987; Loope 1998a). Kamke (1987) found that Chapel Lake had the second highest diversity of molluscs and midges of the four lakes he studied. Midges (Diptera) made up 61% of the aquatic insects he sampled in the lake. Macroinvertebrate fauna was generally limited due to the lack of littoral habitat in the southern basin; however, he collected 42 genera from 22 families and 12 orders, and found that the stream riffle beetle was common in many of the littoral habitats. While often associated with riffle habitat in streams, this beetle may be found in well-oxygenated, unpolluted littoral zones of lakes (McCafferty 1981; PIRO, Lora Loope, Aquatic Ecologist, pers. comm. 2006). He found only one genus of mayflies (Ephemeroptera) and two genera of dragonflies (Odonata) in the lake. Nichols et al. (2001) found Chapel Lake to have the largest number of unionid mussels among PIRO lakes. Nuhfer (1988) found northern pike, white sucker, and yellow perch in a gill net survey on Chapel Lake.

*Spray Creek Watershed*

The 1,580-1,846 ha Spray Creek watershed (Handy and Twenter 1985; MIDNR Watershed Council 2000) includes 5.63 km Spray Creek, which originates in alder/willow wetlands within the IBZ (Loope 2004). Spray Creek is a low-gradient stream with a nearly uniform discharge along its length, indicating that little water is added by groundwater seepage or small tributaries (Loope 2004). Its five month average discharge was 0.168 $m^3sec^{-1}$ (Loope 2004), with a recorded range of 0.096 $m^3sec^{-1}$ to 0.390 $m^3sec^{-1}$ (Handy and Twenter 1985). Spray Creek has four unnamed tributaries: a southwest 1.15 km tributary and three eastern tributaries. Of these, the southernmost is 0.74 km, and the middle and northernmost are each 0.93 km.

*Legion Lake, Section 36 Lake, and the Shoe Lakes*

Legion Lake, Section 36 Lake, and the Shoe Lakes, are small, acidic (pH≤5) kettle lakes with Sphagnum bogs (Lewin 1991), situated on the major watershed divide between Lakes Superior and Michigan. Data are sparse for Legion Lake and almost nonexistent for the others in this group, with the exception of sediment cores collected by Stottlemyer (1989). Further study may be warranted, although Section 36 Lake and the Shoe Lakes are in the IBZ and outside park jurisdiction.

The approximately 72 ha Legion Lake watershed is 5 km from Lake Superior and 80 m above it, and it contains mostly glacially-derived outwash sands with low cation exchange capacity (Lewin 1991; Loope 1998a). Legion Lake, a kettle seepage lake of about 14 ha, has an elongate outline, with the greatest fetch occurring in a southeast to northwest direction. The lake has three distinct basins, each with a Sphagnum bog associated with each shoreline (Loope 1998a). The southern basin is the deepest, with a mean depth of 13 m, and the middle and southern basin both have a mean depth of 10 m (Lewin 1991). The surface area to watershed area ratio is 5:1 (Lewin 1991).

The lake color is bluish-green, distinctly different from most other kettle lakes in PIRO, but similar to Section 36 and the Upper and Lower Shoe Lakes (Loope 1998a). Boyle et al. (1999) reported an average Secchi transparency of 7.0 m from 1994 – 1998, with a maximum of 8.5 m. Dissolved oxygen exhibited a metalimnetic maximum, increasing abruptly just below the thermocline, most likely because of a 1- 3 m layer of phytoplankton, and then decreasing markedly below this layer to the bottom (Loope 1998a). Boyle et al. (1999) reported average chlorophyll a concentrations between 1.3 – 4.0 µg/L from 1994 – 1996.

Legion Lake's acidity (pH 4.7-5.0) appears to be naturally occurring (Stottlemyer 1989; Lewin 1991) and related to its Sphagnum bogs, limited buffering capacity and reduced alkalinity (Lewin et al. 1990a, 1990b; Lewin 1991). Stottlemyer (1989) determined that Legion Lake is disconnected from groundwater and watershed processes which might increase buffering capacity or add elements such as silicon. Lewin (1991) stated that Legion Lake has probably been acidic for at least several centuries due primarily to organic acid inputs, and that it has lost additional buffering capacity due to the precipitation of in-lake humic loading. Benthic core analysis of diatoms was unsuccessful because of the low numbers in the sediments, perhaps related to low silica levels in the lake. The cores did show a sedimentation rate higher than expected for a clear-water oligotrophic lake and an order of magnitude higher than some other regional lakes. Lewin attributed the high flocculation rate to precipitation of humic acid inputs originating from the surrounding bogs.

Lead, sulfur, copper, and zinc deposition rates since the 1880's have been higher in Legion Lake than in other lakes in the region (Lewin 1991). Sulfur, calcium, magnesium, and manganese, as well as lead, zinc, and copper in the sediments, increased since 1940 according to core analysis combined with $^{210}Pb$ dating (Lewin 1991). Total dissolved solids are 0.01 g/L (Loope 1998a).

Loope (1995) reported five taxa of zooplankton, including cladocerans, copepods, and rotifers, and 23 taxa of phytoplankton, including blue-green algae, dinoflagellates, diatoms, golden brown algae, and green algae. Aquatic macrophytes included drepanocladus moss (*Drepanocladus aduncus*), sevenangle pipewort (*Eriocaulon septangulare*), and pond-lilies (Lewin 1991). Lewin (1991) reported that the benthic macroinvertebrate community contained 13 different taxa, but was dominated by chironomids (71-94%), with dragonflies, caddisflies, alderflies, and freshwater sponges also common. Roundworms, clams, aquatic earthworms, water mites, and true flies were also found, but no amphipods, isopods, mayflies, snails, or leeches were present. The greatest population density was found in the 1-5 m depth range. In addition, Loope (1995) reported predacious diving beetles and waterboatmen.

Fish stocking was done by the MIDNR for several years, ending in the late 1980s (Loope 2004). A 2004 USFWS survey (Newman 2005) found only central mudminnows (*Umbra limi*).

*Beaver Watershed and Beaver Lake*

The Beaver watershed area has been variously reported as 2,694 ha (Doepke 1972), 3,030 ha (MIDNR Watershed Council 2000), and 3,962 ha (Handy and Twenter 1985). It includes Little Beaver Lake (16.1 ha) and its tributaries, Arsenault Creek, Little Beaver Creek, and Bills Creek, as well as Beaver Lake (310 ha), the east and west branches of Lowney Creek, and Trappers Lake (20.25 ha), located to the northeast (Limnetics, Inc. 1970; Doepke 1972).

Beaver Creek drains Beaver Lake to the north to Lake Superior and is ca. 1 km long, with discharges ranging from 0.518 $m^3sec^{-1}$ in August to 1.127 $m^3sec^{-1}$ in April (Handy and Twenter 1985). Its mouth is categorized as having vegetated low to steep banks and mud flats with medium-high sensitivity to fuel spills (USEPA Region 5 2000). Lowney Creek, the main tributary to Beaver Lake from the southeast, is 3.1 km long, with two main tributaries, the east (3.2 km) and west (1.3 km) branches. Four small ponds near the headwaters of the east branch of Lowney Creek vary in size from 0.16 – 0.81 ha. There is also a 0.81 ha flowage along the east branch of Lowney Creek. All tributaries arise within PIRO boundaries.

Beaver Lake was formed by the deposition of glacial sands which isolated a previous bay of Lake Superior (Doepke 1972). Beaver Lake is oval, with a surface area of approximately 310 ha (Humphreys and Colby 1965; Limnetics, Inc. 1970; Doepke 1972; Handy and Twenter 1985; Kamke 1987; Boyle et al. 1999; Loope 2004). Kamke (1987) reported the shoreline length as 7,705 m, volume as 21.1 $x10^6 m^3$, and the shoreline development factor as 1.24. Maximum and mean depths are 13.1 and 6.7 m, respectively. A prominent sand shelf includes the entire littoral zone and extends 55-60 m from shore (Kamke 1987), and the deeper substrates of the lake consist of muck (Doepke 1972). Approximately 29% of the lake volume occurs below the 6 m depth interval, and the lake has a basin exchange time of 2.9 years (Doepke 1972).

The fetch is nearly parallel to the prevailing winds, which provides significant wind-generated mixing. Therefore, this lake does not permanently stratify every summer and can be classified as cold polymictic (Doepke 1972; Kamke 1987; Boyle et al. 1999). In 1970, the thermocline was well established and the hypolimnion was nearly anoxic (Limnetics, Inc. 1970). However, Kamke (1987) found a weak, easily disrupted thermocline, resulting in vertical DO profiles that were mostly orthograde, indicating that DO levels remained high even near the bottom. The lake has a slight tea color, but approximately 5% of the incident light reaches a depth of 4 m (Doepke 1972). Kamke (1987) found that the mean Secchi transparency was 3.2 m and exhibited no distinct seasonal pattern

Kamke (1987) reported that the mean pH was 7.2 and the lake had low values for carbon dioxide, color, turbidity, chloride, conductivity, hardness, sulfate, and iron compared to the other lakes he studied within PIRO. These data are indicative of the soil types occurring within the watershed, predominately mineral sand originating from old beach terraces with low nutrient levels. Aluminum and zinc were within normal ranges for natural lakes, and lead and mercury were below detectable levels. Alkalinity levels were in the medium range. Mean nutrient levels were low in Beaver Lake among the four PIRO lakes he studied.

Doepke (1972) stated that Beaver Lake was a moderately fertile lake close to its peak natural productivity. He stated that the lake was aging slowly, and that the water quality was good and was expected to remain good for many years. Kamke (1987) classified Beaver Lake as mesotrophic, based on mean chlorophyll-a concentrations from 62-1352 mg $m^{-3}$ (mean 743 mg $m^{-3}$) and low mean nutrient levels. He also found that the TSI of 43 and WQI values of 33-44 were in ranges that indicated moderately good water quality. Data collected by Elias (2006) in summer 2005 indicate that Beaver Lake is mesotrophic, based on TSI values of 47 (chlorophyll a), 40 (Secchi), and 40 (total phosphorus).

Zooplankton densities were higher than in other lakes Kamke (1987) studied within PIRO. Most species found were more common in the shallow water of the west bay than in the open water zone. Major zooplankton species found included calanoid, cladoceran, and cyclopoid species. The exotic zooplankter spiny waterflea (*Bythotrephes longimanus*) is found in the lake and was probably introduced since 1987 (Loope 1998b). It is of special concern since it has been shown to affect food web dynamics of native species in lakes.

Aquatic macrophytes are limited by wind exposure and resulting sandy substrates in shallow areas. In 1953 the Institute for Fisheries Research documented nine species of aquatic macrophytes in the lake, including the abundant species variableleaf and whitestem pondweed (*Potamogeton gramineus* and *P. praelongus*) and the algae *Chara* sp. and *Nitella* sp., Kamke (1987) also collected *Chara* sp., as well as water-milfoils, water plantain, and several species of pondweed. Crispin et al. (1984) found the alternate flower water-milfoil, a species of special concern in Michigan. Nichols et al. (2001) found Beaver Lake to have the greatest number, but not the greatest density, of unionid mussels lakewide among PIRO lakes. They also found large (basketball-sized) freshwater sponges in Beaver Lake.

Kamke (1987) collected 45 genera from 21 families and 10 orders of benthic organisms. Annelids, molluscs, and crustaceans were common in the littoral benthos. The littoral biota was limited despite alkalinity values that suggest a fertile watershed. Kamke (1987) suggested that littoral biota were limited by the sand substrate and not by available nutrients, since organisms not limited by substrate diversity were abundant (Diptera, 53% and Chironomidae, 38%). Larger aquatic insects made up only a small portion of the littoral benthos. The MIDNR reports 18 species of fish in the lake, with yellow perch, white sucker, northern pike, and rock bass (*Ambloplites rupestris*) the most common species. Splake were stocked in the lake by the MIDNR beginning in 1967 with good carryover (Doepke 1972). Sea lamprey have invaded from Lake Superior, and apparently move through Beaver Creek, Beaver Lake, and Lowney Creek to the dam on the trout pond (Loope 2004).

Little Beaver Lake is a ca. 16.1 ha lake (Humphreys and Colby 1965; Doepke 1972) situated near the southwest end of Beaver Lake and connected to it by a narrow neck. The watershed area is 699 ha, and the lake has a short basin exchange time of 0.3 years (Doepke 1972). Maximum and mean depths are 6.5 and 3.3 m respectively, with 4% of the volume located below 6.1 m (Doepke 1972). It was formed ca. 3,000 to 6,000 years ago from an embayment of Lake Nipissing during the last glacial period (Loope 1998a). The lake sediments are mostly composed of loose organic material, termed *gyttja* (Limnetics, Inc. 1970; Doepke 1972).

Three main tributaries feed Little Beaver Lake: Arsenault, Little Beaver, and Bills Creeks. Bills Creek (1.3 km) is the southernmost tributary. Little Beaver Creek (2.9 km), which feeds the lake from the southwest, has two unnamed tributaries; a 0.7 km southern tributary that feeds the 0.53 ha flowage on Little Beaver Creek, and a 0.9 km upstream tributary that feeds Little Beaver Creek from the south. Arsenault Creek (1.7 km) feeds the lake from the northwest and has one unnamed tributary (1.8 km) and an unnamed (1.6 ha) pond at the headwaters. Little Beaver Lake flows into Lake Superior via Beaver Creek.

The pH of Little Beaver Lake ranges from 6.6 – 8.4 (Limnetics, Inc. 1970; Doepke 1972). Specific conductivity ranges between 132 – 173 µmhos/cm, and total alkalinity is between 59 and 72 ppm $CaCO_3$ (Limnetics, Inc. 1970; Doepke 1972). The lake is well buffered and has moderately hard water, with total hardness varing between 58 – 81 ppm (Limnetics, Inc. 1970; Doepke 1972). Little Beaver Lake thermally stratifies during the summer months, and the hypolimnion becomes anoxic (Doepke 1972). Secchi transparency depths are 1.4 – 2 m (Limnetics, Inc. 1970; Loope 1998a).

Twenty-two species of zooplankton have been found in the lake, including 17 species of cladocerans, some apparently unique among PIRO lakes (Limnetics, Inc. 1970). The lake has 16 species of aquatic macrophytes, mostly restricted to shallow shoreline areas (Doepke 1972), including water starwort (Crispin et al. 1984) and alternate flower water-milfoil (Doepke 1972), Michigan species of special concern. The lake's dark brown color limits the growth of both higher and lower aquatic plants, and light intensity at 1.2 m is less than 5% of the surface intensity (Doepke 1972).

The benthic community is limited; Limnetics, Inc. (1970) reported no benthos in the limnetic zone in their study. However, Nichols et al. (2001) found Little Beaver to be one of the PIRO lakes with the greatest number of unionid mussels. Northern pike, smallmouth bass, yellow perch, and white sucker have been collected, but other species may be present (Doepke 1972), although the anoxic hypolimnion in mid to late summer may limit the fish populations (Loope 2004).

Doepke (1972) believed that the lake had passed its peak level of productivity, and that watershed development would be unlikely to have much further influence on water quality. Data collected by Elias (2006) in summer 2005 indicate that Little Beaver Lake is in an early eutrophic stage, based on TSI values of 53 (chlorophyll a), 45 (Secchi), and 48 (total phosphorus). Information on Little Beaver Lake is meager, and more detailed studies are needed in the future.

Trappers Lake is a closed basin lake similar to Beaver and Little Beaver Lakes (Limnetics, Inc. 1970), with a surface area between 17.4 ha (Humphreys and Colby 1965) and 20.25 ha (Limnetics, Inc. 1970). Its shoreline length is 2.41 km and varied, with the northern end having a gentle slope and the southern end having a steep slope and forested shoreline. The average depth is approximately 1.7 m and appears to be rather uniform. The sediments are mostly organic (Limnetics, Inc. 1970). Trappers Lake does not appear to stratify during the summer months (Limnetics, Inc. 1970; Loope 1998a). Data collected by Elias (2006) in summer 2005 indicate that Trappers Lake is mesotrophic, based on TSI values of 42 (chlorophyll a) and 37 (total phosphorus).

The lake water is classified as soft, with alkalinity reported by Limnetics, Inc. (1970) as 80 mg/L

$CaCO_3$. The pH range is 7.6 – 9.06 (Limnetics, Inc. 1970; Loope 1998a). Nutrients are low, and a total phosphorus level of 0.05 mg/L was reported by Limnetics, Inc. during 1970. Metals such as lead, copper, and arsenic were below detectable levels (Limnetics, Inc. 1970).

The lake's zooplankton and phytoplankton are fairly diverse, with 13 zooplankton species and 16 phytoplankton species, including 6 species of blue-green algae, reported (Limnetics, Inc. 1970). Trappers Lake's benthos is very meager, but two species of mollusks (*Helisoma anceps* and *Amnicola limnosa*) have been collected (Limnetics, Inc. 1970).

*Sevenmile Creek Watershed*

The 2,103 ha Sevenmile Creek watershed (Handy and Twenter 1985) includes 0.77 ha Hyde Lake, 1.94 ha Sevenmile Lake, a 0.53 ha unnamed western lake north of Sevenmile Lake, and the 2.54 km Sevenmile Creek, all within the shoreline zone. Sevenmile Creek is a mostly sandy low gradient stream with recorded discharges ranging from 0.439 $m^3sec^{-1}$ (August 1981) to 0.694 $m^3sec^{-1}$ (October 1981) (Handy and Twenter 1985).

A single sample collected by Limnetics, Inc (1970) had a pH of 7.5, a specific conductance of 82 µmhos/cm, total alkalinity of 82 mg/L as $CaCO_3$, and a total hardness of 52 mg/L as $CaCO_3$. Three samples collected by Handy and Twenter (1985) from 1979-1981 had similar pH (7.5-8.0) and alkalinity (71-80 mg/L as $CaCO_3$) but higher specific conductance (133-161 µmhos/cm) and hardness (64-74 mg/L as $CaCO_3$). Total nitrogen was 0.47 mg/L in 1970 (Limnetics, Inc. 1970); reactive phosphorus values were 0.006 mg/L in 1970 and 0.01 mg/L in 1979 and 1980 (Handy and Twenter 1985). Biological data are sparse; Boyle et al. (1999) reported brook trout, western blacknose dace, brook stickleback (*Culaea inconstan*s), finescale dace [*Chrosomus (Phoxinus) neogaeus*], longnose dace (*Rhinichthys cataractae*), mottled sculpin, central mudminnow, and coho salmon.

*Kingston Lake Area*

Kingston Lake is a 101.2 ha non-acidic kettle lake in the IBZ. Its maximum depth is 9.75 m, but lake levels are highly variable depending on summer precipitation (Humphreys and Colby 1965; Handy and Twenter 1985). Two small ponds are associated with Kingston Lake: 1.38 ha Kingston Pond near the southeast end and an unnamed 0.51 ha pond near the southwest end (Humphreys and Colby 1965). Nichols et al. (2001) found four species of freshwater mussels in the lake. The MIDNR operates a 16-site rustic campground on the lake.

*Twelvemile Bog Area*

Twelvemile Bog is an approximately 6 ha (Futyma 1990) wetland near Lake Superior, less than ½ km east of the Twelvemile Beach campground and picnic area. There are four shallow basins that become connected during increased precipitation and high water periods. Sediment and pollen analyses indicate that the bog has become more acidic since its origin 4,000-5,000 years BP (Futyma 1990). In the early stages sedges (*Carex* spp.), grasses, and cattails (*Typha* spp.) were common, but have given way to the current community dominated by black spruce (*Picea mariana*), tamarack (*Larix laricina*), leatherleaf, Labrador tea, sedges, and Sphagnum (Futyma 1990).

*Sullivan Creek Watershed*

Sullivan Creek watershed is 1,885 ha (Handy and Twenter 1985). The headwaters of 6.91 km Sullivan Creek occur in open beaver ponds and sedge meadows within the IBZ. Recorded discharges range from 0.068 $m^3sec^{-1}$ (August 1981) to 0.210 $m^3sec^{-1}$ (June 1979) (Handy and Twenter 1985). Sullivan Lake is 1.59 ha and occurs at the headwaters. An unnamed 3.44 hectare lake is located to the west of Sullivan Creek and ca. 0.84 km from the Lake Superior shore. An unnamed 6 ha dystrophic (brown water) pond between the Twelvemile Bog catchment and Sullivan Creek has a maximum depth of 2 m. It receives some water from an adjacent cedar swamp to the east-southeast during wet periods. A beaver lodge is located in the northeast portion of the pond (Loope 2004).

A single sample collected from Sullivan Creek by Limnetics, Inc (1970) had a pH of 7.6, a specific conductance of 151 µmhos/cm, total alkalinity of 81 mg/L as $CaCO_3$, and a total hardness of 52 mg/L as $CaCO_3$. Three samples collected by Handy and Twenter (1985) from 1979-1981 had similar pH (7.5-8.0), alkalinity (63-82 mg/L as $CaCO_3$), and specific conductance (130-150 µmhos/cm), but higher hardness (69-84 mg/L as $CaCO_3$). Total nitrogen was 0.13 mg/L in 1970 (Limnetics, Inc. 1970); reactive phosphorus values were 0.003 mg/L in 1970 and <0.01-0.01 mg/L from 1979-1981 (Handy and Twenter 1985). Biological data are sparse; Limnetics et al (1970) reported that *Glossosoma* sp. (caddisflies) were dominant among aquatic invertebrates, and Boyle et al.

(1999) reported brook trout and finescale dace.

*Hurricane Watershed*

The 3,548 ha Hurricane watershed includes the low gradient 5.63 km Hurricane River (Limnetics, Inc. 1970; Handy and Twenter 1985). Its headwater area is located in open sedge meadows and alder thickets. Beaver ponds along the river provide some lentic habitat. Recorded discharges ranged from 0.269 $m^3sec^{-1}$ to 0.844 $m^3sec^{-1}$ during 1981 (Handy and Twenter 1985), and the three year (1994-1996) average discharge at the mouth was 0.444 $m^3sec^{-1}$ (Loope 2004). Two main unnamed southwest tributary streams to the Hurricane River originate outside the IBZ. The headwaters of the 3.13 km southernmost tributary occur in swampy wetlands 0.60 km northeast of the eastern end of Preacher Lake. This tributary may become intermittent during dry times of the year. The downstream southern tributary is 1.37 km long. There is also a 0.63 km northwest tributary. Hurricane Falls is located approximately 400 m from the river mouth.

Boyle et al. (1999) reported values for total nitrogen and total phosphorus exceeding the USEPA criteria for these nutrients in the ecoregion. However, they reported the river to be in good health based on fish analysis and aquatic macroinvertebrate community metrics such as density, taxa richness, Shannon's Diversity, Simpson's D, and EPT. A MIDEQ (2005b) survey also found excellent macroinvertebrate populations, with EPT percentages above 60%. Sea lamprey are known to spawn in the Hurricane River (Loope 2004).

*Sable Watershed and Grand Sable Lake*

The Sable watershed area is 3,263 to 5,024 ha (Doepke 1972; Handy and Twenter 1985; Michigan DNR Watershed Council 2000). This easternmost PIRO watershed consists of Grand Sable Lake and its feeder streams Rhody, DeMull, Sable, and Towes creeks. The 3.19 km Sable Creek drains Grand Sable Lake to the north and enters Lake Superior at Sable Falls. An unnamed 1.22 km southeast tributary stream originates within the shoreline zone and joins Sable Creek ca. halfway to Lake Superior. Towes Creek (3.58 km) flows into Grand Sable Lake from the southeast and originates within the IBZ. Rhody Creek (4.52 km), the main tributary stream, enters the lake from the southwest and originates outside the IBZ. A southern unnamed 1.22 km tributary to Rhody Creek originates in the IBZ. DeMull Creek (2.03 km) is a southeast tributary stream that joins with Rhody Creek at the mouth and originates within the shoreline zone. Recorded discharges for Sable Creek range from 0.079 $m^3sec^{-1}$ (August 1979) to 1.246 $m^3sec^{-1}$ (April 1981) (Handy and Twenter 1985).

Grand Sable Lake is a large, deep, elongate glacial kettle lake, narrowest at the southwest and northeast ends, with a surface area of ca. 255 ha (Humphreys and Colby 1965; Doepke 1972; Handy and Twenter 1985; Kamke 1987). The lake has a mean depth of 9.7 - 10.5 m, maximum depth of 20.1 - 25.9 m, and approximately 52% of its volume below the 6.1 m depth profile (Doepke 1972; Kamke 1987). Kamke (1987) determined the shoreline length as 9.9 km, the volume as 29.7 X $10^6$ $m^3$, and the shoreline development factor as 1.60. The basin exchange rate is 3.7 years (Doepke 1972). The bottom substrate is sandy *gyttja*, grading to *gyttja* with increased distance from the dunes, and with some gravel and organic sediment areas along the southeast shoreline.

Kamke (1987) found that thermal stratification in Grand Sable Lake occurred from late June – early July and exhibited a typical pattern for a northern temperate lake, with the thermocline occurring at 4-7 m. Complete mixing occurred during spring and fall; however, the narrow southern end was isothermal throughout the year. He found that DO was abundant throughout the water column at all times of the year. Grim (1990b) reported DO values ranging from 8.3 mg/L at the surface to 5.6 mg/L near the bottom. Conversely, Doepke (1972) reported that reduced DO in the hypolimnion was a limiting factor for aerobic organisms.

Grand Sable Lake had the clearest water of the four PIRO lakes Kamke (1987) studied, with mean Secchi transparency of 3.1 m. Specific conductance was 101 µmhos/cm, total alkalinity was 47 mg/L as $CaCO_3$, hardness was 46 mg/L as $CaCO_3$, and pH was 6.7. Chemical parameters did not vary significantly between years within the epilimnion, and only alkalinity was significantly different between years in the hypolimnion (Kamke 1987). Grim (1990b), while studying the basic limnology and fisheries of Grand Sable Lake, reported a similar Secchi transparency (3.7 m), but a higher pH (8.0). Whitman et al. (2002) found low levels of nutrients, cations, and turbidity, and moderate hardness in 1997 -1998.

Doepke (1972) stated that Grand Sable Lake is close to its peak productivity, and current conditions can be expected to be retained for several hundred years without human interference. The relatively high basin retention time means that nutrient additions will be entrained within the lake. Overall the watershed is fairly infertile, with 71% of the soils in the watershed classified as having low fertility (Doepke 1972). Kamke (1987) found nutrient levels in Grand Sable Lake to be low compared to other PIRO lakes he studied, and stated that the lake was in the late oligotrophic stage. This characterization was supported by low alkalinity, high Secchi transparency, relatively low algal biomass (1081 to 384 mg $m^{-3}$), low zooplankton densities, and low observed littoral biota. The TSI values (20-54) also supported this conclusion. He reported that the mean values for nutrients and Secchi transparency, as well as the mean TSI, ranked the water quality as "very good". Whitman et al. (2002) characterized Grand Sable Lake as moderately productive. Data collected by Elias (2006) in summer 2005 indicate that Grand Sable Lake is mesotrophic, based on TSI values of 42 (chlorophyll a), 40 (Secchi), and 37 (total phosphorus).

Kamke (1987) reported high chlorophyll a concentrations (5.73 to 16.14 mg $m^{-3}$) and seasonal patterns of phytoplankton typical of an oligotrophic northern lake. The phytoplankton community was dominated by diatoms in May (81%), followed by yellow-green algae (60%) in early July, which remained dominant throughout the season. Phytoplankton counts were highest in May ($1.75 \times 10^6$/L). Whitman et al. (2002) also found yellow-green algae dominant from June to September 1997, comprising 60% of the algal community in June. They identified 40 algal taxa, and reported that chlorophyll a concentrations were high but did not exhibit a specific pattern. For zooplankton, Kamke (1987) reported low mean density compared to other PIRO lakes (26-45 organisms/L), but diversity was high. Rotifers dominated the zooplankton community, and *Bosmina longirostris* and waterfleas were also common.

Doepke (1972) found low densities of aquatic macrophytes due to the erosive effects of wave action. He reported 20 species in protected shoreline areas, while Kamke (1987) reported 21, including pondweed and *Chara* sp., but no exotic species. Macrophytes covered ca. 30% of the littoral zone. Crispin et al. (1984) found water starwort, and Doepke (1972) found alternate flower water-milfoil, both species of Special Concern in Michigan.

The benthos of Grand Sable Lake is diverse, and 65 genera from 25 families representing 11 orders and including 21 genera of midges (Diptera; Chironomidae) were collected by Kamke (1987). He found aquatic insects to be especially diverse, especially in the littoral zone, with Coleoptera, Ephemeroptera, and Trichoptera well represented. He attributed the high diversity to the lake's substrate diversity.

Nichols et al. (2001) found only 19 live clams in Grand Sable Lake during three days of quantitative sampling, and concluded that the populations were on the verge of extinction. The distribution of clams in Grand Sable is limited to areas above the thermocline in 1.5-3 m of water, which includes 23 ha (8% of lake area) in a ribbon-like edge around the lake. They hypothesized that the lake may not have supported high clam densities historically because of its cold, oligotrophic nature. Another factor may be the lake trout stocking which led to the decline of the yellow perch population, since yellow perch are the preferred host fish for unionid glochidia, especially *Ellliptio* spp., which in PIRO are found only in Grand Sable Lake.

Bluegills (*Lepomis macrochirus*), walleye, rainbow trout, smelt, lake trout, and splake have been stocked in the lake. Bluegill and walleye, stocked in the 1930s and 1940s, did not produce sustaining populations, but smelt did become established. In the early 1970s, the major fish species consisted of yellow perch, rock bass, white sucker, and northern pike (Doepke 1972). Grim (1990b) found few smallmouth bass, rock bass, yellow perch, or white sucker compared to the historical data, but found all 11 species that had been stocked in the lake, as well as coho salmon and white suckers, in 1988. He suggested managing Grand Sable Lake as a two story fishery with lake trout and coolwater species in the hypolimnion and smelt as a forage species. Lake trout stocking was scheduled to terminate in 2005 (Loope 2004).

**Sources of Pollutants**

*Atmospheric Pollutants*

Long-range Atmospheric Pollution: Nine persistent bio-accumulative chemicals have been identified as critical pollutants in the Lake Superior ecosystem [mercury, polychlorinated biphenyls (PCBs), aldrin/dieldrin, chlordane, DDT/DDE, toxaphene, dioxin, hexachlorobenzene (HCB), and octachlorostyrene (OCS)] (LSBP 2000). The Lake Superior Binational Program's Zero Discharge Demonstration Program has set a target of eliminating the use of these nine critical pollutants in industrial processes or products, and preventing their release in the Lake Superior Basin by 2020.

Concentrations of a suite of toxic organic contaminants in water, including the Lake Superior critical and lakewide remediation pollutants, declined more than 50 percent between 1986-87 and 1996-97 (LSBP 2006). Further monitoring was conducted in 2005, but results have not yet been published. Because many local sources of the critical pollutants have been eliminated, long-range atmospheric transport has become the major source of some of these pollutants. Some of the sources may be as far away as Mexico and Central America, where these substances are still in use. For example, there are no longer any major sources of the banned pesticides (aldrin/dieldrin, chlordane, DDT/DDE, and toxaphene) on the critical pollutants list in the U.S. (LSBP 2000).

Atmospheric deposition now accounts for an estimated 82 to 95 percent of PCB loadings and 80 to 100 percent of dioxins/furans loading to Lake Superior (LSBP 2000). Between 1990 and 1999, most pulp mills in the basin switched from chlorine bleaching to a chlorine dioxide bleaching process or a process that uses no chlorine, which reduced dioxin releases significantly. In 2003, new Canadian regulations required the closing of hospital incinerators, which left open burning of household waste as the largest dioxin source category in Ontario (LSBP 2000). Dioxin sources also appear to be the main sources of HCB and OCS in the basin.

Mercury releases in the basin decreased by 66% from 1990 to 1999. However, mercury-containing products, taconite production, and fuel consumption for energy production are still significant mercury sources (LSBP 2000).

Some researchers have suggested that the list of toxic contaminants should be expanded to include such compounds as polychlorinated naphthalenes (PCNs), polychlorinated alkanes (PCAs), endocrine disrupting chemicals, in-use pesticides, pharmaceuticals, and personal care products. Such chemicals might be added to Lake Superior through atmospheric deposition (such as brominated flame retardants including polybrominated diphenyl ethers, PDBE), but wastewater and stormwater discharges and release from contaminated sediments are other routes of contamination. These compounds represent emerging issues and potential future stressors to the ecosystem (Environment Canada and USEPA 2005).

**Acid Deposition**: Acid deposition includes gases, particles, rain, snow, clouds, and fog that are made up of sulfuric acid, nitric acid, and ammonium, derived from sulfur dioxide ($SO_2$), nitrogen oxides ($NO_X$), and ammonia ($NH_3$), respectively. These compounds are emitted primarily by the burning of fossil fuels, but also by agricultural activities (Driscoll et al. 2001). As a result of the Clean Air Act Amendments (CAAA) of 1990, sulfate wet deposition has decreased in the Upper Peninsula, but nitrate and ammonia emissions and deposition, which have not yet been fully addressed by the CAAA, continue to increase. In addition, the emission and atmospheric deposition of base cations that help counteract acid deposition have declined significantly since the early 1960s with the enactment of particulate matter pollution controls (Driscoll et al. 2001). During the 1980s, precipitation in PIRO was acidic (Stottlemyer 1982b, 1989). The range of pH values at Grand Marais from 1981-1987 was 3.7-4.3 (DeGuire 1993), while the National Atmospheric Deposition Program (NADP) reported a range of 4.4-4.9 in 1998 and 4.7-5.0 in 2004 (NADP 2006). Dry deposition is also important but is more variable and difficult to quantify on a regional scale (Driscoll et al. 2001).

**Local Air Emissions**: Locally, other air pollutant releases may affect water resources. The USEPA (2005a) lists seven facilities with federally regulated air emissions in Alger County (Table 11, Figure 17). Only one, Neenah Papers (formerly Kimberly-Clark) in Munising, is listed on the USEPA Toxic Releases Inventory (USEPA 2005a). In 2003, this facility released 130,537 kilograms (kg) of regulated emissions to the air, including 41,390 kg of ammonia, 88,862 kg of hydrochloric acid aerosols, and 285 kg of lead.

The potential local effect of these emissions on water resources is not known. Bennett and Bannerjee (1995) consider PIRO to be at a medium-low risk for air pollution overall, based on its location and plant community composition.

The Timber Products Michigan facility at Munising appears on the USEPA Aerometric Information Retrieval System (AIRS) list of sources of air emissions in Alger County under Standard Industrial Classification (SIC) Codes 2421 (sawmills and planing mills) and 2435 (hardwood veneer and plywood) (USEPA 2005a). Specific information on the quantity and type of releases from this facility was not available. However, emissions from facilities with these SIC codes generally include volatile organic compounds (VOCs), including methanol and formaldehyde, and nitrogen oxides ($NO_X$) from combustion of scrap wood and other fuels (National Center for Manufacturing Sciences 2004). The potential effects of these emissions on water resources are not known either, but prevailing winds from the northwest may limit the impact of all these sources on the park.

However, the USEPA estimates that in Alger County, major point sources contributed only 1.6% of the hazardous air pollutants in 1999 (the most recent year for which data are available). Nonroad vehicles (a category which include 2 or 4 stroke and diesel engines, nonroad vehicles, aircraft, commercial marine vehicles, recreational boats, and locomotives) contributed 91% of the hazardous air pollutants, or 1,622,200 kg, in 1999. Area sources (such as dry cleaners and gasoline stations) contributed 5%, and onroad vehicles contributed 2% (USEPA 2006). Off-highway vehicles also generated 630 metric tons, or 55%, of all estimated $NO_X$ emissions in Alger County in 2001 (16% non-road gasoline, 15% non-road diesel, 23% marine vessels, and 1% other) (USEPA 2006). A 2002 personalized watercraft environmental assessment for PIRO estimated that motorized watercraft would have a moderate impact on carbon monoxide levels in PIRO, but a negligible impact on VOCs, $NO_X$, particulate matter (PM), and hydrocarbons (HC) (NPS 2002). However, this conclusion may need to be reevaluated in light of these USEPA estimates.

**Table 11. Sources of air emissions in Alger County (USEPA 2005a).**

| Facility | EPA Listing | Community | Location | Standard Industrial Classification Code |
|---|---|---|---|---|
| Neenah Papers | TRI, AIRS | Munising | 501 East Munising Avenue | Paper mills |
| Timber Products Michigan | AIRS | Munising | Highway M-28 E | Sawmills and planing mills; hardwood veneer and plywood |
| Nebel Building Supply | AIRS | Wetmore | Hwy 13 | Ready-mix concrete |
| Gerou Excavating, Inc | AIRS | Munising | M28 and Hwy 13 | Concrete block and brick |
| Hiawatha Log Homes, Inc | AIRS | Wetmore | M28 E | Prefabricated wood building manufacturing |
| Munising Memorial Hospital | AIRS | Munising | 1500 Sand Point Road | General medical and surgical hospitals |
| Wood Island Waste Management | AIRS | Wetmore | M28 and M94 E | Refuse systems |

**Air Monitoring**: PIRO is a Class II air quality area. Air monitoring stations in the vicinity of PIRO include a wet deposition monitoring site operated since 2000 by the NADP National Trends Network (NTN) at the Seney National Wildlife Refuge, Michigan (NWR), Michigan (site #MI48), about 40 km southeast of PIRO and a dry deposition site operated since 2000 by the Clean Air Status and Trends Network (CASTNet) at Hoxeyville, Michigan, about 265 km south-southeast of PIRO (Maniero and Pohlman 2003). Seney NWR also has hosted a particulate matter monitoring site as part of the Interagency Monitoring of Protected Visual Environments (IMPROVE) network, which includes a "haze camera", since 1999, and an ozone monitor since 2002 (Maniero and Pohlman 2003). In October 2005, the MIDEQ installed two particulate matter less than 2.5 microns in diameter (PM2.5) monitors at Channing and Crystal Falls, about 144 km southwest of PIRO, to monitor wood smoke (MIDEQ, Craig Fitzner, Air Toxics Supervisor, pers. comm. 2005). The Michigan Inter-Tribal Council also operates PM2.5 monitors in Sault Ste. Marie and in Brimley, 177 km east of PIRO (MIDEQ, Craig Fitzner, Air Toxics Supervisor, pers. comm. 2005).

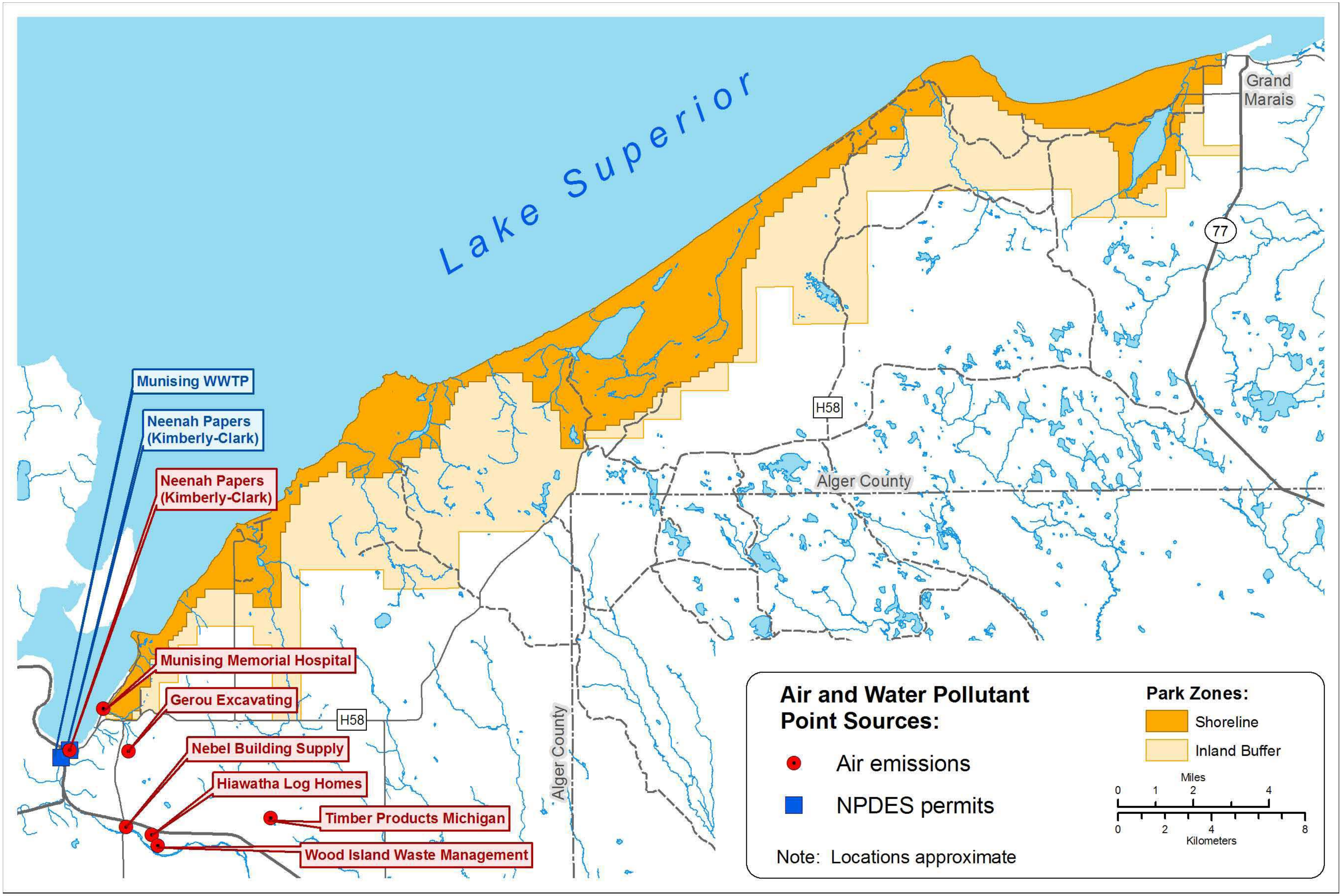


Figure 17. Sources of air emissions and locations of NPDES discharge permits in the Pictured Rocks area.
(Source: USEPA 2005a)

*Point Sources Affecting Primarily Lake Superior*

**Facilities with NPDES permits**: Three NPDES permits have been issued in Alger County (Figure 17) (USEPA 2005a). One is for the Michigan Department of Corrections Camp Cusino facility at Shingleton, which discharges to Hickey Creek in the Lake Michigan drainage basin and so will not be discussed further. The others are the Munising Wastewater Treatment plant and the Neenah Papers (formerly Kimberly-Clark) paper mill in Munising. The next closest facilities to PIRO that have NPDES permits are located in Marquette, Michigan, approximately 69 km to the northwest.

***Munising Wastewater Treatment Plant***: The Munising wastewater treatment plant is an activated sludge plant with phosphorus removal capabilities. It was built in 1973 and expanded in 1990. Dechlorination facilities were also added in 1990. The plant treats an average of 2,600-3,000 cubic meters/day ($m^3day^{-1}$) of wastewater, which is within its design capacity of 3,500 $m^3day^{-1}$. The plant discharges to the Anna River near its mouth at Lake Superior (MIDEQ 2001a).

Because the collection system is in poor condition, the treatment plant receives approximately 1100-2200 $m^3day^{-1}$ of infiltration/inflow (CUPPAD 2000). On November 8, 2005, Munising voters accepted an $8.5 million federal loan and $1.6 million federal grant to improve sanitary sewers, storm sewers, and force mains, and to convert the plant to an oxidation ditch system (City of Munising, Doug Bovin, City Manager, pers. comm. 2005).

The plant treats municipal wastewater for 3,000 people in the city of Munising and 1,000 people at the Alger Maximum Security Prison. It does not receive wastewater from any reportable industrial or commercial processes. Some areas of the city are still served by on-site wastewater treatment systems.

The plant's effluent characteristics are described in its 2001 permit application (Table 12). From 2002-2004, the plant met its required flow limits and its water quality limits for biological oxygen demand, fecal coliform, ammonia nitrogen, dissolved oxygen, pH, and total phosphorus. It had a violation for total residual chlorine (2.11 mg/L) in February 2003. It did not meet its required 85% reduction of total suspended solids in April 2002 (78% removal), March 2004 (79%), June 2004 (83%), and July 2004 (78%) (USEPA 2005a).

The plant produces 110 tons of biosolids per year. They are land applied twice a year on 40 ha of farmland near Traunik, Michigan, approximately 32 km southwest of Munising and outside of PIRO's watershed (MIDEQ 2001a).

***Neenah Papers (formerly Kimberly-Clark Corporation)***: The Neenah Papers mill manufactures fine and specialty papers from pulp not manufactured on site. Its NPDES

**Table 12. Effluent characteristics for the City of Munising Wastewater Treatment Plant (MIDEQ 2001a).**

| Parameter | Maximum daily concentration | Maximum monthly concentration | Units | Number of Analyses | Grab or 24-hour composite sample |
|---|---|---|---|---|---|
| Carbonaceous BOD5 | 10.5 | 5.73 | mg/L | 260 | 24-hour |
| Carbonaceous BOD5, Lowest % removal | | 92 | % | 260 | 24-hour |
| Ammonia nitrogen (as N) | 9.37 | 6.23 | mg/L | 52 | 24-hour |
| Total suspended solids | 26.8 | 9.3 | mg/L | 260 | 24-hour |
| Total suspended solids, Lowest % removal | 83.8 | | % | 260 | 24-hour |
| Total phosphorus (as P) | 1.78 | 0.56 | mg/L | 260 | 24-hour |
| Fecal coliform bacteria (geometric mean) | (max. 7-day) 70 | 25 | counts/ 100 ml | 260 | Grab |
| Total residual chlorine | 0.032 | 0.0081 | mg/L* | 365 | Grab |
| Dissolved oxygen | (min. daily) 4.31 | | mg/L | 365 | Grab |
| pH | minimum 6.49 | maximum 7.34 | | 260 | Grab |

***not stated but assumed from values**

Table 13. Sources of water and composition of water discharges, Kimberly-Clark Corporation, (now Neenah Papers), Munising, MI (MIDEQ 2001b).

| Water Sources | Water Discharges to Lake Superior | | | |
|---|---|---|---|---|
| | Sanitary wastewater | Process water | Minimally contaminated non-contact cooling water | Regulated storm water |
| **City of Munising, 61 $m^3day^{-1}$** | 61 $m^3day^{-1}$ | | | |
| **Lake Superior, 22,334 $m^3day^{-1}$** | | 16,656 $m^3day^{-1}$ | 3,785 $m^3day^{-1}$ | |
| **Precipitation and snowmelt** | | | | 0-1,325 $m^3day^{-1}$ |

permit allows it to discharge 37,850 $m^3day^{-1}$ of treated wastewater to Lake Superior (MIDEQ 2001b). In 2001, it withdrew approximately 22,334 $m^3day^{-1}$ of Lake Superior water, and returned approximately 20,441 $m^3day^{-1}$ (a 10% loss through evaporation is assumed). The sources of the plant's water and composition of the wastewater are shown in Table 13.

The Neenah Papers wastewater treatment system consists of a primary clarifier, a recarbonization basin to reduce pH, and a series of final polishing ponds. Water that may contain latex or fillers from the papermaking process is treated with calcium hydroxide, ferric chloride, and a polymer to coagulate and precipitate these materials before going to the clarifier. The sludge is dewatered and recycled into a glass aggregate substance by an outside vendor.

Table 14. Parameters detected in wastewater, Kimberly-Clark Corporation (now Neenah Papers), Munising, MI (MIDEQ 2001b).

| Parameter | Result | Units |
|---|---|---|
| Chloroform | 0.56 | µg/L |
| Ethylbenzene | 0.19 | µg/L |
| Copper, total | 16 | µg/L |
| Lead, total | 3.2 | µg/L |
| Chloride | 20 | mg/L |
| Nickel, total | 0.004 | mg/L |
| Zinc, total | 0.024 | mg/L |
| Cyanide, amen. to chlorine | 0.008 | mg/L |
| Mercury, ultra low level | 0.9 | ng/L |
| Mercury at mill intake | 0.61 | ng/L |
| Fecal coliform | 4 | Colonies/100 ml |
| Aluminum, total | 0.055 | mg/L |
| Iron, total | 0.11 | mg/L |
| Surfactants (MBAS), anionic | 0.038 | mg/L |
| Oil and grease, water (hexane) | 2.7 | mg/L |
| Hydrogen sulfide, water | 0.2 | mg/L |
| Meta, para-Xylene | 0.36 | µg/L |
| Ortho-Xylene | 0.34 | µg/L |
| Styrene | 0.95 | µg/L |
| Toluene | 0.18 | µg/L |

During the repermitting process in 2001, the wastewater was tested once for organic toxic pollutants, pesticides, metals, cyanide, total phenols, dioxin and furan congeners, and other selected pollutants. All results were below detection limits with the exception of those in Table 14.

Results from the plant's routine water quality monitoring are shown in Table 15. From 2002-2005, the plant met all required water quality limits for flow, water temperature, biological oxygen demand, pH, total suspended solids, and mercury. The USEPA Toxic Releases Inventory shows that in 2003, this facility released 750 pounds of ammonia into Lake Superior (USEPA 2005a).

**Deer Lake AOC**: The United States and Canada, through the Great Lakes Water Quality Agreement, have agreed to develop remedial action plans for the most polluted areas in the Great Lakes, known as Areas of Concern (AOCs). Deer Lake, in central Marquette County, Michigan, is an AOC because of mercury contamination associated with past mining and ore assaying activities (USEPA 2001a). This AOC, approximately 69 km northwest of PIRO, is the nearest AOC to PIRO. It is not considered a threat to park resources.

*Nonpoint Sources Affecting Primarily Lake Superior*

**Great Lakes shipping**: Lake Superior is an important waterway for the transfer of goods and materials. The largest port on the lake, Duluth, handles 40 million metric tons of cargo annually, and is ranked 18th in the nation in terms of total cargo volume (Duluth Seaway Port Authority 2004). Smaller ports closer to

Table 15. Routine water quality monitoring results, Kimberly-Clark Corporation (now Neenah Papers), Munising, MI (MIDEQ 2001b).

| Parameter | Maximum daily concentration | Maximum monthly concentration | Units | Number of analyses | Grab or 24-hour composite sample |
|---|---|---|---|---|---|
| **Biochemical oxygen demand – five day** | 8.9 | 3.1 | mg/L | 366 | 24-hour |
| **Total suspended solids** | 8.0 | 3.4 | mg/L | 366 | 24-hour |
| **pH** | minimum 6.3 | maximum 8.8 | standard units | continuous | |
| **Temperature, Summer** | 86 | 83 | degrees F | 183 | Grab |
| **Temperature, Winter** | 73 | 61 | degrees F | 183 | Grab |
| **Oil and Grease** | 0 | 0 | mg/L | 366 | Visual, grab |
| **Formaldehyde** | 459 | | μg/L | 24 | Grab |

PIRO include Marquette, which is a receiving port for limestone and coal, and Munising, which is also a receiving port for coal (Lake Carriers Association 2004).

About 1,100 vessels visit the port of Duluth each year. Because ships from Duluth must travel northward to round the Keewenaw peninsula, they are between 40-55 km offshore at their closest approach to PIRO. Ships that travel to Marquette in the main shipping lane come within 7 km of PIRO at Au Sable Point, while those downbound from Marquette are about 11 km out (Figure 18) (NOAA 2005). Shipping lanes are not always shown on the navigation charts for small ports.

The risk of shipwreck and a resultant spill of cargo or fuel is not insignificant: Lake Superior's cliffs and reefs, and unpredictable weather, have contributed to many shipwrecks in the past, including 116 reported wrecks in the general vicinity of PIRO (NPS 2002). The Alger Underwater Diving Preserve offshore from the park officially contains the remains of nine ships.

Shipping vessels may affect the quality of the waters on which they travel in numerous ways. Discharges from vessels could include spilled cargo and fuel, normal losses of fuel during engine operation, and discharges of garbage, dunnage (material placed between cargo during shipping), human sewage, bilge water, and ballast water. Bilge water is the water that collects at the bottom of the hull of a ship or boat. It is often contaminated with fuel as well as oily materials used to lubricate the boat's moving parts. Bilge water may also carry solid wastes, and often has a high oxygen demand (Copeland 2004). Ballast water is water carried in the cargo areas of a ship to weigh it down when it is not carrying cargo.

Many regulations are in place to attempt to prevent water pollution from both recreational boating and commercial shipping activities. The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) and its amendments is an international treaty that addresses pollution from oil, noxious substances, harmful substances in packaged form, sewage, garbage, and air pollution. Specifically, it forbids the discharge of bilge water that produces a sheen or has an oil content of more than 15 ppm (International Maritime Organization 1978). The Refuse Act of 1899 prohibits the throwing of any refuse into the waters of the United States (Code of Federal Regulations 1899). The Federal Water Pollution Control Act prohibits the discharge of oil or hazardous substances into U.S. navigable waters (Code of Federal Regulations 1987). All vessels with propulsion capability must have capacity to retain oily materials on board.

Coast Guard regulations make it illegal to dump plastics, dunnage, lining and packaging materials, and garbage (except dishwater, greywater, and fresh fish parts) anywhere in the Great Lakes. The discharge of raw sewage from boats is also prohibited in the Great Lakes, and no discharge of treated sewage from marine sanitation devices is permitted in Lake Superior in Michigan (USEPA 2005c).

*Cargo*: Shipping data for Lake Superior indicate that for the port of Duluth, the major commodities shipped (by weight) include iron ore (40%), coal (40%), and grain (10%) (Duluth Seaway Port Authority 2004). Thunder Bay cargoes are about one-third iron ore and two-thirds grains and soybeans (USEPA and

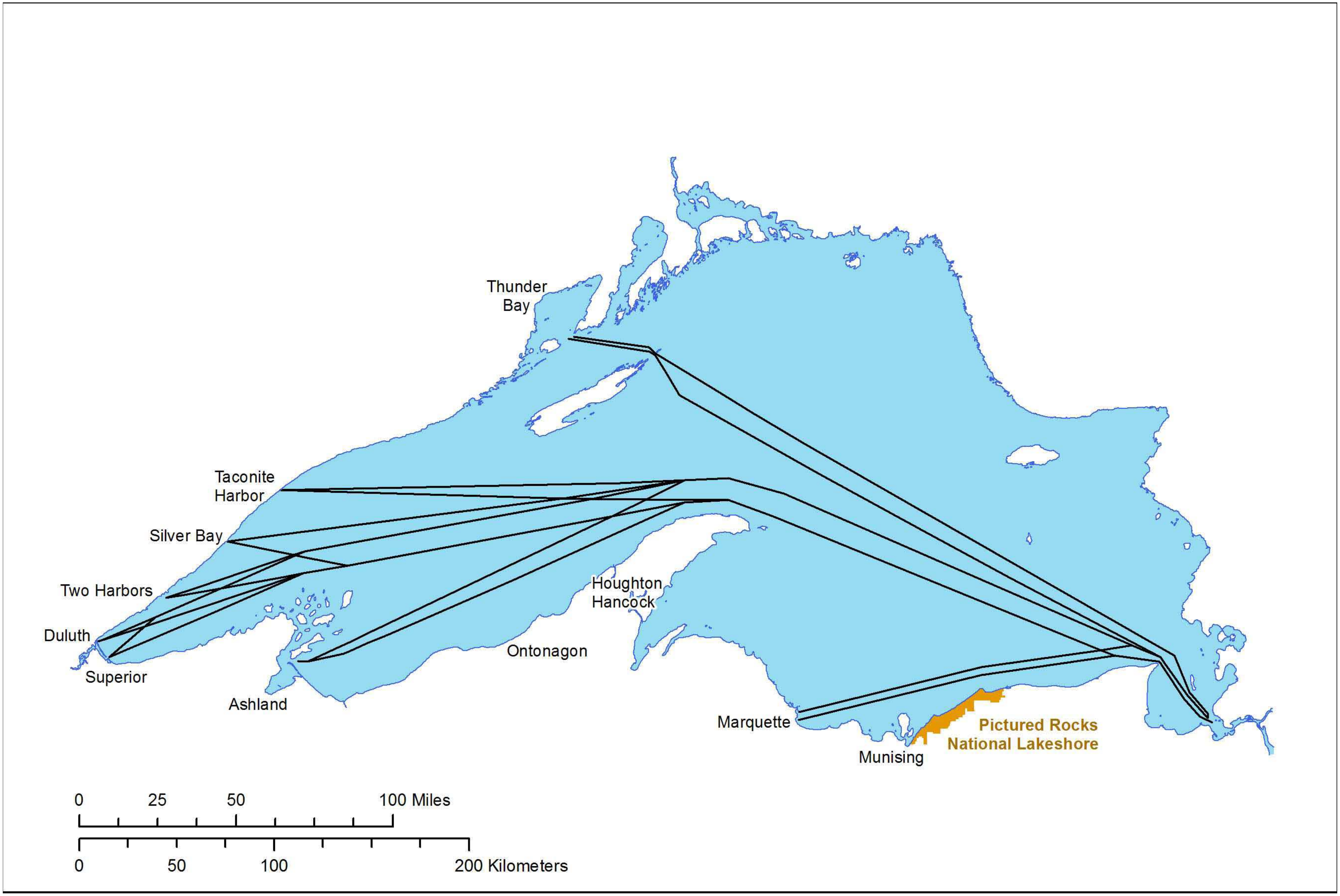


Figure 18. Lake Superior shipping lanes.
(Source: NOAA 2005)

Government of Canada 1995). The other smaller ports whose shipping lanes join the Duluth shipping lane (Two Harbors, Silver Bay, Taconite Harbor, Ashland, Ontonagon, Houghton, and Hancock) ship iron ore and coal. In addition, grain and cement are shipped from the port at Superior, Wisconsin. Iron ore, coal, and limestone cargoes are shipped at Presque Isle and Marquette, in the closer shipping lane to the park (Lake Carriers Association 2004). These cargoes, if spilled, would not likely create a major threat to the park.

***Fuel***: Ore carriers and other cargo ships on Lake Superior are very large vessels and carry large volumes of fuel. For example, the *SS Edmund Fitzgerald*, which famously sank in Lake Superior in 1975, was 222 m long and carried 273 $m^3$ of fuel (Wikipedia contributors 2005). A typical 305 m lake freighter carries 689 $m^3$ of primarily #6 fuel oil, 167 $m^3$ of #2 fuel oil, and 72 $m^3$ of lube and waste oil (U.S. Coast Guard, Greg Schultz, pers. comm. 2005). Of the bulk carriers and tankers reported in a 2003 study of oceangoing transport ships, 91% were operated with two-stroke engines, and 95% of those engines burn heavy fuel oil (also known as residual fuel or bunker C fuel) (Corbett and Koehler 2003).

The potential harm from an oil spill resulting from a bulk cargo vessel running aground was evaluated for Isle Royale National Park (also located in Lake Superior) (Rayburn et al. 2004). The simulation assumed a spill of approximately 100 $m^3$ of Intermediate Fuel Oil. Conclusions pertinent to PIRO included that shoreline cleaning methods for freshwaters are not well documented, and that floating platforms would be needed in the nearshore environment for cleanup operations. The greatest risks under the "natural attenuation" scenario, in which pollutants are allowed to degrade naturally, included risks to terrestrial mammals; birds, fish and macroinvertebrates in coastal wetlands; shoreline vegetation, mammals, birds, and herptiles; and nearshore fish.

In 2000, the USEPA led an interagency effort to develop atlases that showed the sensitivity of water resources in Region 5 to oil spills. The report for the Upper Peninsula of Michigan shows that PIRO has 22.28 km (13.85 miles) of rocky shores with low sensitivity, 39.48 km (24.54 miles) of sand and gravel beaches with low-medium sensitivity, and 1.38 km (0.86 miles) of vegetated low to steep banks and mud flats with medium sensitivity (Table 4, Figure 19). No areas of marsh and shrub-scrub wetlands, which have the highest sensitivity ratings, were reported (USEPA Region 5 2000).

***Bilge Water***: Despite regulations, illegal bilge discharges from ships and boats do occur. Specific data for Lake Superior were not found, but data on ships' practices in the ocean may provide some insight into possible risks to the lake. Currently, 50% of the oil entering the sea from shipping activities comes from bilge and fuel oil sludges, mainly due to the lack of onshore reception facilities, according to the Ocean Conservancy (2001). A study of foreign-flag cruise ships found 72 cases in which they had discharged oil or oil-based products into U.S. waters between 1993 and 1998 (USGAO 2000).

In 2002, the World Wildlife Fund of Canada reported that 300,000 birds are killed each year on Canada's ocean coast because of illegal bilge discharges (Wiese 2002). Bird mortality rates in the U.S. were significantly lower. Fines up to 1000 times higher were thought to dissuade more ships from discharging in U.S. waters.

***Ballast Water***: Concerns with ballast water discharges center around the possible introduction of exotic invasive species. Ballast water contains organisms ranging from bacteria and algae to worms and fish. All oceangoing ships are required to exchange their ballast water in the open ocean before traveling into the Great Lakes (LSBP 2000). However, 90% of ships that enter the Great Lakes are reported as "no ballast on board" (NOBOB), because they are filled with cargo. The ballast tanks of NOBOB ships are not completely empty, and some organisms survive in sediments or the small remaining amount of water in the tanks. As the ships unload cargo, they take on additional ballast water from other Great Lakes ports. From 1981-2000, 70% of NOBOB ships made their final stop at Lake Superior, where they discharge their mixed ballast water as new cargo is loaded. Lake Superior also receives about 75% of the ballast water discharged by transoceanic ships that enter the Great Lakes with ballast on board (Grigorovich et al. 2003a).

Grigorovich et al. (2003b) identified 67% of the 43 aquatic animal and protist species introduced and established in the Great Lakes since 1959 as having originated in ballast water from commercial vessels. Thus, Lake Superior appears to be at high risk for the introduction of exotic species. However, Lake Superior's oligotrophic

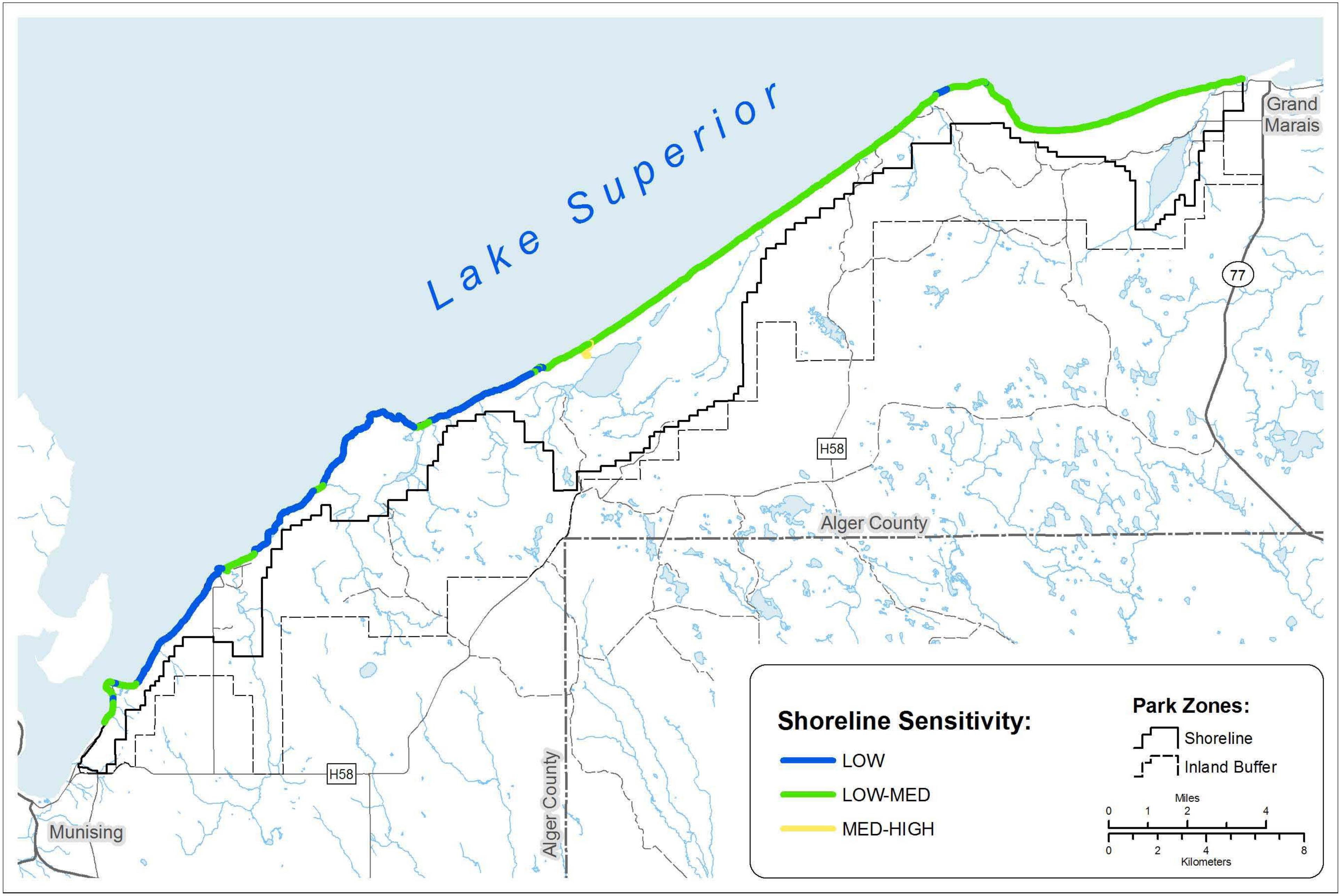


Figure 19. Shoreline sensitivity to spills classifications for Pictured Rocks National Lakeshore.
(Source: USEPA Region 5 2000)

nutrient state, limited primary productivity, and high ratio of profundal-limnetic to littoral zones may be mitigating factors that limit aquatic invasive species (Grigorovich et al. 2003a).

Nevertheless, the state of Michigan has responded by establishing a voluntary Ballast Water Reporting list. To be listed, oceangoing vessels state that they have complied with the "Code of Best Management Practices for Ballast Water Management" provided by the Shipping Federation of Canada. Nonoceangoing vessels state their compliance with the "Voluntary Management Practices to Reduce the Transfer of Aquatic Nuisance Species within the Great Lakes by United States and Canadian Domestic Shipping," provided by the Lake Carriers' Association and the Canadian Shipowners' Association to the MIDEQ. Vessel owners, operators, and anyone who contracts for transportation of cargo with an operator not on the list become ineligible for any new grant, loan, or award administered by the MIDEQ (MIDEQ 2002c). Michigan has also taken the lead among Great Lakes states by requiring that beginning in 2007, oceangoing ships must demonstrate that they will not discharge exotic species into state waters, and must obtain a permit to use Michigan ports (National Sea Grant Law Center 2005).

In April 2005, a U.S. District Judge ordered the USEPA to repeal regulations exempting ship owners from obtaining pollution discharge permits for ballast water, and in September 2006, a federal court ordered it to develop new ballast water regulations under the Clean Water Act by September 2008 (Ocean Conservancy 2006). Technologies exist to treat ballast water, including the use of filtration, ultraviolet light, acoustics, salinity, heat, chemical biocides, sedimentation, pH treatment, oxygen deprivation, or discharge to reception vessels (Reeves 1996), although some shippers dispute their affordability.

**Tour Boats**: Local tour boat operations may also pose a risk to Lake Superior waters. Commercial tours are offered by Pictured Rocks Cruises, Inc., which operates four boats out of Munising, traveling to Chapel Rock and occasionally farther eastward to Spray Falls (Pictured Rocks Cruises, Inc. 2004). Approximately 10 tours of the Pictured Rocks are offered each day during the summer months, and less frequently in late May, June, September, and early October. Tour boats use twin diesel engines (approximately 440 horsepower) and within the park boundaries, operate at no-wake speeds for four to eight hours per day (NPS 2002). Two commercial operators offer scuba diving and snorkeling trips to the Alger Underwater Diving Preserve. North Star Charters operates the *Linda K*, which is 8 m long and carries 1040 L of diesel fuel (Wood 2004). Shipwreck Dive Tours operates the *Fireball*, which is 17 m long (Wood 2001).

Tour boat air emissions were estimated and considered insignificant in an analysis done for PIRO's Environmental Impact Statement for personal watercraft (NPS 2002). However, no analysis has been done of the risk of a tour boat accident or fuel spill. In September 2005, a small engine fire required the evacuation of the *Miner's Castle*, one of the boats in Pictured Rocks Cruises fleet. Passengers were evacuated from the 21 m ship onto its sister ship, and it was towed back to the Munising dock (Brownlee 2005).

**Personal Watercraft and Motorboats**: The major impacts of motorized watercraft, including motorboats and personal watercraft ("jet skis"), on aquatic ecosystems include sediment resuspension, water pollution, disturbance of fish and wildlife, destruction of aquatic plants, and shoreline erosion (Asplund 2000). Most motorized watercraft have two-stroke engines, which are inefficient and lose about 30% of their fuel to the environment (California Environmental Protection Agency Air Resources Board 1999), although newer models are becoming more efficient and have the advantage of being lighter in weight than four-stroke engines. The primary pollutants of concern from marine engines in Michigan include PAHs (polyaromatic hydrocarbons), BTEX (benzene, toluene, ethylbenzene, and xylene), and heavy metals such as copper (NPS 2002). Other mechanisms by which motorized watercraft may harm the environment include propeller contact with plants and animals, turbulence from the propulsion system, wakes, noise, and movement that disturbs wildlife (Asplund 2000).

Motor boat and personal watercraft use within PIRO is regulated by the State of Michigan. In addition, the NPS has adopted the state's personal watercraft regulation in park rules. Approximately 50-150 private motorboats go out in PIRO's Lake Superior waters per day in the peak months of July and August. Locally, boats are launched at Munising, Sand Point, and Grand Marais. Approximately 6-25 personal watercraft also use the Lake Superior waters in PIRO each week (NPS 2002). New rules enacted in 2005 allow personal watercraft users to launch at Sand Point and operate on Lake Superior within the national lakeshore boundary from the western lakeshore boundary up to the east end of Miners Beach only (Pepin 2005).

The 2002 Personal Watercraft Use Environmental Assessment concluded that erosion would not be a major factor and that emissions would be concentrated at Munising, Grand Marais, and Sand Point (NPS 2002). Under the adopted alternative, "cumulative impacts from personal watercraft and motorized boat use (including commercial fishing, commercial boating, and recreational boating) would range from negligible to moderate. Total PAH concentrations would be a concern for aquatic life, due to potential phototoxicity. Benzene concentrations could be detectable, but are expected to remain below the human health criterion. By 2012 impacts would be reduced substantially through improved emission controls." (NPS 2002). These statements are based on calculations of the volume of water required to dilute a contaminant to meet a standard protective of aquatic life. However, since the emissions do not instantly disperse, short-term localized impacts could exist.

**Marinas**: Two marinas are located on PIRO's edges. The Bayshore Marina at Munising has ten transient slips and nine seasonal slips. Amenities include restrooms, showers, gasoline, and a wastewater pumpout station (MIDNR 2004). The harbor on Grand Marais Bay is the only Harbor of Refuge between Little Lake and Grand Island (NOAA 2006). Burt Township Marina, located there, provides transient docking, and also provides restrooms, gasoline, diesel, and a pumpout station (Dahl 2001).

Pollution sources at marinas may include boat washing, repair and maintenance activities, runoff from parking lots and piers, fuel and oil spills, dirty bilge water, improper sewage disposal, and garbage disposal. Recent research in Isle Royale National Park found clear evidence of PAH contamination at significant levels near marinas (Clements and Cox 2006). Michigan has initiated a voluntary Clean Marinas program through the MIDEQ, the Michigan Sea Grant College Program, and the Michigan Boating Industries Association. Marina operators complete a self-assessment checklist, sign a pledge, and then can become certified and fly the Clean Marinas flag. The program is fairly new, and these two marinas have not yet enrolled in it (MIDEQ, Jeff Spencer, Michigan Clean Marina Program, pers. comm. 2005).

**Stormwater**: Stormwater contains a variety of contaminants washed from parking lots, streets, rooftops, lawns, and other areas. In the 117 ha urban watershed of Marquette, MI, parking lots contributed 30% of the total zinc, 25% of the total cadmium, 22% of the total copper, and 64% of the PAHs that left the basin as a whole. Low-traffic streets contributed 27% of total suspended solids, 21% of nitrate-nitrite nitrogen, and 25% of total cadmium (Steuer et at 1997).

Munising covers 1,399 ha and has 32 km of storm sewer mains that serve 1,165 ha of land (City of Munising, Doug Bovin, City Manager, pers. comm. 2005). A total of 25 outfalls, including eight major outlet pipes, deliver stormwater to Munising Bay, some via the Anna River (Munising Sewer and Water Department, Mike Niemi, Public Works Director, pers. comm. 2005). Grand Marais has storm sewers, maintained by the Alger County Highway department, that discharge into local streams, ditches, and wetlands that eventually discharge to Lake Superior (Burt Township Department of Public Works, Mike Beek, Manager, pers. comm. 2005). No monitoring data was found for these discharges. Neither community is large enough to be covered by current USEPA or MIDEQ stormwater regulations (MIDEQ, Lindsey Ringuette, Environmental Quality Analyst, pers. comm. 2005).

**Wood Island Waste Management Landfill**: The Wood Island Waste Management Landfill, located on Highway M-28 to the southwest of PIRO, is one of two landfills that regularly accept waste from throughout Michigan's Upper Peninsula. It currently receives some of Alger County's waste and most of Dickinson and Schoolcraft Counties' wastes (CUPPAD 2004).

Groundwater in the upper part of the unconsolidated aquifer under the landfill flows south toward Wetmore Creek and Wetmore Pond, which empties into Lake Superior west of PIRO (MIDEQ, Carl Smith, District Geologist, pers. comm. 2005), but outside of PIRO's watershed. Data from the MIDEQ show exceedences of site-specific statistical limits and some drinking water quality standards for numerous parameters, including metals and organic compounds, in a number of the site's downgradient wells (MIDEQ, Margie Ring, Waste and Hazardous Materials Division, pers. comm. 2005).

*Nonpoint Sources Affecting Primarily Inland Waters*

**On-site wastewater treatment systems**: Approximately 25 percent of the U.S. population relies on on-site wastewater treatment systems to treat and dispose of human wastes and household wastewater. Of all those systems, approximately 95% are septic systems, which means that the wastewater is treated using natural anaerobic processes and then is returned to the ground (NSFC 2001). Conventional septic systems work well for wastewater disposal in many cases, despite the fact that the basic technology has not changed much in the last 100 years. Risks to the environment from these systems increase when aquifers consist of coarse soils, when systems are located close to groundwater tables or surface water bodies, when systems are periodically flooded, when lot sizes are small, or as systems age, especially if they are not properly maintained. Contaminants of concern from on-site systems include phosphorus, nitrogen, carbon, chloride, synthetic organic chemicals, and pathogens (MPCA 2002).

In 2001, Michigan was the only state in the nation without some type of minimum statewide regulation for single and two family on-site systems. In Alger County, responsibility for permitting of new and replacement on-site systems falls to the Luce-Mackinac-Alger-Schoolcraft District Health Department (LMASDHD). Its Superior Environmental Health Code specifies minimum and maximum soil permeability rates (1-18 min/cm); minimum separation distances from surface water (23 m), groundwater and seasonal water tables (1.2 m); and minimum system sizes. It permits earth privies and vaulted privies but prohibits cesspools, and allows holding tanks only temporarily or after other methods have been tried and have failed (LMASDHD 1998).

**Table 16. Locations of on-site waste disposal systems at Pictured Rocks National Lakeshore.**

| | |
|---|---|
| Sand Point Headquarters | Sable Falls Comfort Station |
| Sand Point Seasonal Quarters | Grand Marais Seasonal Quarters |
| West District Maintenance Area | Grand Marais VIP Pad |
| Miners Castle Comfort Station | Grand Marais Ranger Station |
| Sullivan's Quarters | Grand Marais Ranger Residence |
| Grand Sable Visitor Center | Grand Marais Harbor of Refuge |

In general, the density of on-site systems in the Upper Peninsula is low, from 0-6 per km$^2$ (MIDEQ 2001c). In Alger County, approximately 130 systems are installed each year, of which about 2/3 are new systems and 1/3 are replacements of failed systems (LMASDHD, Tom Moseley, Sanitarian, pers. comm. 2005). Around PIRO, on-site systems may be found within the shoreline zone, within the city of Munising, and in Munising and Burt Townships in the IBZ.

Twelve on-site systems are managed by NPS at sites in the shoreline zone (Figure 20, Table 16). The on-site system at the Sand Point headquarters will soon be moved farther away from Lake Superior (PIRO, Lora Loope, Aquatic Ecologist, pers. comm. 2006). NPS also has vault toilets (which are pumped periodically and do not discharge to the environment) at 18 locations in the park. Outhouses with simple pits (non-vaulted) are located at the backcountry campgrounds near the mouth of Mosquito River and at Chapel Beach, and are moved every 10 years or so (PIRO, John Ochman, Maintenance Supervisor, pers. comm. 2005).

The city of Munising has a wastewater treatment plant, but approximately 79 homes in the city still use on-site systems (Munising Sewer and Water Department, Mike Niemi, Public Works Director, pers. comm. 2005). They are located mainly in areas north of the hospital, along Connors Road, Cemetery Road, St. Martin Road, Gage Road, Sand Point Road, and West Shore Drive (City of Munising Planning Commission 2004; Munising Sewer and Water Department, Mike Niemi, Public Works Director, pers. comm. 2005).

Neither Munising Township nor Burt Township has a wastewater treatment plant, although Burt Township is currently conducting a feasibility study as of fall 2005. Up to 1,154 housing units in Munising Township and 715 in Burt Township (including those in Grand Marais) have some

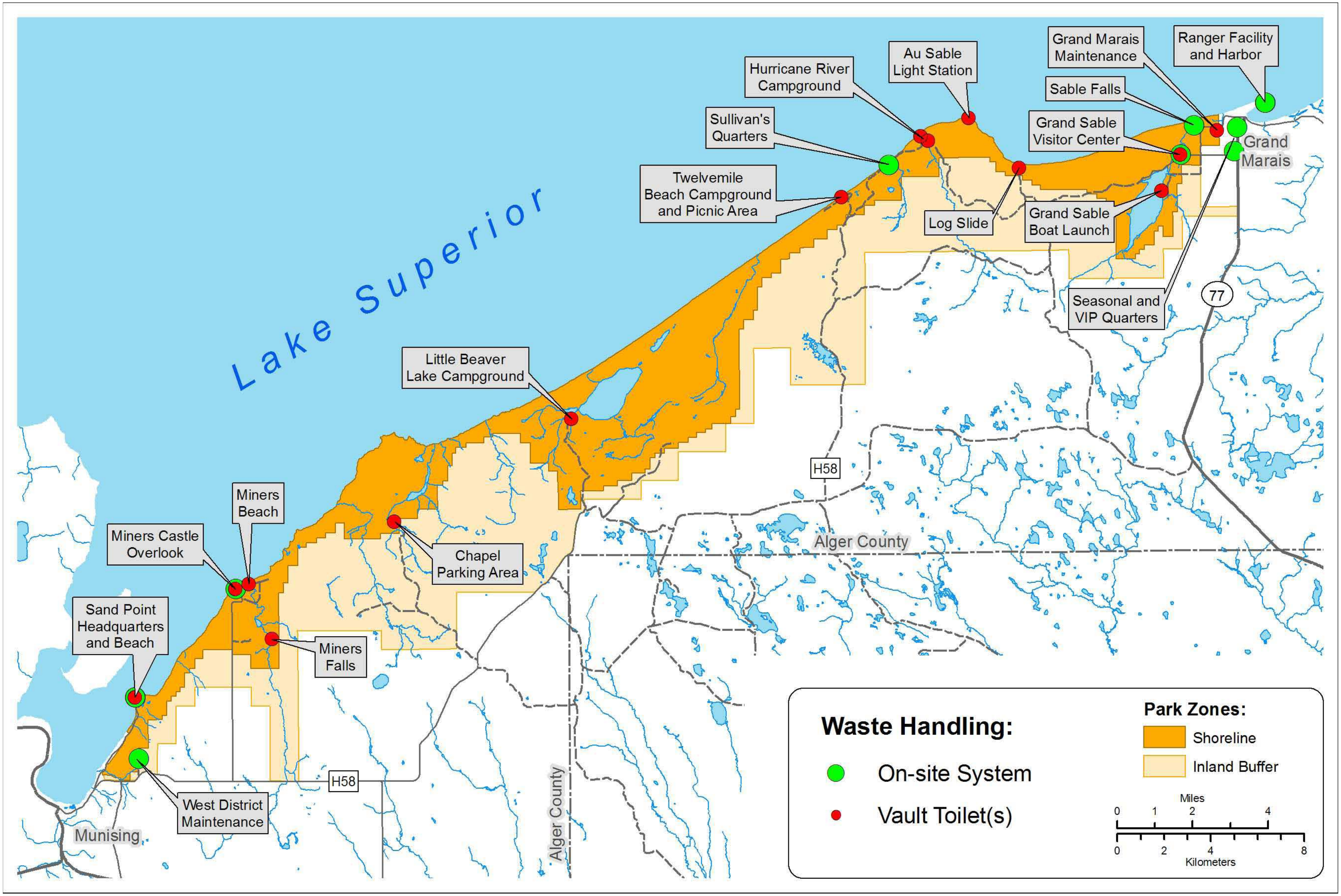


Figure 20. Locations of on-site waste disposal systems and vault toilets operated by Pictured Rocks National Lakeshore.
(Source: PIRO, John Ochman, Maintenance Supervisor, pers. comm. 2005)

type of on-site system.

**Personal watercraft and motorboats in park inland waters**: Personal watercraft are currently not allowed in PIRO's inland lakes because of horsepower restrictions, and are not feasible to operate in park streams and rivers. Motorboats with a 50 horsepower limit are permitted, and boat ramps are provided, on Grand Sable Lake. A boat ramp is provided at Little Beaver Lake for access to it and Beaver Lake through a short, natural channel. Electric motors only have been permitted on these two lakes since the area was identified as potential wilderness in the 2004 General Management Plan.

Research indicates that impacts of boat use are felt most acutely in shallow waters (<10 feet deep) and along the shorelines of lakes and rivers not exposed to high winds (<1000 feet of open water) (Asplund 2000). A fuel spill from a boat in the inland waters would not likely exceed 5 gallons (NPS 2004b). Personal watercraft and motorboats, and angling activities conducted from motorboats, may transfer aquatic invasive species into PIRO inland waters.

**Golf Courses**: Golf courses are intensively managed landscapes, where improperly applied chemicals and poorly managed runoff may contribute nutrients and other pollutants to surface waters and groundwater. Construction of new courses may remove woodlands and wetlands, and construction site erosion may contribute to sedimentation of waterways (Skoglund 2004). An 18- hole golf course, Pictured Rocks Golf and Country Club, is located on Highway H-58, just east of Munising. It is in PIRO's watershed but not within the IBZ. As of 2004, the golf course was a member of Michigan's Turfgrass Environmental Stewardship Program, which is supported by the Michigan Department of Agriculture, Michigan Turfgrass Foundation, MIDEQ, Michigan State University, Michigan Golf Course Owners Association and Golf Association of Michigan. The program has two parts. A pollution prevention module addresses site evaluation, wellhead protection, fuel storage, pesticide handling and application, pesticide and fertilizer storage, and pesticide mixing and loading pads. An environmental enhancement module, meant to improve the "green space" value of golf courses through promoting fish and wildlife habitat, indigenous vegetation, and water quality protection through the development of buffer strips, is currently being developed (MIDEQ 2002a).

**Agriculture**: The Michigan IFMAP program classifies only 3.6 ha in the watershed as non-vegetated farmland and 48 ha as forage crops. The 2002 Census of Agriculture (USDA 2002) shows that in Alger County, 986 ha of land were treated with commercial fertilizer, lime, or soil conditioners; 384 ha had manure applied to them; and 316 ha were treated with chemicals to control weeds, grass, or brush. In agricultural areas, soil erosion, manure storage and spreading, fertilizers, and pesticides may pose threats to the quality of both surface water and groundwater, but the production of crops and livestock is a minor activity within PIRO's watershed.

**Logging, Road Building, and Runoff**: Logging in the 19th and early 20th centuries had significant impacts on water resources in parts of Michigan's Upper Peninsula, some of which can still be seen. For example, in the Hiawatha National Forest, a great deal of sand remains in stream beds from stream banks destabilized by logging. PIRO, although it shares a similar logging history, does not have significant residual sand bed loads in its streams, perhaps because its stream gradients are much steeper (Loope and Holman 1991). However, Beaver Lake does show some residual biological and physical effects of a logging dam that was installed around 1905, used for 5 to 10 years, and finally removed in the early 1960s (Loope 1993).

Today in Michigan, erosion and sedimentation to water bodies are still considered the most significant potential water quality problems related to logging. Chemical pollution from machinery, thermal pollution effects as shade cover is removed, and debris and slash in waterways are also potential concerns (Hausler and Peterson 2001).

Logging is not permitted within PIRO's shoreline zone, but "continuing sustained yield timber harvest" is one of the permitted uses within the IBZ (NPS 2004a), as specified in the park's 1966 enabling legislation (Public Law 89-668). Jack pine is usually clearcut, while hardwoods are usually selectively logged. Each parcel in the IBZ is inspected annually by rangers in the Visitor Services and Land Protection division, and logging activities are noted, but the park does not keep records of the number of board feet harvested or number of acres logged (PIRO, Lora Loope, Aquatic Ecologist, pers. comm. 2005).

A study in PIRO's Mosquito River watershed in 1988 showed no detectable effect of limited selective cutting on water quality (Mullen 1988, cited in Boyle et al. 1999), but this cutting occurred in winter and may not have general applicability to other seasons or watersheds. In 1999, a risk assessment was done to look at the potential impacts of both logging and road building on park water resources (Boyle et al. 1999). Stream substrate size, fish analysis, and aquatic macroinvertebrate community metrics such as density, taxa richness, Shannon's Diversity, Simpson's D, and EPT were used to determine disturbance effects. Maps were developed showing areas of high, medium and low risk for the Miners River, Hurricane River, and Mosquito River watersheds. Cobble/gravel, mud/silt, and organic substrates were identified as being at highest risk. For timber harvest, the risk was low in most areas of the Mosquito River and Hurricane River watersheds. The risk was higher in areas paralleling the stream corridor of the Miners River.

Logging is one of the major reasons for the construction of new roads in the IBZ, but other new roads may be constructed as well. Boyle et al. (1999) assign higher risk overall to road building than to logging in the Hurricane, Miners, and Mosquito River watersheds, with the Mosquito and Miners watersheds having large areas of moderate risk. The 2004 General Management Plan recommends the use of MIDEQ best management practices to protect water quality during future road construction, which include silt fencing, prompt revegetation, and consideration of slope factors (NPS 2004b). The effects of sedimentation at road crossings on the spawning of anadromous fish was dismissed as an insignificant factor in the 2004 General Management Plan (NPS 2004b). Boyle et al. have recommended a monitoring plan to assess the impact of future logging or road building activities.

Runoff from roads and parking lots, especially those sealed with coal-tar emulsion sealants, has been shown to contain PAHs at levels 65 times higher than those from unsealed asphalt or cement surfaces, even after four years. These sealants are a major source of PAHs even among the other sources in urban settings (Mahler et al. 2005). PIRO-owned roads and parking lots are not blacktopped (PIRO, John Ochman, Maintenance Supervisor, pers. comm. 2006), but an evaluation should be made of the maintenance practices on county road H-58, which is within the park boundary in several places.

**Surface Water Quality**

Numerous water quality studies have been done in PIRO and the surrounding area since 1970. In 1993, the NPS contracted to gather and analyze all surface water quality data found in the USEPA's STORET data system for the National Parks. The report for PIRO (commonly referred to as the Horizon Report after its contractor) was completed in 1995 and summarized STORET data through September 1992. Seventy-six monitoring stations were identified, and 7,466 observations were noted for 237 separate parameters, with data collected by the USEPA, USGS, NPS, MIDEQ, and MIDNR. Thirty-five stations were located within the park boundary, and fourteen of those yielded longer-term records. Some STORET data exist for all Level 1 parameters in PIRO, but most of the data are old (collected prior to 1985) (NPS 1995) and not useful for temporal tracking of water quality trends.

We identified several additional samples that were not included in the Horizon report. Coordinates for the MIDEQ samples from 1974 and 1987 labeled "Grand Sable Lake in NW Basin – Burt Township" plotted outside PIRO, but seem quite likely to be in one of its major lakes. On the other hand, a set of USEPA Large Lakes Program data from 1973-76 plots at a PIRO location where no water body occurs, and we could not document their proper location. Other samples in Lake Superior and in Munising Harbor exist but were just outside the one-mile downstream boundary set up for the Horizon study.

*Monitoring Programs*

The state of Michigan has established water quality standards for bodies of water within PIRO, and the MIDEQ monitors the condition of watersheds in PIRO and throughout the state on a rotating five-year basis, with a target of assessing 80% of the river/stream miles in each watershed. Monitoring parameters include biological (benthic invertebrates and/or fish), habitat, water, sediment, aquatic macrophytes and algae, and fish tissue indicators in wadeable streams (MIDEQ 2004b). In PIRO, Sable Creek and Towes Creek were sampled in 1999 and 2004. In 2000, Hurricane River, Miners Creek, and Mosquito River were sampled. In 2005, they were resampled, and Sullivan Creek was added (MIDEQ 2000a, 2005b; MIDEQ, William Taft, Aquatic Biologist, pers. comm. 2005).

Field work for a multi-park study inland lakes study, including Beaver and Grand Sable Lakes, was completed by the USGS Great Lakes Science Center (Whitman et al. 2002) in 1999. Data were obtained and samples were collected for analyses of water chemistry, water transparency, dissolved oxygen, temperature, primary productivity, phytoplankton, zooplankton, benthos, and sediment chemistry, and a final approved report is pending.

Michigan's Water Chemistry Trend Monitoring Program does not have any open water sampling sites on Lake Superior (Aiello 2005), but relies on sampling the quality of streams that enter the lake. The MIDEQ assesses the health of inland lakes through a citizen volunteer monitoring program coupled with a baseline monitoring program for public access lakes (MIDEQ 2004b). The MIDEQ also conducts monitoring programs that sample contaminants in fish tissues and track drinking water quality (MIDEQ 2004b).

In Michigan, grants are awarded to local health departments to monitor beaches for *E. coli* to determine whether body-contact water quality standards are being met. The LMASDHD has contracted with the state to conduct beach monitoring in cooperation with Lake Superior State University beginning in 2006 (LMASDHD, Peggy French, Director of Environmental Health, pers. comm. 2005). No past beach sampling records were found for Lake Superior or inland lake sites in Alger County (USEPA 2005d; MIDEQ 2005a), although a sample is collected each year at Sand Point on one of the hottest days of the year when bather use is heaviest (PIRO, Lora Loope, Aquatic Ecologist, pers. comm. 2006).

Park staff regularly monitors lakes within PIRO for dissolved oxygen, temperature, specific conductance, total dissolved solids, pH, and Secchi transparency depth during the spring, summer and fall months (PIRO, Lora Loope, Aquatic Ecologist, pers. comm. 2005). They have also developed a detailed Aquatic Monitoring Plan for PIRO (Loope 2004), but the plan is on hold because of work being done by the NPS's Great Lakes Inventory and Monitoring Network (GLKN). GLKN is currently finalizing an ecosystem-based Vital Signs monitoring program to track parameters that "best indicate the overall condition of park resources…respond in predictable ways to stressors, or … are of particular importance to people" in PIRO and other network parks (Route and Elias 2004).

*Water Quality Monitoring Data and Results*

Although numerous sampling efforts have been undertaken in and around PIRO since 1970, few data sets exist that allow the tracking of water quality trends over time (Table 17). Thus, interpretation of the data is somewhat limited to discussing individual data points and comparing them to established legal standards and guidelines for various beneficial uses. In general, the water resources of PIRO are of good quality (NPS 1995; MIDEQ 2004b, 2005b; Ledder 2005). Results for individual parameters are examined in more detail below.

*Designated Beneficial Uses or Classifications*

All surface waters within the boundaries of PIRO have been designated as Outstanding State Resource Waters (OSRWs) by the state of Michigan. OSRW is an antidegradation policy, which means that no reduction in water quality is permitted. In addition, all waters of Lake Superior not designated as OSRWs are designated as Outstanding International Resource Waters (MIDEQ 1999). Also, all coastal streams in PIRO [except for a tributary to Little Chapel Lake, a tributary to Little Beaver Lake, tributaries to Beaver Lake, two unnamed tributaries to Grand Sable Lake, and Towes Creek (Ledder 2005)] are Designated Trout Streams (MIDEQ 2002b). The state of Michigan has designated Lake Superior waters offshore from PIRO as part of the Alger Great Lakes state bottomland preserve for protection and recreational use of numerous shipwrecks (see Figure 4).

A 14 km segment of the Miners River and a 10.5 km segment of the Mosquito River are listed on the Nationwide Rivers Inventory prepared by the NPS to track rivers that may be eligible for inclusion in the National Wild and Scenic River system (NPS 2004b). Much of the middle third of the shoreline zone was proposed to be designated wilderness in 2004, including Beaver Basin, Chapel Basin, and adjacent areas (NPS 2004b).

There are no known local or municipal water quality management plans that pertain to PIRO.

*Ecosystem Concerns*

**Color**: Handy and Twenter (1985) indicated that most PIRO waters were colored and dystrophic due to high dissolved organic carbon (DOC)

Table 17. Number of sampling dates for streams and inland lakes in Pictured Rocks National Lakeshore, 1949-2005.

| | Institute for Fisheries Research 1949-1953* | Limnetics, Inc 1970 | Doepke 1972 | Kamke 1983-1985 | Handy and Twenter 1979-1981 | Lewin 1985-1989 | Loope 1997-2005 | Boyle 1994-1996 | MIDEQ 1999-2005 | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| **Munising Falls Creek** | | | | | 3 | | | | | 3 |
| **Miners River** | | 1 | | | 3 | | | | 2 | 6 |
| **Mosquito River** | | 1 | | | 3 | | | | 2 | 6 |
| **Chapel Creek** | | 1 | | | 3 | | | | | 4 |
| **Spray Creek** | | 1 | | | 3 | | | | | 4 |
| **Beaver Creek** | | 1 | | | 3 | | | | | 4 |
| **Sevenmile Creek** | | 1 | | | 3 | | | | | 4 |
| **Sullivan Creek** | | 1 | | | 3 | | | | 2 | 6 |
| **Hurricane River** | | 1 | | | 3 | | | | 2 | 6 |
| **Sable/Grand Sable Creek** | | 1 | | | 3 | | | | 1 | 5 |
| **Towes Creek** | | | | | | | | | 1 | 1 |
| **Beaver Lake** | 1 | 1 | 1 | 5 | 3 | | 45 | 3 | | 59 |
| **Grand Sable Lake** | 1 | 1 | 1 | 6 | 3 | | 52 | 3 | 1 | 68 |
| **Kingston Lake** | | 1 | | | 3 | | | | | 4 |
| **Chapel Lake** | | 1 | | 6 | 3 | | 18 | 3 | | 31 |
| **Trappers Lake** | | 1 | | | | | 10 | | | 11 |
| **Little Beaver Lake** | | 1 | 1 | | | | 12 | | | 14 |
| **Legion Lake** | | | | | | ~56 | 17 | 3 | | ~76 |
| **Upper Shoe Lake** | | | | | | 1 | | | | 1 |
| **Lower Shoe Lake** | | | | | | 1 | | | | 1 |
| **Miners Lake** | | 1 | | 6 | | | 11 | 3 | | 21 |
| **Section 36 Lake** | | | | | | | | 3 | | 3 |
| **Little Chapel Lake** | | 1 | | | | | 1 | | | 2 |
| **Twelvemile Pond** | | | | | | | 1 | | | 1 |
| **Unnamed (Lac Chelydra)** | | | | | | | 1 | | | 1 |
| **Two Lakes (Sand Pt Beaver Ponds)** | | | | | | | 1 | | | 1 |

*as reported in Doepke 1972

and high levels of dissolved humic and tannic acids resulting from decomposing organic matter originating from swamps in their headwater reaches. This staining limits light penetration and results in lower phytoplankton production in lakes. However, color levels were adequate for aquatic life based on USEPA criteria, except in Chapel and Grand Sable Lakes.

**Nutrients**: Nutrients, most notably nitrogen and phosphorus, are important for the growth of both desirable and undesirable plants in surface water bodies. USEPA has divided the nation into ecoregions for establishing criteria by which to interpret nutrient data in surface waters. Values above the criteria that have been established are expected to contribute to excessive weed and algae growth in water bodies.

PIRO is located in the level III ecoregion 50 (Northern Lakes and Forests) of USEPA Ecoregion VIII, where the criteria for total nitrogen in surface water is 0.40 mg/L for lakes and reservoirs, and 0.36 mg/L for rivers and streams (USEPA 2000, 2001b). One sample collected from Lake Superior, samples from Trappers, Miners, and Little Chapel Lakes, and samples from the Hurricane River and Towes Creek exceeded their criterion (Table 18, Figure 21). The criterion for total phosphorus in surface water is 9.69 µg/L for lakes and reservoirs, and 12 µg/L for rivers and streams. Three samples collected from Lake Superior, samples from Beaver, Trappers, Little Beaver, Miners, and Little Chapel Lakes, and samples from the Mosquito and Hurricane Rivers and Sullivan, Sable, and Towes Creeks exceeded their criterion (Table 18, Figure 22). However, as of 2000, phosphorus concentrations in open water samples in Lake Superior had significantly decreased below levels in the late 1970s (MIDEQ 2000b). Conversely, some data suggest that the lakewide nitrate level has been slowly increasing over the period of record (LSBP 2006). The MIDEQ reported that the nutrient samples collected on PIRO streams in 2000 fell within the range of reference sites used for the ecoregion in 1994 (MIDEQ 2005b).

The ratio of nitrogen to phosphorus in surface waters is also considered important in determining which of the nutrients is the limiting factor in plant growth. If the ratio of total nitrogen to total phosphorus is less than 10:1, nitrogen is considered the limiting factor. Values between 10:1 and 15:1 are considered transitional. Values greater than 15:1 indicate that phosphorus is the limiting nutrient (Shaw et al. 1996). By this criterion, Lake Superior; Grand Sable, Chapel, Trappers, Miners, and Little Chapel Lakes; Mosquito and Miners Rivers; and Sullivan, Sable, and Towes Creeks are phosphorus limited. Beaver and Little Beaver Lakes are transitional, and Hurricane River is nitrogen limited. If more recent ratios of 10:1 (Scheffer 2004) or 7:1 (Dillon et al. 2004) are used to indicate phosphorus limitation, all sampled water bodies except the Hurricane River are phosphorus limited (Table 18).

**Alkalinity and Susceptibility to Acid Rain**: Michigan's Upper Peninsula is one of the areas of the country whose surface waters are most susceptible to acid precipitation, and lakes in and around PIRO were accordingly monitored as part of the USEPA's Long-Term Monitoring project from 1983 to 1995 (USEPA 2003). Within PIRO, the alkalinity which provides buffering capacity to streams and lakes depends mainly on soils within their watersheds. Kalkaska sand and Rubicon sand, two of the most common PIRO soils, have low buffering capacity. However, most surface waters in PIRO are not currently considered sensitive to acidification from atmospheric deposition (Maniero and Pohlman 2003), perhaps in part because precipitation in the PIRO vicinity has become slightly less acidic since the 1980s (Stottlemyer 1982b, 1989; NADP 2006).

USEPA defines surface waters as 'acidic' if their acid neutralizing capacity (analogous to alkalinity) is less than zero, which corresponds to pH values less than about 5.2. Lakes are further designated as having high sensitivity to acid rain if their alkalinities range from 0-2 mg/L as $CaCO_3$, as having moderate sensitivity with alkalinities from 2-10 mg/L, as having low sensitivity with alkalinities from 10-25 mg/L, and as being non- sensitive with alkalinities greater than 25 mg/L (Sheffy 1984; Shaw et al. 1996). Based on this criterion and the available data, Little Chapel Lake, Upper and Lower Shoe Lakes, and Legion Lake may be categorized as susceptible to acid rain (Table 19, Figure 23). As previously noted, Legion Lake is naturally one of the most acidic clear water lakes in the nation.

*Exceedences of Aquatic Life and Human Health Criteria*

In 1979 and 1980, samples collected from Sevenmile Creek, Spray Creek, Chapel Creek, and Mosquito River each exceeded once the acute freshwater criterion for cadmium, and

**Table 18. Total phosphorus, total nitrogen, nitrogen to phosphorus ratios and most recent sampling dates for waterbodies in Pictured Rocks National Lakeshore. (Samples with asterisks exceed USEPA water quality criteria for that parameter) (NPS 1995; MIDEQ 2000a, 2005b; Elias 2006).**

| | Total N mg/L | Date | Total P µg/L | Date | N:P Ratio |
|---|---|---|---|---|---|
| LAKE SUPERIOR | | | | | |
| 0.9km SW Grand Marais horn | 0.33 | 7/10/1975 | 7 | 7/10/1975 | 47 |
| Site 7 (N of Au Sable Point) | | | 7 | 7/07/1970 | |
| Site 6 (N of Twelvemile Beach) | | | 7 | 7/07/1970 | |
| Site 5 (N of Sevenmile Creek) | | | 10* | 7/07/1970 | |
| Site 4 (NW of Beaver Creek) | | | 10* | 7/07/1970 | |
| Site 3 (NW of Grand Portal Point) | | | 7 | 7/07/1970 | |
| Open Lake Station (NW of Miners River) | | | 3 | 9/06/1992 | |
| Site 1 (in Munising Bay) | | | 7 | 7/07/1970 | |
| 1.7km NE of Anna River | 0.51* | 8/27/1974 | 26* | 8/27/1974 | 20 |
| LAKES | | | | | |
| Beaver Lake | 0.18 | summer 2005 | 12.217* | summer 2005 | 15 |
| Grand Sable Lake | 0.21 | summer 2005 | 8.114 | summer 2005 | 26 |
| Kingston Lake | 0.29 | 8/28/1979 | | | |
| Chapel Lake | 0.23 | summer 2005 | 8.576 | summer 2005 | 27 |
| Trappers Lake | 0.74* | summer 2005 | 9.996* | summer 2005 | 74 |
| Little Beaver Lake | 0.31 | summer 2005 | 21.197* | summer 2005 | 15 |
| Miners Lake | 0.42* | summer 2005 | 16.339* | summer 2005 | 26 |
| Little Chapel Lake | 0.96* | 10/15/1970 | 60* | 10/15/1970 | 16 |
| STREAMS | | | | | |
| Miners River | 0.373 | 7/2005 | 6 | 7/2005 | 62 |
| Mosquito River | 0.34 | 7/2005 | 16* | 7/2005 | 21 |
| Sullivan Creek | 0.272 | 7/2005 | 12* | 7/2005 | 23 |
| Hurricane River | 0.397* | 7/2005 | 48* | 7/2005 | 8 |
| Sable Creek | 0.296 | 6/1999 | 11* | 6/1999 | 27 |
| Towes Creek | 0.667* | 6/1999 | 19* | 6/1999 | 35 |

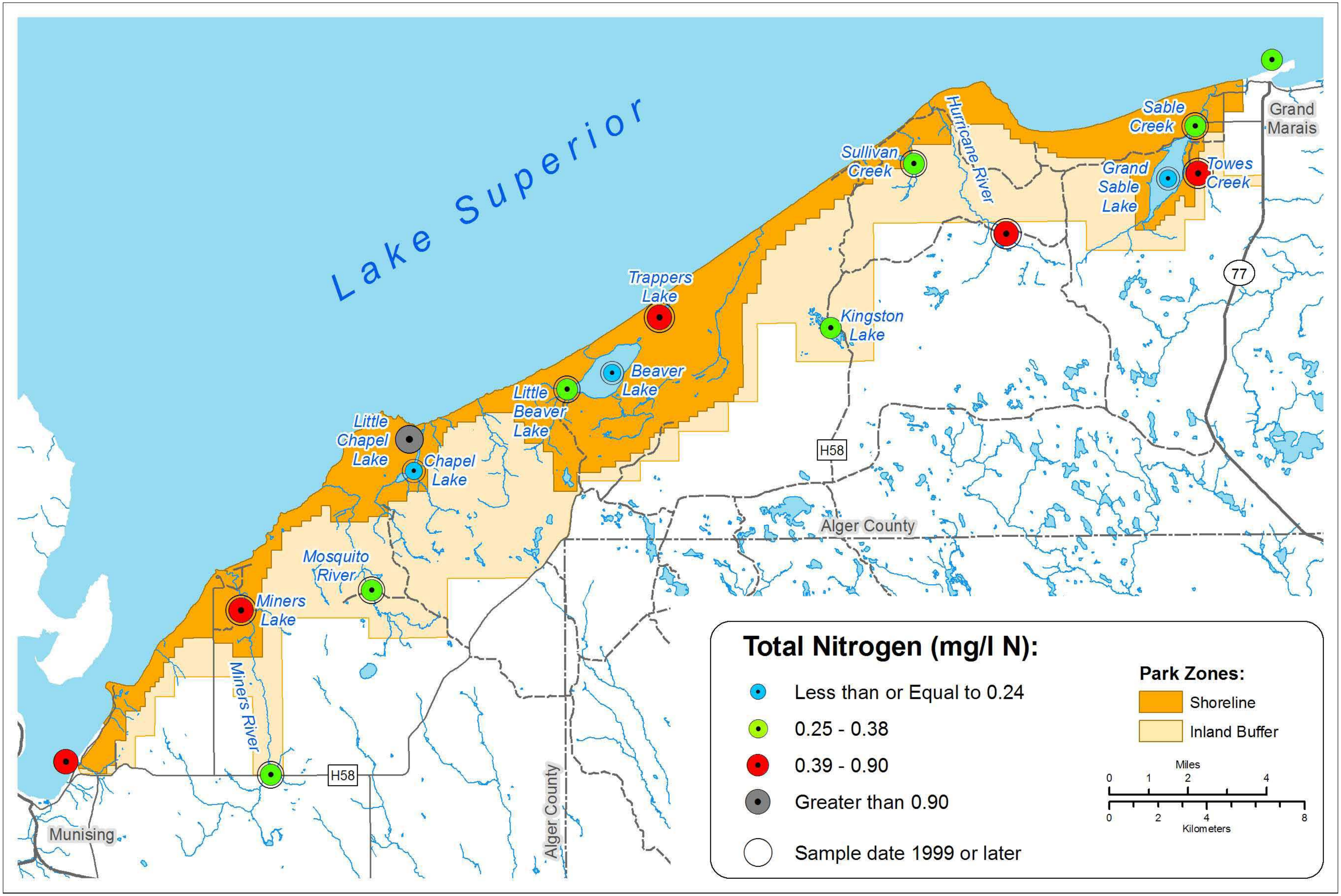


Figure 21. Total nitrogen for most recent sampling dates for waterbodies in the Pictured Rocks area.

(Source: NPS 1995; MIDEQ 1999, 2005b; Elias 2006)

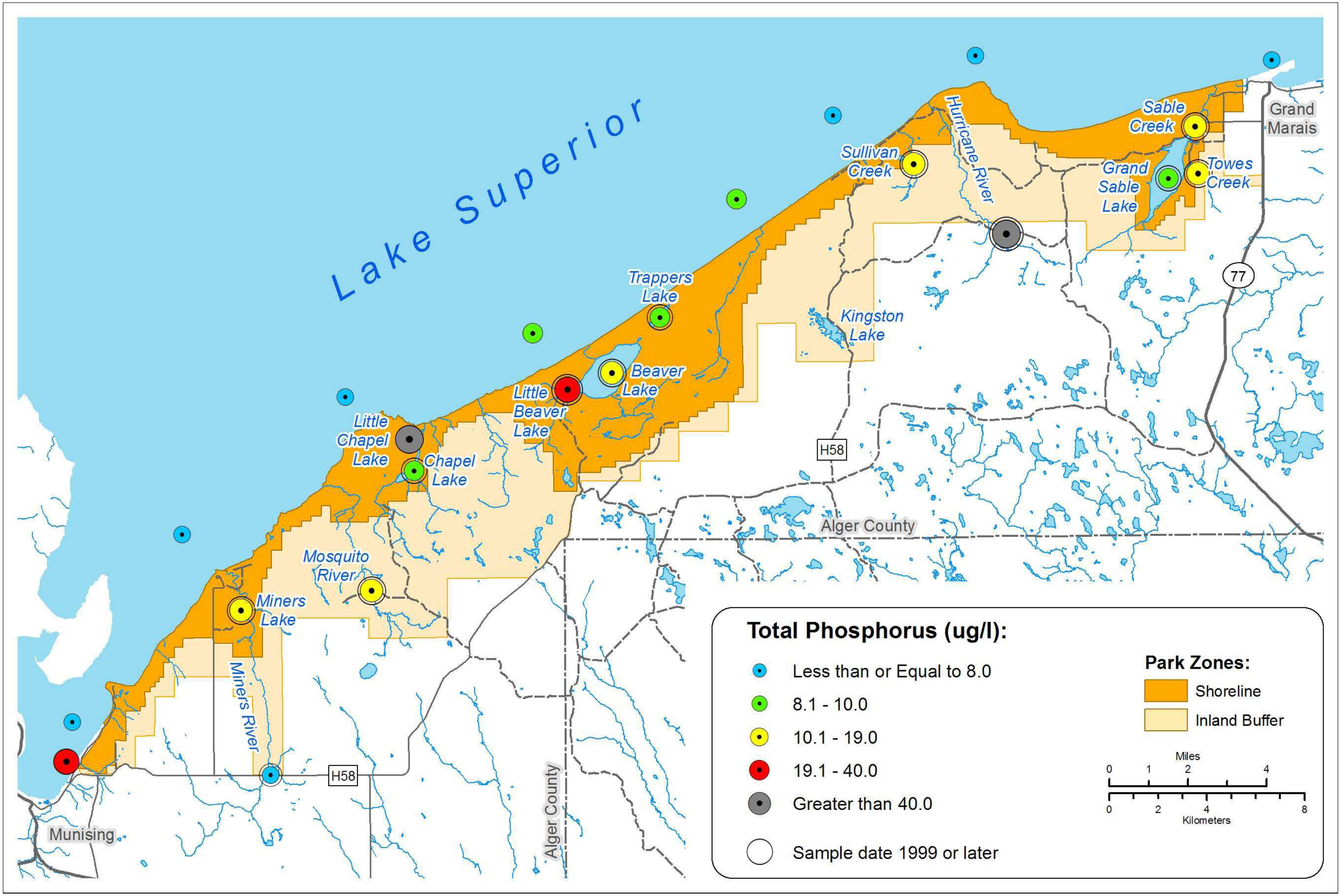


Figure 22. Total phosphorus for most recent sampling dates for waterbodies in the Pictured Rocks area.
(Source: NPS 1995; MIDEQ 1999, 2005b; Elias 2006)

Table 19. Total alkalinity and most recent sampling date for waterbodies in Pictured Rocks National Lakeshore. *estimated, based on pH measurements of 4.8, 5.0, and 4.8. (Lewin 1991; NPS 1995; MIDEQ 2000a, 2005b; Elias 2006).

| | Total Alkalinity (mg/L as CaCO3) | Date |
|---|---|---|
| LAKE SUPERIOR | | |
| 0.9km SW Grand Marais horn | 40 | 7/10/1975 |
| Site 7 (N of Au Sable Point) | 50 | 7/07/1970 |
| Site 6 (N of Twelvemile Beach) | 49 | 7/07/1970 |
| Site 5 (N of Sevenmile Creek) | 49 | 7/07/1970 |
| Site 4 (NW of Beaver Creek) | 50 | 7/07/1970 |
| Site 3 (NW of Grand Portal Point) | 48 | 7/07/1970 |
| Open Lake Station (NW of Miners River) | 44 (filtered) | 9/06/1992 |
| Site 1 (in Munising Bay) | 48 | 7/07/1970 |
| 1.7km NE of Anna River | 43 | 8/27/1974 |
| LAKES | | |
| Beaver Lake | 76 | summer 2005 |
| Grand Sable Lake | 46 | summer 2005 |
| Kingston Lake | 38 | 10/20/1981 |
| Chapel Lake | 86 | summer 2005 |
| Trappers Lake | 70 | summer 2005 |
| Little Beaver Lake | 66 | summer 2005 |
| Miners Lake | 142 | summer 2005 |
| Little Chapel Lake | 20 | 10/15/1970 |
| Upper Shoe Lake | ND* | 7/27/1989 |
| Lower Shoe Lake | ND* | 7/27/1989 |
| Legion Lake | ND* | 12/00/1989 |
| STREAMS | | |
| Munising Falls Creek | 71 | 10/19/1981 |
| Miners River | 122 | 6/00/2005 |
| Mosquito River | 61 | 6/00/2005 |
| Chapel Creek | 90 | 10/19/1981 |
| Spray Creek | 57 | 10/19/1981 |
| Beaver Creek | 84 | 10/20/1981 |
| Sevenmile Creek | 71 | 10/20/1981 |
| Sullivan Creek | 66 | 10/21/1981 |
| Hurricane River | 57 | 6/00/2005 |
| Sable Creek | 54 | 6/00/1999 |
| Towes Creek | 41 | 6/00/1999 |

those from Sevenmile Creek and Chapel Creek also exceeded the drinking water criterion (Handy and Twenter 1985; NPS 1995). Similarly, two samples collected in 1979 from Sevenmile Creek and Chapel Creek had lead concentrations of 26 µg/L and 33 µg/L, respectively, above the drinking water action level of 15 µg/L (Handy and Twenter 1985). No further sampling for these streams has been recorded. The source of these contaminants may have been local development activities (NPS 1995).

In 1973, two samples at a site 9.6 km north of Castle Point in Lake Superior exceeded the 200 CFU per 100 mL criterion for fecal coliform in recreational waters (Figure 24) (NPS 1995). No further fecal coliform analysis has been recorded.

In 1972, one sample from the Mosquito River near Melstrand had a pH of 6.3 standard units, which is below the USEPA chronic criteria minimum of 6.5 for freshwater aquatic life (NPS 1995) (Figure 24). A single sample from the Mosquito River at the County 639 crossing in June 2000 showed a pH of 7.17 (MIDEQ 2005b).

Handy and Twenter (1985) also noted that color in Chapel and Grand Sable Lakes exceeded USEPA freshwater aquatic life standards. Though not a violation of a standard, a single 1997 sediment sample from Beaver Lake that was analyzed for organic contaminants, including mercury, had a mercury concentration of 0.35 mg/kg, nearly double the regional benchmark of 0.18 mg/kg (Whitman et al. 2002). Followup

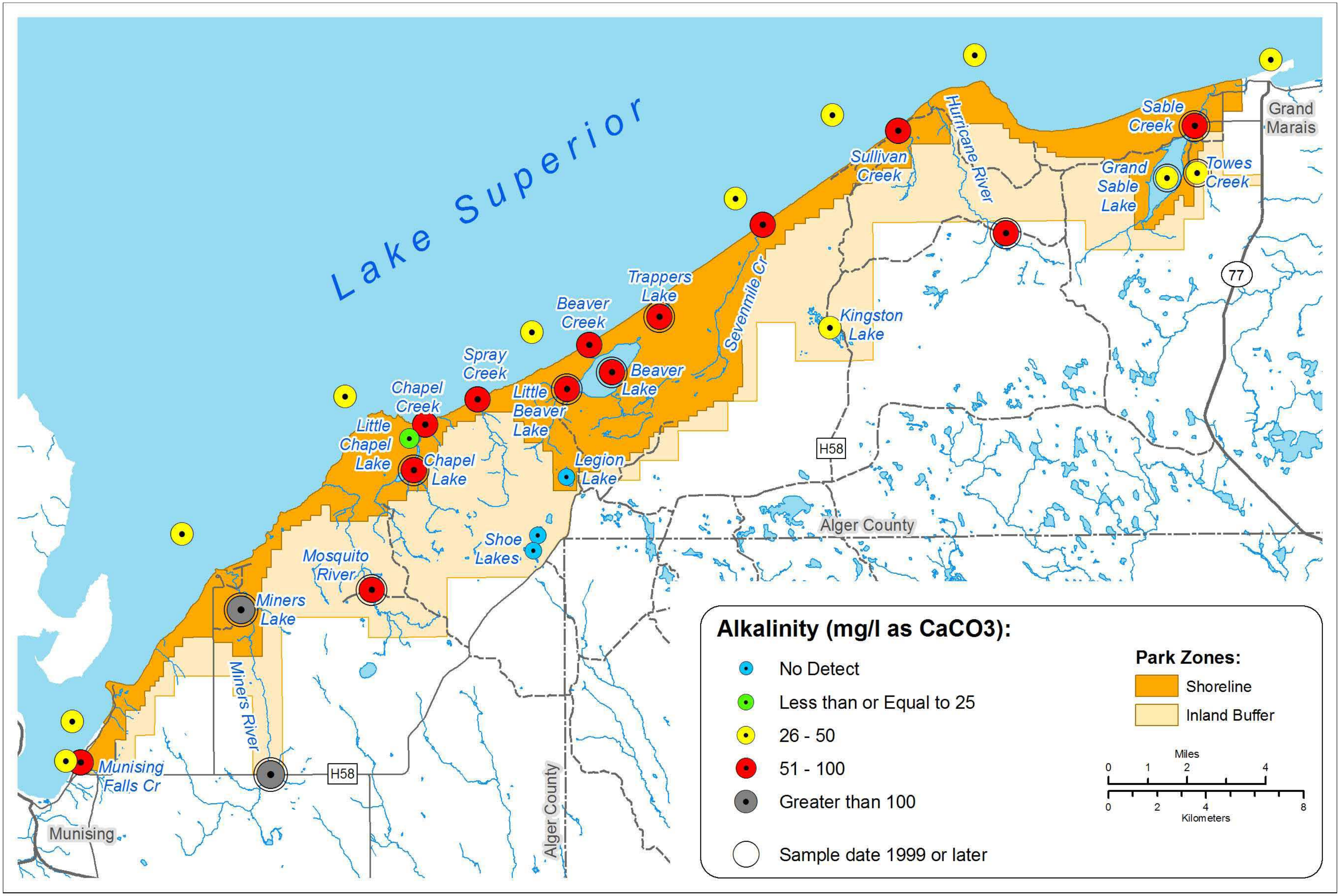


Figure 23. Alkalinity for most recent sampling dates for waterbodies in the Pictured Rocks area.
(Source: Lewin 1991; NPS 1995; MIDEQ 1999, 2005b; Elias 2006)

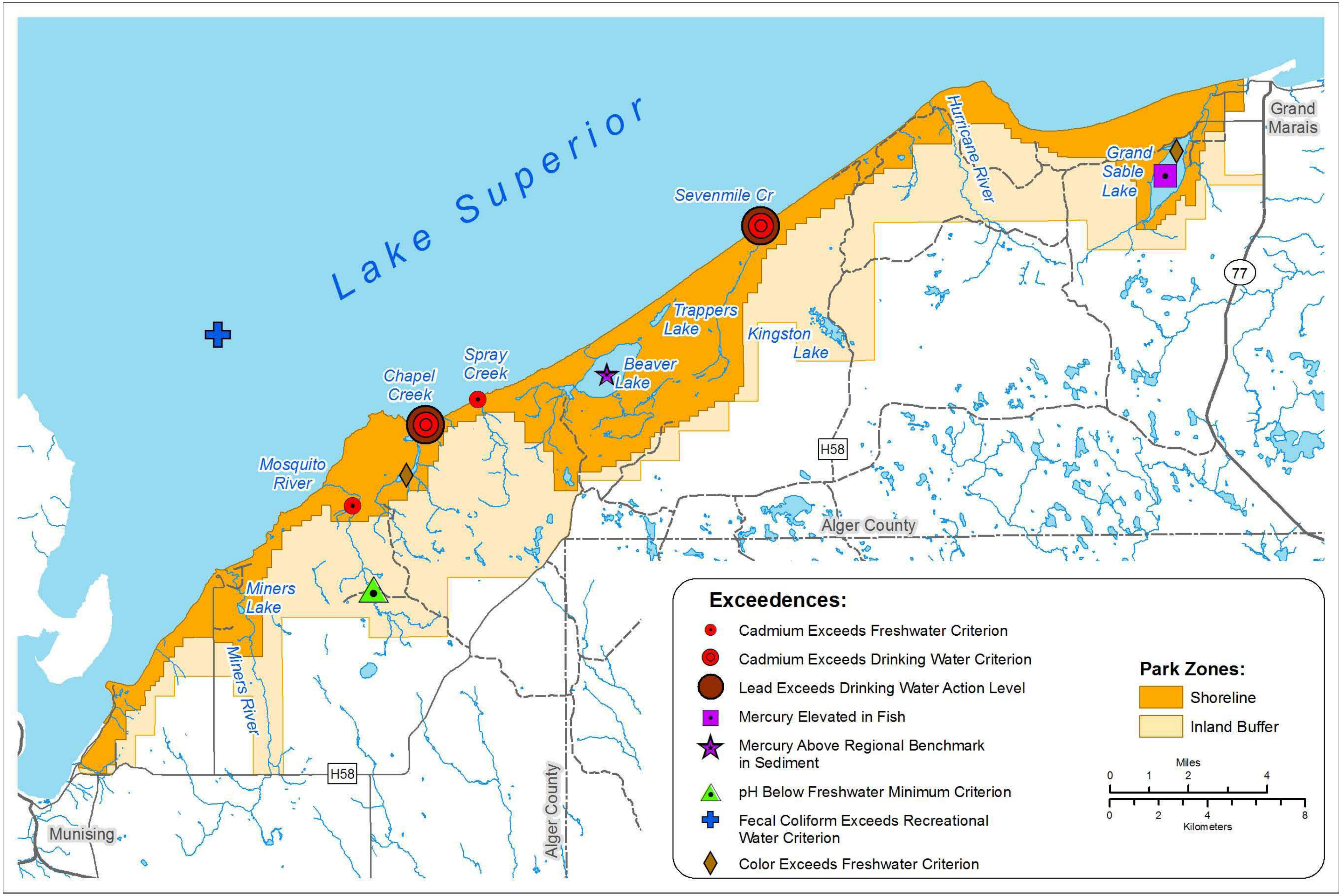


Figure 24. Exceedences of aquatic life and human health criteria in the Pictured Rocks area.

(Source: Handy and Twenter 1985; NPS 1995; MIDEQ 2004b)

**Table 20. Cadmium levels and exceedences in streams, Pictured Rocks National Lakeshore (Handy and Twenter 1985; MIDEQ 2005b; MIDEQ, William Taft, Aquatic Biologist, pers. comm. 2005).**

| Location | Date | Cadmium (µg/L as Cd) | Exceeds acute freshwater criterion? (3.9 µg/L) | Exceeds drinking water criterion? (5.0 µg/L) |
|---|---|---|---|---|
| Sevenmile Creek near Grand Marais | 8/28/1979 | 7.0 | Y | Y |
| | 5/6/1980 | 3.0 | N | N |
| | 10/20/1981 | 1.0 | N | N |
| Spray Creek near Melstrand | 8/28/1979 | <2.0 | N | N |
| | 5/7/1980 | 4.0 | Y | N |
| | 10/19/1981 | <1.0 | N | N |
| Chapel Creek near Melstrand | 8/28/1979 | 6.0 | Y | Y |
| | 5/7/1980 | 0 | N | N |
| | 10/19/1981 | <1.0 | N | N |
| Mosquito River near Melstrand | 8/28/1979 | 4.0 | Y | N |
| | 5/6/1980 | 1.0 | N | N |
| | 10/19/1981 | <1.0 | N | N |
| Mosquito River County 639 Crossing | 6/2000 | <0.2 | N | N |
| | 7/2005 | <0.2 | N | N |

testing by MIDEQ and PIRO staff showed that mercury was not elevated in fish tissues from walleye and yellow perch in Beaver Lake (PIRO, Lora Loope, Aquatic Ecologist, pers. comm. 2006).

*Impairments and 303(d) Reports*

The federal Water Pollution Control Act, also known as the Clean Water Act (PL92-500), requires states to prepare a biennial report on the quality of its water resources, often called a Section 305(b) report after the pertinent subsection of the Act. Michigan includes five lakes in Alger County on its list of impaired water bodies, often called a section 303(d) list, again after the pertinent subsection of the Act. These water bodies must have total maximum daily loads of pollution (TDMLs) established for them. Within PIRO, only Grand Sable Lake appears on the 303(d) list, because of levels of mercury in fish tissues that exceed state standards (Figure 24) (MIDEQ 2004b). However, all inland lakes in Michigan have an advisory against eating more than one meal of fish per week because of mercury contamination, with additional restrictions for more sensitive groups. In addition, many fish species from Lake Superior have fish consumption advisories, especially for women and children, because of PCB contamination. Siscowet lake trout also have restrictions because of high chlordane and dioxin levels, and lean lake trout have restrictions because of high chlordane and mercury levels (MDCH 2004).

**Groundwater Quality, Quantity, and Use**

Alger County has 73 public water supplies that provide drinking water for as many as 9,412 people each day. Public water supply wells in the county fall into one of three categories: community water supplies, non-transient non-community water supplies, and transient non-community water supplies. Community water supplies are those that serve at least 25 residents or 15 service connections (homes) year round. Non-transient non-community water supplies include locations such as schools that are not served by community water supplies, but serve 25 or more people on a regular basis for six months or more of the year. The third category, transient non-community water supplies, serve at least 25 people at least 60 days of the year, but do not serve the same 25 people over 6 months of the year. These include campgrounds, resorts, convenience stores, and other similar service businesses.

Three community water systems in PIRO's vicinity include Munising, which serves 2,783 people; Munising Industrial Park (which includes the Alger Maximum Security Correctional Facility), 465 people; and Burt Township, 317 people. In 2004, Munising pumped an average of 1,070 $m^3day^{-1}$; the Munising Industrial Park pumped 238 $m^3day^{-1}$, and Burt Township pumped 476 $m^3day^{-1}$. There are 63 transient noncommunity water systems in Alger County that serve 4,832 people (USEPA 2005b). Many of these wells are located along Highway M-28 east of Munising (Figure 25). Timber Products Michigan in Alger County is a major industrial water user that used 1,325 $m^3day^{-1}$ of groundwater in 2004 (MIDEQ 2004a). No irrigation wells are reported within

**Table 21. Number of people served by drinking water wells, and methods of wastewater disposal, in Pictured Rocks National Lakeshore (PIRO, John Ochman, Maintenance Supervisor, pers. comm. 2005).**

| Location | Public transient non-community system | Average number of people served | Wastewater disposal method |
|---|---|---|---|
| Log Slide | Yes | 50 | Vault toilet |
| 12 Mile East Campground | Yes | 200 | Vault toilet |
| 12 Mile West Campground | Yes | 50 | Vault toilet |
| Grand Sable Visitors Center | Yes | 100 | Vault toilet |
| Little Beaver Campground | Yes | 50 | Vault toilet |
| Lower Hurricane Campground | Yes | 140 | Vault toilet |
| Upper Hurricane Campground | Yes | 25 | Vault toilet |
| Miners Castle Comfort Station | Yes | 500 | Septic system |
| Sable Falls Comfort Station | Yes | 25 | Septic system |
| Sand Point Headquarters | Yes | 25 | Septic system |
| Au Sable Light Station | Yes | 100 | Vault toilet |
| Grand Marais Maintenance Area | No | 2 | Vault toilet |
| Munising West District Maintenance Shop (2 wells) | No | 10 | Septic system |
| Sullivan's Quarters | No | 2 | Septic system |
| TOTAL | | 1279 | |

PIRO's watershed.

Fifteen water wells are operated by the NPS within PIRO, and of these, eleven are considered to be transient non-community water systems (Table 21). On average, the fifteen wells serve 1,279 people per day (PIRO, John Ochman, Maintenance Supervisor, pers. comm. 2005). During peak use times in July and August, the water supplies may experience heavier use, since approximately 2,900 people per day are expected to visit the park at those times (NPS 2004b). In a recreational setting, water use is estimated to be 38-57 liters/person/day (Handy and Twenter 1985), so total daily visitor water use may be 48-165 m$^3$day$^{-1}$. Some of that water is returned to the ground through on-site waste disposal systems. Other public transient non-community water supplies within the PIRO watershed include the Pictured Rocks Golf and Country Club, which serves 80 people, and the MIDNR Kingston Lake Campground, which serves 75.

Michigan's Wellogic data base lists 443 private wells for Munising Township, and 165 for Burt Township (MIDEQ 2005g). Of those wells, 139 are within PIRO's watershed. With an average domestic water use of 300-375 L/person/day (USGS 2005), and a county average of 2.35 persons per household (U.S. Census Bureau 2005), private well users withdraw approximately 100 m$^3$day$^{-1}$. However, much of that water is returned to the ground through on-site waste disposal systems.

In general, homeowners drill wells only to the shallowest aquifer that provides a sufficient quantity of potable water. Accordingly, approximately 28% of the wells in Alger County are completed in glacial deposits, while 68% are completed in bedrock, and 4% could not be determined (MIDEQ 2005f). Most private wells in both Munising and Burt townships are in the 15-30 m depth range (Figure 26).

Michigan's Wellogic data base lists 443 private wells for Munising Township, and 165 for Burt Township (MIDEQ 2005g). Of those wells, 139 are within PIRO's watershed. With an average domestic water use of 300-375 L/person/day (USGS 2005), and a county average of 2.35 persons per household (U.S. Census Bureau 2005), private well users withdraw approximately 100 m$^3$day$^{-1}$. However, much of that water is returned to the ground through on-site waste disposal systems.

In general, homeowners drill wells only to the shallowest aquifer that provides a sufficient quantity of potable water. Accordingly, approximately 28% of the wells in Alger County are completed in glacial deposits, while 68% are completed in bedrock, and 4% could not be determined (MIDEQ 2005f). Most private wells in both Munising and Burt townships are in the 15-30 m depth range (Figure 26).

Within PIRO, wells drilled into the bedrock generally have higher specific conductance, and so higher mineral content, than wells drilled in glacial deposits. However, wells in glacial deposits often have considerably higher levels

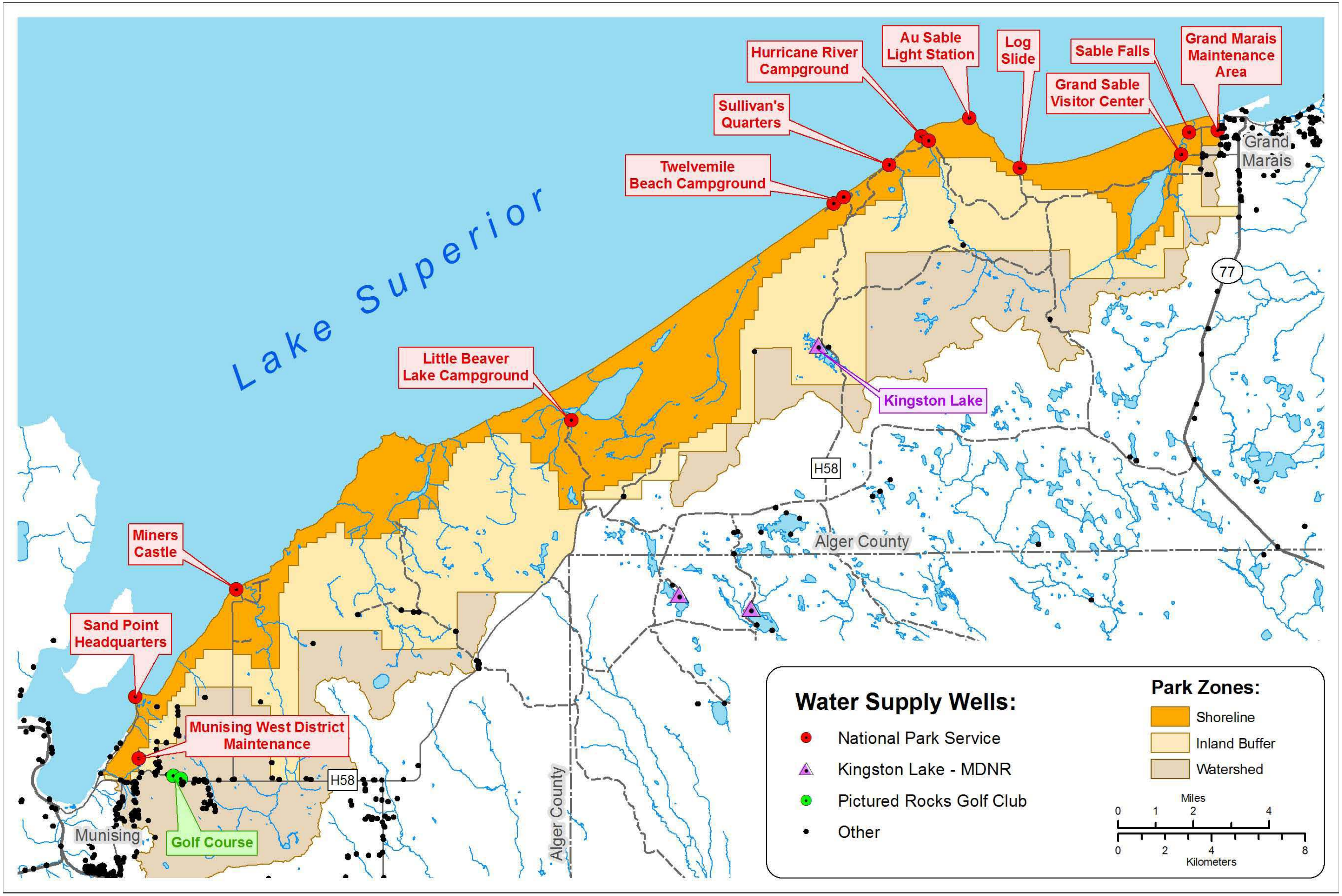


Figure 25. Water supply wells in the Pictured Rocks area.

(Source: MIDEQ 2005g)

of iron, which gives water an objectionable taste and color. Some wells sampled in a 1985 study had levels of iron, manganese, pH, and color outside the acceptable range according to USEPA standards (Handy and Twenter 1985).

Alger County's 73 public water supplies are monitored for contaminants on a schedule determined by state and federal regulations (MIDEQ 2005c). Some contaminants in drinking water supplies, such as coliform bacteria, are more an indication of construction or maintenance problems in the well and water distribution system than an indication of groundwater problems, but drinking water samples can be looked at to some extent to give an indication of groundwater quality in an area.

In 2004, two water systems in Alger County (Mathias Township and USFS Wide Waters Campground) had violations under the Michigan Safe Drinking Water Act because of the presence of coliform bacteria in one or more water samples (MIDEQ 2005d). In 2003, three water systems (Mathias Township, Munising, and Coleman's Paradise Resort) had coliform violations (MIDEQ 2004c). No violations for any chemical parameter were reported for any public water supply in Alger County for either of those two years. The MIDEQ has produced county-level maps for nitrate, VOC, and arsenic sampling from its WaterChem database (MIDEQ 2005e), which have been combined into a single map for this report (Figure 27). Nitrate values were less than or equal to 5 mg/L at the sampling points shown. Arsenic was detected in a number of wells, but all values were below the 10 µg/L drinking water standard. One positive VOC sample was detected in Alger County outside PIRO's watershed boundary.

Private water supplies are not routinely monitored by any governmental agency. Testing of private wells is the owner's responsibility. Samples may be sent to any number of private laboratories, so it can be difficult to accurately determine the number of private wells that have water quality problems. However, between 1997 and 2000, the Michigan Department of Agriculture conducted a survey designed to provide statistically accurate estimates of the number of rural domestic wells in Michigan that were contaminated with nitrate, pesticides, or volatile organic compounds (Pigg 2001).

The study estimated that less than 1.9 percent of all rural domestic wells in Michigan have nitrate-nitrogen levels above 10 mg/L, which is the maximum contaminant level for public water supplies. It further estimated that less than 1.75 percent of all Michigan's rural domestic wells have a detectable level of a pesticide. For volatile organic compounds, the detection rate was estimated to be 7.1 percent + 3.9 percent.

One of the samples collected for this study was taken in Alger County. Since Alger County has little agricultural activity, it is unlikely that it would be a site for "hotspots" of these contaminants. However, because of well construction problems and the very local nature of some contaminants, a contaminated well

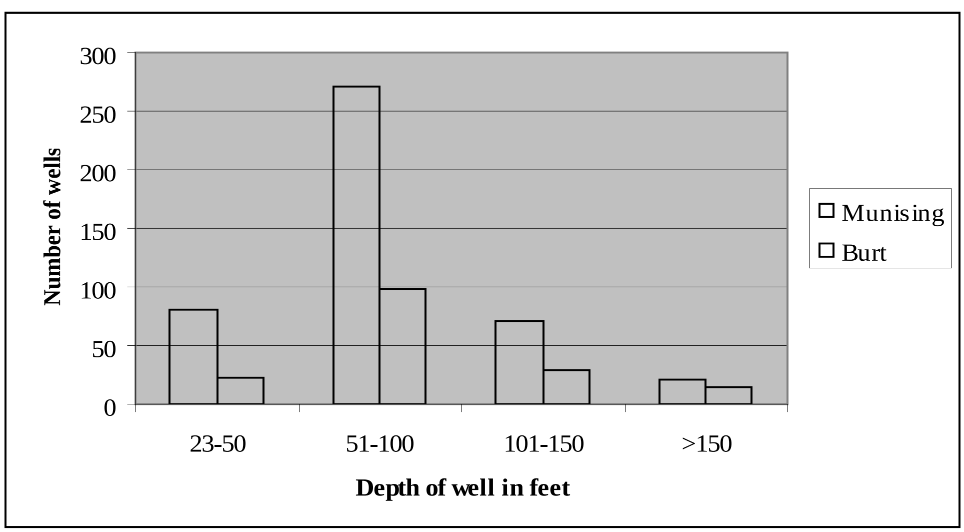


**Figure 26. Number of private household wells at various depths in Munising and Burt Townships near Pictured Rocks National Lakeshore (MIDEQ 2005f).**

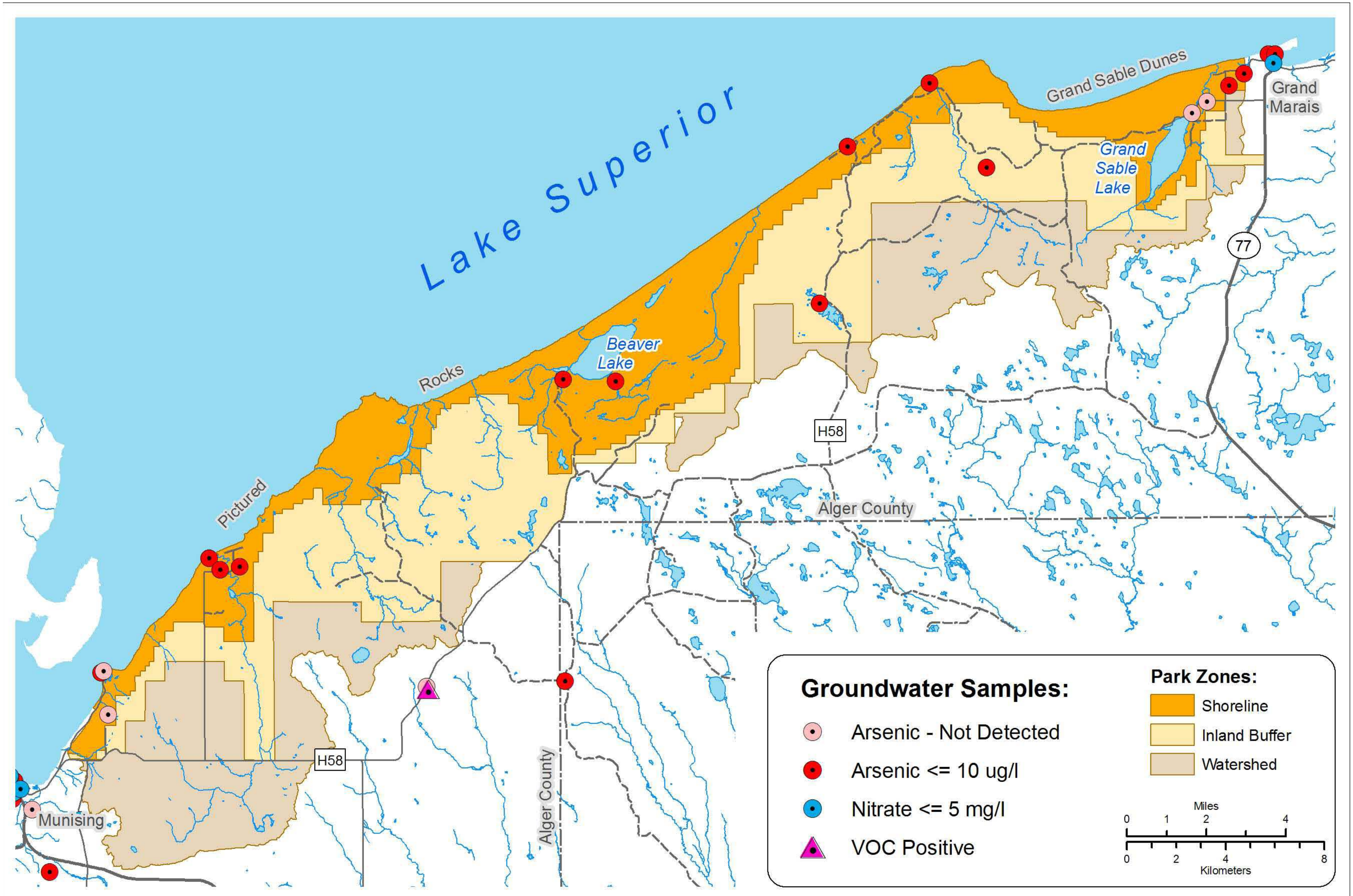


Figure 27. Nitrate, VOC, and arsenic samples in the Pictured Rocks area.

(Source: after MIDEQ 2005e)

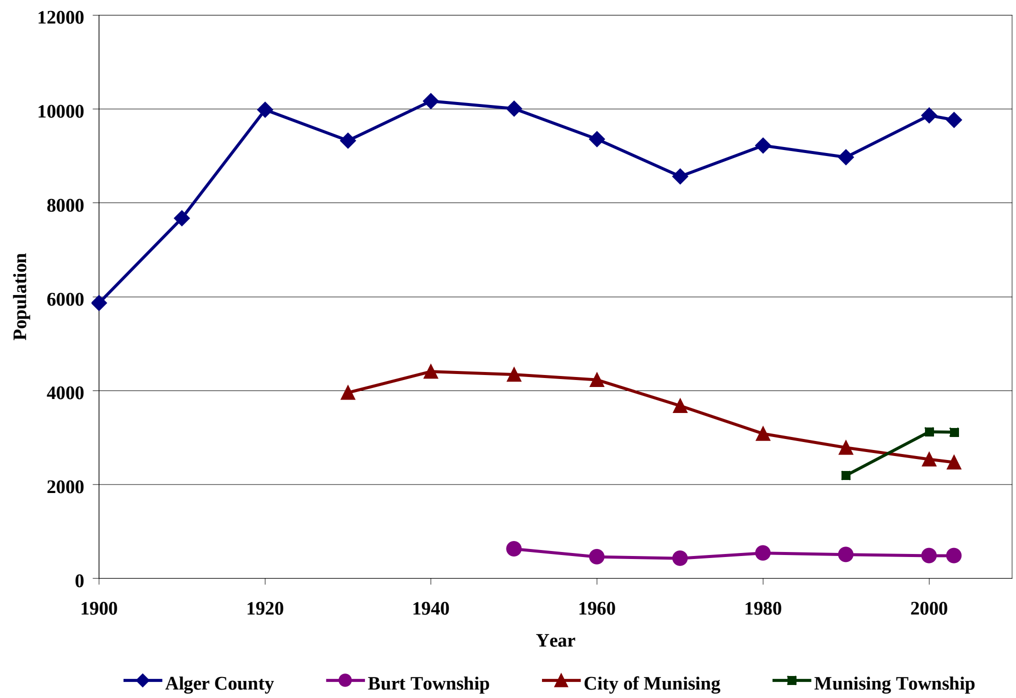


**Figure 28. Population of areas that border Pictured Rocks National Lakeshore, 1900-2003 (Burt Township Planning Commission 1993; CUPPAD 2000, 2004).**

could occur even in a relatively pristine region.

### Other Areas of Concern

*Demographics and Development*

Michigan's central Upper Peninsula, where PIRO is located, accounts for 12% of the total state land area but only 1.75% of its population. Alger County, the home of PIRO, (Figure 3) has a population density of 4.1 people/km$^2$ (U.S. Census Bureau 2005). The county's population peaked at 10,167 in 1940 and was estimated at 9,767 in 2003. It grew 9.9 percent from 1990-2000, but most of the growth was attributed to the opening of the Alger Maximum Security Prison, which houses approximately 10% of the total population of Alger County. Likewise, most of the growth of Munising Township, which borders PIRO, from 1990-2000 can be attributed to the prison (CUPPAD 2004). Burt Township, which also borders PIRO, has experienced a slight population decline since 1980 (CUPPAD 2004; Burt Township Planning Commission 1993), and the city of Munising's population has been declining since its peak in 1940 (Figure 28) (CUPPAD 2000).

In the late 1960s, park officials worked with local officials to draft zoning safeguards for development in the IBZ (Karamanski 1995). Today, PIRO's chief ranger reviews all proposed developments within the IBZ to see that they conform to the zoning ordinance for the respective jurisdiction, but only a few such proposals are received each year (PIRO, Larry Hach, Chief Ranger, pers. comm. 2005). The only lakes in the IBZ with potential for development are the Shoe Lakes. Two years ago, a seasonal cabin on Lower Shoe Lake was converted to a permanent home (PIRO, Lora Loope, Aquatic Ecologist, pers. comm 2007)

Twenty-five ha within the City of Munising are in the park's IBZ. City zoning allows only limited uses within this zone, including one-family dwellings, family child care facilities, and adult foster care family homes, on minimum lot sizes of 2 acres (City of Munising Planning Commission 2004).

Parts of both Burt and Munising Townships are also in the IBZ. Zoning laws have been enacted in both townships to help protect the park's water resources. In Burt Township, the Rural Residential – IBZ district requires a minimum lot size of 0.8 ha; the Seasonal Commercial – IBZ and the Resource Management – IBZ districts require 4 ha, and the Seasonal Dwelling/Timber Production – IBZ district requires 8 ha (Burt Township, Michigan 1995). In Munising Township, parcels in the IBZ closest to the park are zoned for seasonal use only and must be a minimum of 4 ha. Closer to Munising, some 0.8 ha parcels in the IBZ are zoned as rural residential. Some smaller parcels that existed before November 2004 are also grandfathered in. The Munising Township zoning administrator reports that development in the township is slow and mainly focused on the M-28 East corridor and waterfront development on inland lakes outside the IBZ. From November 2004 to July 2005, he had received no requests for building permits in the IBZ (Munising Township, John Shauver, Zoning Administrator, pers. comm. 2005).

Around the nation, development pressures are affecting national parks, compromising views and increasing stormwater runoff problems, noise, and invasion by exotic species (Spillman 2006). However, because of Alger County's rural nature, limited economic opportunities, and slow to negative population growth rates, residential development in the IBZ does not appear to be a major threat to PIRO at this time.

*Visitor Use*

In the last three years, PIRO has evaluated visitor use patterns for a personal watercraft use environmental assessment (NPS 2002), a general management plan (NPS 2004b), and a fire management plan (NPS 2005a). Since 1995, visitor numbers have ranged from a high of 462,687 in 1995 to a low of 380,217 in 2004 (Figure 29). Approximately 50% of visitors come to PIRO in July and August (NPS 2005c), which equals about 2900 people per day (NPS 2004b).

All of County Highway H-58 within Alger County is expected to be paved by fall, 2008, and portions that provide access to the central and eastern parts of the park will be paved for the first time. Park staff expect slightly greater park visitation and an increase in the proportion of travelers and campers who use recreational vehicles as a result (PIRO, Jim Northup, Superintendent, pers. comm. 2007). Past projections were that park visitation would remain fairly stable in the next ten years, plus or minus 5% (NPS 2004b).

The Lake Superior shoreline is the focus of nearly all visits to PIRO (NPS 2005c). In 2002, visitor use data for 2000 were compiled to show the distribution of summer activities among park visitors (Table 22) (NPS 2002). The top five visitor activities included sightseeing, beach activities, day hiking, enjoying solitude, and visiting the Grand Sable Banks and Dunes. Other activities for which specific percentages are not listed include motorboating, fishing, camping, ice fishing, snowshoeing, hunting, cross-country skiing, and snowmobiling. Many of the popular activities in the park can be related to its outstanding water resources.

*Commercial and Sport Fishery*

Commercial fishing began in Lake Superior in the 1830s. Species exploited included lake trout, lake sturgeon, lake herring, lake whitefish, and deepwater ciscoes (GLFC 2001). For larger species, such as lake trout, lake whitefish, and lake sturgeon, maximum commercial harvest occurred before 1904 (Table 23) (Baldwin et al. 2002). Numerous authors have documented the near collapse of the commercial fishing industry between 1940 and 1960, and its causes (LSBP 2000), which included overfishing, logging, dam building, discharge of paper mill wastes, toxic contaminants in water and air, mining, agriculture, urban development, and

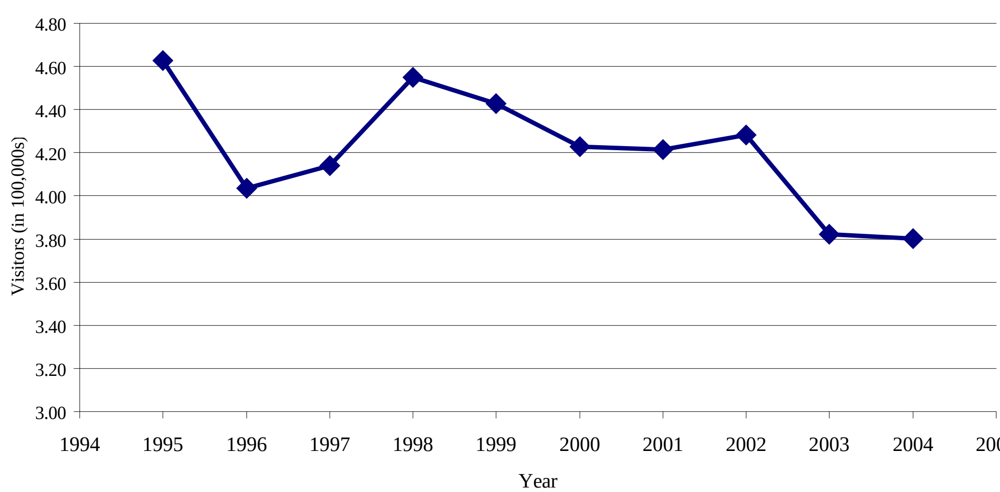


**Figure 29. Numbers of visitors (in 100,000s) to Pictured Rocks National Lakeshore from 1995 to 2004 (NPS 2004b, 2005d).**

**Table 22. Activities of park visitors, Pictured Rocks National Lakeshore, July and August, 2000, and summer, 2001 (NPS 2002, 2004b).**

| Activity | Percent of visitors who participated |
|---|---|
| Sightseeing | 78% |
| Beach activities | 67% |
| Day hiking | 66% |
| Enjoying solitude and quiet | 65% |
| Visit Grand Sable Banks and Dunes | 60% |
| Visit Miners area | 59 - 65% |
| Visit Munising Falls | 47% |
| Visit Visitor Information Center | 42% |
| Swimming (mainly in Lake Superior) | 37% |
| Shoreline boat tours | 24% |
| Backpacking | 12% |
| Canoeing on Lake Superior | 7% |
| Sea kayaking | 6% |
| Canoeing on Lake Superior | 7% |

road and railroad construction (GLFC 2001). The introduction of non-indigenous species, some accidental (such as the sea lamprey and rainbow smelt) and others deliberate (including rainbow trout and salmon) also affected the natural food web and fish distribution within the lake. The 1960s marked the period of maximum degradation of the lake and its fisheries (GLFC 2001).

As of 2001, lake trout populations had recovered so that stocking was no longer required in most areas of the lake, but sea lamprey predation continues to be a problem. Populations of rainbow smelt have greatly declined. Populations of some near-shore fish, especially lake sturgeon, walleye, and brook trout are still below historic levels, but state and tribal management agencies are attempting rehabilitation. Harvest controls are being developed by state and tribal management agencies. With some notable exceptions in embayments and tributaries, the status of fish habitat in the lake is generally good at this time (GLFC 2001).

The lake whitefish was the most important fish species commercially harvested in Lake Superior in the year 2000, with an estimated value of $1.7 million. Throughout the 1990s, most lake whitefish were harvested from Michigan and Wisconsin waters (Kinnunen 2003). Most lake trout harvested also came mainly from Michigan and Wisconsin, at a value of $151,258. Lake herring, chubs, smelt, and siscowet lake trout were also commercially important species in 2000, although the market for siscowet has declined because of its high fat content.

In 2004, 2,044 charter angler trips occurred on Lake Superior (Thayer 2005). This number has been fairly steadily declining in the period since 1990, with a high of 3,588 in 1991. Lake trout comprise most of the fish harvested. For example, in 2003, 188 charter angling trips departed from the port of Marquette, about 40 miles west of PIRO. Anglers harvested 1,841 lake trout, 10 coho salmon, six rainbow trout, and three Chinook salmon (MIDNR 2005b).

In 1998, MIDNR and park staff collaborated on a survey of anglers on Beaver Lake and Grand Sable Lake from May 15 to September 30 (Lockwood 2000). For Beaver Lake, 1,847 angler trips yielded a total catch of 4,989 fish, of which 1,290 were harvested and 3,699 were released. Species caught included walleye, northern pike, yellow perch, smallmouth bass, and bluegill. For Grand Sable Lake, 1,468 angler trips yielded 2,660 fish, of which 399 were harvested and 2,261 were released. Species caught in Grand Sable Lake included northern pike, rock bass, yellow perch, smallmouth bass, and lake trout.

*Nuisance and Invasive Species*

Exotic invasive species, sometimes called nuisance species, may be defined as those organisms not native to an area whose introduction harms or is likely to harm the economy, environment, or human health (USEPA 2005e). PIRO is home to both terrestrial and aquatic invasive species.

**Aquatic Invasive Species**: Aquatic invasive species may threaten the diversity or abundance of native species or the ecological stability of the

**Table 23. Commercial harvest of Lake Superior fish from 1867-2000 (Baldwin et al. 2002).**

| Species | Maximum Harvest (pounds) | Year | Pounds harvested in 2000 |
|---|---|---|---|
| Lake Herring | 19,271,000 | 1941 | 756,000 |
| Lake Trout | 7,352,000 | 1903 | 130,000 |
| Lake Whitefish | 5,178,000 | 1885 | 497,000 |
| Smelt | 4,041,000 | 1976 | 11,000 |
| Chubs | 2,196,000 | 1965 | 1,000 |
| Suckers | 570,000 | 1988 | 31,000 |
| Walleye | 378,000 | 1966 | 0 |
| Lake Sturgeon | 225,000 | 1885 | 0 |
| Round Whitefish | 182,000 | 1995 | 3,000 |
| Yellow Perch | 138,000 | 1981 | 47,000 |
| Sauger | 124,000 | 1952 | 0 |
| Northern Pike | 115,000 | 1921 | 6,000 |
| Burbot | 79,000 | 1978 | 0 |
| Pacific Salmon | 29,000 | 1989 | 5,000 |
| Rainbow Trout | 1,000 | 1999 | 1,000 |
| Carp | 2,000 | 1998 | 1,000 |

waters into which they are introduced, or impair the water for some human use (MIDEQ 2002c). One hundred sixty-two non-indigenous species have been introduced to the Great Lakes alone, and the introduction of aquatic invasives may be the most serious threat to the ecological health of the Great Lakes today (Jude et al. 2002).

Numerous pathways, both natural and human-made, exist to transfer aquatic species from one location to another. Ludwig Jr. and Leitch (1996) list connections between basins at times of high water, animal transport, and extraordinary meteorological events as natural mechanisms for species transfer. These natural events are difficult to predict or manage. However, human-initiated mechanisms, including escapes from aquaculture facilities, aquarium release, stocking activities, ballast release, and angler escape or release are more amenable to control through management and public education.

**History of Non-native Aquatic Species at PIRO**: As early as the early 1900s, sport fish were being introduced to the inland waters of PIRO. Some were hatchery-raised native species, such as the brook trout planted in Chapel Creek between 1903-1905 and in Miners River from 1904-1914 (Vogel 2000). However, a number of non-native species were also introduced, such as the salmon planted in Miners River in 1904 and the steelheads planted from 1908-1912. Brown trout were also introduced at the turn of the century, probably by anglers. Rainbow smelt were introduced to Grand Sable Lake in 1950, hybrid splake were stocked in Beaver, Grand Sable, Legion, and Trappers Lakes throughout the 1970s and 1980s, and lake trout were stocked in Grand Sable Lake until 2005 (Vogel 2000; NPS 2003).

Stocking of non-native species also occurred in Lake Superior. Today, of the eight top predator fish, only three are native species (lake trout, burbot, and walleye), while the other five are introduced species (sea lamprey, coho salmon, Chinook salmon, rainbow trout, and brown trout (GLFC 2001). Pink salmon and hybrid splake have also been introduced (Loope 2004). Environmental changes, including the overfishing and logging of the late 19th century, as well as the introduction of these non-native species, mean that natural, pre-European settlement fish communities may never return to either Lake Superior or the inland waters of PIRO. However, fisheries management philosophy has changed so that current fish stocking plans for PIRO emphasize the establishment of stable, naturally reproducing populations of native species (Vogel 2000).

Other non-native species have been accidentally introduced, and some of these are major threats to aquatic and terrestrial resources in PIRO (NPS 2003). The parasitic sea lamprey colonized Lake Superior in the 1940s, and had nearly decimated the lean lake trout population by the 1950s (Smith et al. 1974). The spiny waterflea (*Bythotrephes longimanus*) has been present in Lake Superior since 1987 (Cullis and Johnson 1988), and was first observed in Beaver Lake in 1997 and in Grand Sable Lake in 2002 (NPS 2003). Alewife (*Alosa pseudoharengus*) is present in the nearshore waters of Lake

Superior (Newman 2003). Curly-leaf pondweed (*Potamogeton crispus*), a non-native aquatic macrophyte, was found in Beaver Lake in the early 1970s (Doepke 1972), but has not been observed since. A few isolated areas of purple loosestrife (*Lythrum salicaria*) were found along the Mosquito River Trail and at the Little Beaver Lake boat ramp in the 1990s and were eradicated (NPS 2003).

***Sea Lamprey***: Probably the best known exotic species in PIRO is the sea lamprey (*Petromyzon marinus*). This species, native to the Atlantic Ocean, entered Lake Superior via the St. Lawrence Seaway in the early 1940s (Smith et al. 1974). Adult lampreys spawn on gravel beds in tributary streams, and immature lampreys grow from 3 to 17 years before migrating into the lake. Adults parasitize fish, especially lake trout. Lamprey spawning has been documented in Munising Falls Creek, Miners River, Beaver Creek and the tributary streams of Beaver Lake, Sevenmile Creek, Sullivan Creek, Hurricane River, and Sable Creek (Loope 2004).

The USFWS has conducted research and control efforts for over 25 years as part of a joint U.S./Canada effort, including annual assessments and treatments of PIRO streams and lakes. Lamprey monitoring has been conducted by the USFWS in Miners River, Beaver Creek, and the Hurricane River since the mid-1950s, and chemical treatments with various lampricides began in 1958 and continue to the present (Loope 2004). A lamprey control dam has been constructed on the Miners River between Miners Lake and Lake Superior at the bridge crossing (Loope 2004).

***Spiny Waterflea***: Spiny waterflea (*Bythotrephes longimanus*) is a large cladoceran (zooplankter) with a long spine, native to freshwater, oligotrophic lakes of Eurasia. It was first found in Lake Superior in 1987 (Cullis and Johnson 1988) and in Beaver Lake in 1997 and Grand Sable Lake in 2002 (NPS 2003). Its spine makes it unattractive as prey for small fish (Lehman and Caceres 1993), and it competes for common zooplankton resources with native pelagic fish (Jude et al. 2002), but it may be a food source for larger fish (Minnesota Sea Grant 2006b). Live bait fish can disperse the spiny waterflea because its resting eggs can survive passage through the digestive tract of fish (Garton and Berg 1990). It is easily introduced into new lakes through fishing and anchor lines, bilge water, and live fish bait. Therefore, lakes that are popular fishing spots are the most susceptible to new invasions of *Bythotrephes* (Jarnigan 1998). A three-year project has been funded, starting in FY08, to investigate spiny water flea effects in Beaver and Grand Sable Lakes, and to examine other PIRO inland lakes for their presence (NPS Midwest Regional Office, Brenda Moraska LaFrancois, Aquatic Ecologist, pers. comm. 2006).

***Alewife***: The alewife (*Alosa pseudoharengus*) is a planktivorous marine member of the herring family, first found in Lake Superior in 1954. Alewives are considered beneficial as prey for salmonines, but are detrimental to zooplankton and the pelagic larvae of native fish species (Jude et al. 2002).

***Curly-leaf Pondweed***: Curly-leaf pondweed (*Potamogeton crispus*) is an exotic plant, accidentally introduced along with the common carp, which forms surface mats that interfere with aquatic recreation. The plant usually drops to the lake bottom by early July (Minnesota Sea Grant 2006b).

***Purple Loosestrife***: Purple loosestrife (*Lythrum salicaria*) is native to Eurasia and was transported to North America in the early 1880s as an ornamental plant (Stackpoole 1997). It is pervasive throughout the upper Midwest especially in Wisconsin and Michigan, including the Upper Peninsula, and is encroaching on Alger County. This species is an aggressive plant that prefers wetlands, stream edges and banks, along with cattails and sedges. Purple loosestrife can have a devastating effect on native plants and animals because it can reduce shelter and niche space and food for native wildlife such as waterfowl, frogs and toads, salamanders, and some fish with its dense growth and resulting obstruction of normal water flow (Stackpoole 1997).

**Potential Threats:** Exotic species considered to be encroaching on PIRO include the zebra mussel, quagga mussel (*Dreissena bugensis*), Asian clam (*Corbicula fluminea*), fishhook waterflea (*Cercopagis pengoi*), Eurasian ruffe (*Gymnocephalus cernuus*), round goby, the zooplankter *Daphnia lumholtzi*, Eurasian water-milfoil (*Myriophyllum spicatum*), rusty crayfish (*Orconectes rusticus*), and the parasitic copepod *Neoergasilus japonicus* (NPS 2003). Additional species that may be of concern include the white perch (*Morone americana*), threespine stickleback (*Gasterosteus aculeatus*), European frog-bit (*Hydrocharis morsus-ranae*), and flowering rush (*Butomus umbellatus*).

***Zebra Mussel, Quagga Mussel, and Asian Clam***: Invasions of zebra mussels (*Dreissena polymorpha*) and quagga mussels (*Dreissena bugensis*) are a major concern in the Great Lakes, and potentially in PIRO, because of the resulting catastrophic decline of native mussels. These two species have expanded their ranges at an alarming rate due to their wide environmental tolerances and high reproductive rate (Nichols 1993). They are very mobile and colonize most hard surfaces, including the shells of native mussels (Nichols et al. 2001). They are omnivores as adults, and will feed on algae, zooplankton, their own young, and detritus. Quagga mussels can live in colder water (Snyder et al. 1997), at greater depths, and on softer substrates than zebra mussels (Dermott and Kerec 1997). The Asian clam (*Corbicula fluminea*) is considered "one of the world's most invasive species" because of its rapid dispersal, high fecundity and growth, and early maturity (Jude et al. 2002).

Zebra mussels probably entered the Great Lakes in 1985 or 1986 in ballast water in Lake St. Clair (Minnesota Sea Grant 2006a). They are known to have occurred in South Bay (Munising Bay) at the Neenah Papers coal unloading site in 2001 as well as on a sunken tugboat in 1998 (Loope 2004). Quagga mussels were first found in Lake St. Clair in 1988 (Minnesota Sea Grant 2006b). Asian clams were found throughout the Great Lakes as early as 1984 (White et al. 1984), and have been found in the Portage Canal at Houghton, MI in effluent water from Upper Peninsula Power Company (Ward and Hodgson 1997).

These three species are not known to exist in PIRO, but the inland lakes accessible by motorboat (Grand Sable Lake, Little Beaver Lake, and Beaver Lake) are considered particularly vulnerable (Loope 2004). Zebra mussels have become established in several boat-accessible inland lakes at Sleeping Bear Dunes National Lakeshore (NPS Midwest Regional Office, Brenda Moraska LaFrancois, Aquatic Ecologist, pers. comm. 2006). PIRO streams may be particularly vulnerable to Asian clam invasion, since the clams prefer running water with sand or gravel substrates, and are pollution intolerant (Balcom 1994).

***Fishhook Waterflea***: The fishhook waterflea (*Cercopagis pengoi*) is an exotic species from the Caspian Sea. It is similar to the spiny waterflea in its size, life history, and habits, although it may eat smaller prey (Jude et al. 2002); however, it does not have a straight caudal spine but rather a spine that is curved at the end. It may compete with larval fish and fish planktivores for small zooplankton (Jude et al. 2002). As of 2001, it has been found in Grand Traverse Bay, Waukegan Harbor and Burnham Harbor in Lake Michigan (Charlebois et al. 2001).

***Eurasian Ruffe***: Ruffe (*Gymnocephalus cernuus*) are a small but aggressive type of exotic percid native to Eurasia. They were introduced to the Great Lakes in ballast water at the St. Louis River near Duluth in the early to mid 1980s. Their population has grown explosively, threatening the populations of walleye, perch, and other smaller forage fish species (USGS 2004).

***Round Goby***: The round goby (*Neogobius melanstomus*), originally from the Black and Caspian Sea areas of Eastern Europe, is a small, aggressive bottom-dwelling fish that exhibits prolific spawning and voracious eating behaviors. It was first introduced to Duluth Harbor in western Lake Superior in 1986 via ballast water. In some areas where it has become well-established, it appears to be the only fish species present (USGS 2000).

***Daphnia lumholtzi***: *Daphnia lumholtzi* is an exotic zooplankter from Africa, Asia, and Australia. It was first documented in North America in 1990, in the Illinois River 10 miles upstream from Lake Michigan in 1997 and 1998 (Stockel and Charlebois 2001), and in the Great Lakes by 2002 (Jude et al. 2002). It has longer spines than native *Daphnia* and feeds on algae and suspended detritus. Young fish that typically feed on zooplankton avoid this species because of the long spines. Low predation rates may allow it to replace native *Daphnia* species (Stockel and Charlebois 2001).

***Eurasian Water-milfoil***: The aquatic macrophyte Eurasian water-milfoil (*Myriophyllum spicatum*) was introduced to North America in the 1940s (Remaley 2005). It is easily transported and spread by boats and waterfowl. This species is found most commonly in the littoral zone of lakes in shallow water where it can attain very high densities and reduce light penetration and shade out native macrophyte species (Weeks and Andrascik 1998). Eurasian water-milfoil has become a major exotic pest species in inland lakes in Wisconsin, but has not yet been detected in the Upper Peninsula of

Michigan (USDA NRCS 2006).

***Rusty Crayfish***: The rusty crayfish (*Orconectes rusticus*) has been invading northern lakes and streams, including some in the western Upper Peninsula of Michigan (Gunderson 2006). Suitable habitat exists within PIRO. They are easily transported as live fish bait, in bait bucket water, and in live wells. They inhabit lakes, ponds, and streams (including pools and riffles), and prefer areas that have rocks and/or logs as cover (Gunderson 2006). They are aggressive toward other crayfish (Capelli 1982), destructive of aquatic macrophytes (Lodge and Lorman 1987), and they consume twice the food of the similar sized *Orconectes virilis*, a native crayfish (Momot 1992).

***Neoergasilus japonicus***: This parasitic copepod of fish fins, native to eastern Asia, has been found in Lake Huron's Saginaw Bay since 1994, but was not found in Lake Superior in limited sampling in 2001 (Hudson and Bowen 2002).

***White Perch***: The white perch (*Morone americana*), not a perch at all, is a species of the bass genus. It was first found in Lake Superior in 1986 in Duluth Harbor, and appears to continue to be restricted to that location, perhaps because it is warmer than the rest of the lake. It eats the eggs of walleye and white bass, and could contribute to a decline in the populations of those two species (Wisconsin Sea Grant 2002), although white bass are not known to exist in the PIRO vicinity.

***Threespine Stickleback***: The threespine stickleback (*Gasterosteus aculeatus*) has been known in Lake Superior since at least 1994. It eats zooplantkton, oligochaetes, chironomid midge larvae, and mosquito larvae, and is a very aggressive fish that may compete with native sticklebacks for food (Zhuikov 1997). It was introduced to the Great Lakes in ballast water, and had not resulted in any documented environmental damage as of 2002 (Jude et al. 2002).

***European Frogbit***: The European frogbit (*Hydrocharis morsus-ranae*), native to Eurasia, is a free-floating plant that has leathery, heart-shaped leaves and long roots, and looks similar to a small water lily. It occurs in marshes, lakes, and rivers along banks and shorelines. This species can form a thick mat of intertwined roots at the water's surface and can reproduce vegetatively, reducing light penetration and shading out native species. It migrated from Canada in the 1930s and has spread into Michigan (IUCN/SSC ISSG 2005), and was found in a canal at the edge of Lake St. Clair in 1997 (Hart et al. 2000).

***Flowering Rush***: Another Eurasian aquatic macrophyte, the flowering rush (*Butomus umbellatus*), can exist as an emergent plant or a submerged plant. It grows in the littoral zone of lakes and can form dense colonies that crowd out native aquatic vegetation. It has been found in the St. Lawrence River and along the border of Lake Erie in southeast Michigan (Hart et al. 2000).

**Terrestrial Invasive Species**: The two most notable terrestrial invasives are the gypsy moth (*Lymantria dispar*) and the spotted knapweed plant (*Centaurea maculosa*) (NPS 2003). Both are recent invaders. Gypsy moths are being trapped in the park, although they are not numerous. Spotted knapweed is a significant threat to resources in the park, particularly dune plant communities. Annual mechanical control activities began at Grand Sable Dunes in 2001, along with some more limited control at Sand Point. Periwinkle (*Vinca minor*) and bishopsweed (*Aegopodium podagraria*) are two other invasive terrestrial plant species that require control in PIRO (NPS 2003).

**Pathways for Introduction and Control Strategies**: The three most apparent pathways for the further introduction of aquatic invasives at PIRO are ballast water from commercial ships, recreational boating, and bait buckets. Ballast water would most likely introduce species into Lake Superior, but they could travel from there to inland waters. Recreational boating and bait buckets pose larger risks to PIRO's inland waters and smaller risks to Lake Superior. PIRO's superintendent has identified bait bucket transfer as a particular area of concern.

As discussed earlier, Michigan passed a regulation in 2001 requiring ships entering or using the Great Lakes to follow ballast water management practices established by shipping associations and federations. Education for recreational boaters, including the posting of signs at boat landings about cleaning boats and equipment before transferring them to other waters, has been emphasized (MIDEQ 2002c). These educational materials also instruct anglers not to dump their unused bait into any body of water.

Such angler education is generally considered to be a critical part of any control program for aquatic invasive species. A 1996 study showed that in Minnesota and North Dakota, the probability of any angler in the Hudson Bay basin releasing live bait that originated in the Mississippi River basin to be 1.2/100. The probability of bait bucket transfer occurring 10,000 times in one year approached 1.0, which in statistical terms makes it nearly a certainty (Ludwig Jr. and Leitch 1996). The authors stated that "effective, wide-ranging measures" would be needed to stop bait bucket transfer of species in the study area.

Besides angler education, controlling the problem of bait bucket transfer will require working with industries that deal in live aquatic species. A study conducted by the USFWS in 2000 found that from 1998-2000, live aquatic organisms in the categories of live fish, aquatic invertebrates, live worms, and bait other than worms were imported into the United States from 44 countries. Of the seven top ports of entry of these organisms into the United States, Detroit, MI was ranked first, and Port Huron, MI was ranked third (Sherfy and Thompson 2001), relatively "locally" on the scale of the entire United States. The authors suggested that relatively little is known about where these exotic bait species are being used, and what motivates anglers to seek them out.

Michigan's Sea Grant program, in cooperation with Minnesota's Sea Grant Program, has developed a Hazard Analysis and Critical Control Point (HACCP) program for members of the aquaculture, hatchery, and baitfish harvesting and transport industries. A HACCP program involves numerous steps, including evaluation of the hazard (in this case, the accidental establishment of an exotic species in a water body), the critical control points, and the critical limits. Then, a monitoring and recordkeeping program is put in place to address the critical points in the process at which these species might be released (Gunderson and Kinnunen 2004).

In February 2002, an Aquatic Nuisance Species Action Team was established in Michigan. The interagency group addresses legislation and policy, information and education, and research and monitoring in both the Great Lakes and Michigan's inland waters (MIDEQ 2002c). Michigan participates in the Great Lakes Panel on Aquatic Nuisance Species, a regional forum that provides a mechanism for state agencies to share information and coordinate planning on prevention and control of exotics. The Michigan Great Lakes Protection Fund, administered by the MIDEQ's Office of the Great Lakes, runs a small grant program for information and education programs as well as research projects on aquatic nuisance species. Regulatory programs in Michigan to control aquatic nuisance species in the state's inland waters fall under the Departments of Environmental Quality, Natural Resources and Agriculture (MIDEQ 2002c).

*Climate Change*

Examination of both historical and geological records demonstrates that Earth's climate has always been in a state of change. However, most climate scientists agree that climate is currently changing at an accelerating pace. Current projections are that Earth's temperature will warm by 0.8-2.6° C by 2050. (McCarthy et al. 2001). In the Great Lakes region, temperatures may warm by 3-7°C in winter, and by 3-11°C in summer, by 2100 (Kling et al. 2003). Many think of climate change as "global warming," and while warming is a component of climate change, many other changes in climate might also occur.

The Great Lakes Water Quality Board has produced a report on possible effects of climate change in the Great Lakes basin (IJC 2003). In addition to an increase in air temperature, the report predicts an increase in total annual precipitation, shifts in seasonal precipitation patterns, and increased intensity in some precipitation events. For the Great Lakes, the report forecasts a reduced ice cover season, declining lake levels, and reduced groundwater levels and stream base flows, but higher runoff during extreme precipitation events.

Climate change has implications for water quality. For example, surface waters will generally be warmer, which will affect chemical, physical, and biological processes. Dissolved oxygen may decline, and the decline may be made worse by extended periods of thermal stratification. Non-point source pollution may also increase because of higher intensity precipitation events.

Overall, biological productivity will likely increase as temperatures increase, but existing natural communities may be greatly changed. Some habitats may be reduced, especially wetlands and their vegetation communities.

Species in PIRO that depend on alpine or arctic habitats, such as the already threatened Arctic crowberry (*Empetrum nigrum*), Lake Huron tansy, and Pitcher's thistle, may be unable to survive (NPS 2005e). Invasive species may be more successful.

PIRO has a global climate change monitoring plan which includes following stream discharges for Miners River, Mosquito River, Chapel Creek, Hurricane River, and Sable Creek; epilimnial temperatures, water clarity, and dissolved oxygen for Grand Sable Lake and Beaver Lake; and ice-off dates for South Bay and Grand Sable Lake (Loope 2004).

*Impacts of Physical Processes*

Physical changes caused both by natural events and by human activities could have a significant impact on the future of the water resources in PIRO. For the picturesque Pictured Rocks cliffs, natural wind, wave, and ice action is the dominant force for physical change. The erosive effects of boat traffic on Lake Superior are considered relatively insignificant by comparison (NPS 2002). Future climate change could both reduce lake levels and increase the intensity of storms, with possible consequences to the Pictured Rocks (IJC 2003).

The Grand Sable Dunes are another significant park resource that will be affected in unknown ways by future climate change. Natural processes currently operate on the dunes to push them farther inland. The dunes are still relatively pristine, but foot traffic has caused erosion in some areas, and the erosive and plant trampling effects of illegal snowmobiling have also been a concern (NPS 2003).

Shoreline erosion caused by boat traffic may be a concern in the three lakes where motorboats are allowed. Boat use impacts are felt most acutely in shallow waters (<3 m) and along the shorelines of lakes and rivers not exposed to high winds (less than 300 m of open water) (Asplund 2000). Beaver Lake, with its shallow sand shelf, and Little Beaver Lake, with its shallow mean depth (3.3 m), may be more vulnerable than large, deep Grand Sable Lake, but current restrictions (electric motors <10 horsepower) may be sufficiently protective for the Beaver Lakes. An additional concern on Little Beaver Lake is that campers "park" their canoes or boats adjacent to their campsites, which may damage emergent vegetation and alter plant, invertebrate, and fish habitat (PIRO, Lora Loope, Aquatic Ecologist, pers. comm. 2006).

Logging and road building were considered the most significant potential sources of erosion and sedimentation in park inland waters in a study conducted by Boyle et al. (1999). Road building posed a greater risk than logging in the Hurricane, Miners, and Mosquito River watersheds, with the Mosquito and Miners watersheds having large areas of moderate risk. Timber harvest posed a low risk in most areas of the Mosquito River and Hurricane River watersheds, with higher risk in areas paralleling the stream corridor of the Miners River.

The foresight shown by Congress in establishing an inland buffer zone for the park has undoubtedly helped to protect the park's water resources from development impacts in the 40 years since its establishment. Park staff provide oversight for new residential development, timber harvest, and other land uses in the IBZ, which helps to reduce the risk from these activities.

# Conclusions

PIRO contains numerous and diverse water resources, including Lake Superior waters and shoreline, inland lakes, streams, waterfalls, wetlands, vernal pools, and groundwater. Some have not yet been adequately characterized, but most available data show these resources to be of high quality. Documented problems include the bioaccumulation of persistent pollutants in Lake Superior, and high mercury levels in fish in Grand Sable Lake. A single sample showed an elevated mercury level in the sediments of Beaver Lake, but followup samples showed no elevated mercury levels in fish.The stressors of greatest future concern for PIRO water resources are deposition from regional air pollution sources, invasive species, and global climate change (Table 24). Recreational boating, residential development, on-site wastewater treatment systems, logging, road building, and increased visitor use may also be stressors. Other stressors that may be of concern, but for which data are sparse, include local air pollution sources and stormwater discharges. Specific conclusions by water resource type are provided below.

### Open Waters of Lake Superior

Lake Superior's great surface area and depth make it improbable that many local sources would have broad impacts on the lake. The main lakewide pollutant issue is regional atmospheric deposition of persistent bio-accumulative chemicals, including PCBs, dioxin/furan and mercury. The problem with these contaminants is reflected in the fish consumption advisories for many fish species, especially for larger fish.

Lake Superior has been classified as an ultra-oligotrophic lake based on its low nutrient levels and low levels of biological productivity. Recent nutrient data from the nearshore areas of PIRO are sparse. Lakewide phosphorus levels have decreased since the 1970s, but nitrate has been slowly increasing over the historical period. The nitrate trend needs further investigation to determine how much change may occur in the lake's trophic status.

Aquatic invasive species are also an increasing problem, especially in the Duluth area of western Lake Superior. Discharge of ballast water from Great Lakes ships has been a significant source, although regulations are likely to be tightened in the next few years. Ships, commercial tour boats and recreational boats could be sources of fuel spills or discharges of human wastes or other contaminants, and recreational boats could be an additional source of invasive species. The effects of global climate change will also need to be monitored over time.

### Inland Lakes

The trophic status of the 14 named inland lakes in PIRO's shoreline zone and IBZ ranges from oligotrophic Legion Lake to early eutrophic Little Beaver and Miners Lakes. Beaver, Little Beaver, Miners, Trappers, and Little Chapel Lakes exceed the expected amount of phosphorus for their ecoregion, and the latter three also exceed the nitrogen criterion. All PIRO's lakes are protected from current small-scale land use disturbances, but have been affected by past logging and other land use practices in ways that are not completely known. Grand Sable Lake and the Beaver Lakes receive the most recreational use. Water quality and biological data are meager for Legion, Little Beaver and Little Chapel Lakes in the shoreline zone and Section 36 and Upper and Lower Shoe Lakes in the IBZ. Other inland water resources with little available data include the Sand Point ponds and the Twelvemile Bog. Some other data are not current; for example, most of the PIRO data in USEPA's STORET water quality database was collected before 1985 (see Table 15 for an example of the amounts and ages of PIRO inland water chemistry data).

Gaps in understanding also exist; examples include the dynamics and ecology of meromictic Chapel Lake, and species composition, community succession, and carbon cycling in vernal pool ecosystems. Major threats to PIRO lakes include the introduction of aquatic invasive species through angler and boater activities, and the deposition of local and regional atmospheric contaminants. Some potential for residential development exists on the Shoe Lakes in the IBZ.

### Streams

PIRO's streams generally appear to be of high quality, although data are sparse. Limited MIDEQ sampling has shown excellent macroinvertebrate habitat in Miners and Hurricane Rivers and good habitat on the Mosquito River. The Mosquito and Hurricane Rivers and Towes, Sable, and Sullivan Creeks contain excessive amounts of phosphorus for their ecoregion; Hurricane River and Towes Creek also exceed the nitrogen criterion for their ecoregion. Munising Falls Creek, Miners

**Table 24. Water quality indicators and current and potential stressors of aquatic resources in Pictured Rocks National Lakeshore.**

| Stressor or Environmental Indicator/Location | Lake Superior | Inland Lakes | Streams | Wetlands | Pictured Rocks escarpment | Grand Sable Dunes shoreline |
|---|---|---|---|---|---|---|
| **Water quality indicators** | | | | | | |
| Water clarity | OK | OK | OK | NA | NA | NA |
| Nutrients | PP | EP | EP | NA | NA | NA |
| Dissolved oxygen | OK | OK | OK | NA | NA | NA |
| Toxic contaminants | EP | PP | PP | PP | NA | NA |
| **Biological indicators** | | | | | | |
| Zooplankton populations | PP | OK | NA | NA | NA | NA |
| Fish consumption advisories | EP | EP (Hg) | PP (Hg) | NA | NA | NA |
| **Air quality** | | | | | | |
| Regional atmospheric deposition and air pollution | EP | EP (Hg) | PP | PP | OK | OK |
| Local air pollution sources | OK | PP | PP | PP | OK | OK |
| **Water quality** | | | | | | |
| Wastewater discharges covered by NPDES permits | OK | NA | NA | NA | NA | NA |
| Stormwater | PP | PP (PAHs) | PP (PAHs) | PP (PAHs) | NA | NA |
| Agriculture | OK | OK | OK | OK | NA | NA |
| Landfills | OK | OK | OK | OK | NA | NA |
| Septic systems | OK | OK | PP | PP | NA | NA |
| Road building | OK | PP | PP | PP | NA | NA |
| Logging | OK | PP | PP | PP | NA | NA |
| Commercial boating | PP | NA | NA | NA | PP | PP |
| Recreational boating | PP | PP | PP | NA | OK | OK |
| **Invasive species** | | | | | | |
| Ballast water discharges | PP | NA | NA | NA | NA | NA |
| Recreational boating | OK | PP | NA | NA | OK | OK |
| Bait bucket transfer | PP | PP | PP | NA | NA | NA |
| **Development and use** | | | | | | |
| Visitor use intensity | OK | PP | PP | PP | PP | PP |
| Residential development | OK | PP | PP | PP | NA | NA |
| Commercial fishery | OK | NA | NA | NA | NA | NA |
| **Global climate change** | PP | PP | PP | PP | PP | PP |

**Definitions: EP= existing problem; PP = potential problem; OK= no detectable problem**

**shaded =limited data; NA= not applicable.**

**Table 25. Crosswalk of report recommendations with the Vital Signs Monitoring program of the NPS Great Lakes Inventory and Monitoring Network (Route and Elias 2006).**

| Recommendation | Vital Signs | Comments |
|---|---|---|
| Updating Lake Superior water quality data | Water level fluctuations, core and advanced water quality suites, diatoms, plant and animal exotics, fish communities | Results of GLKN monitoring should be examined to determine whether additional parameters or increased sampling frequency are warranted. |
| Wetland conditions and biota assessment | Water level fluctuations, aquatic plant communities | |
| Assessment of vernal pools and their ecosystem functions | Amphibians and reptiles | Other important species not covered under GLKN protocols may use vernal pools. |
| Rapid bioassessment for all streams and rivers | Core water quality suite, advanced water quality suite (including macroinvertebrate indices) | |
| Basic monitoring and seasonal water quality trend monitoring for inland lakes | Core and advanced water quality suites | |
| Lake Superior fish surveys | Fish communities, trophic bioaccumulation | The second phase of the GLKN bio-accumulative contaminants protocol will address mercury contamination and fish consumption advisories. |
| Aquatic invasives monitoring and control program | Plant and animal exotics | |
| Evaluation of local and regional air pollutant impacts | Air quality, trophic bioaccumulation | |
| Water and sediment monitoring for marine engine-related contaminants | Trophic bioaccumulation | |
| Documentation of stormwater locations and impacts | Core and advanced water quality suites | |
| Monitoring local land use and impacts | Land use – fine and coarse scales | |

River, and some tributaries of Hurricane River and Sable Creek originate outside the IBZ, beyond the range of park jurisdiction. Increased residential development using septic systems could decrease the quality of stream baseflow. Residential development or road building and maintenance could increase the runoff of contaminants into the streams. Increased logging on state or private forest land without implementation of best management practices could have similar effects. As with other PIRO water resources, the introduction of aquatic invasive species and atmospheric deposition also present threats. The mouth of Beaver Creek is categorized as having vegetated low to steep banks and mud flats with medium-high sensitivity to fuel spills.

# Recommendations and Rationale

The GLKN has recently completed its determination of 46 "vital signs" that represent the health of natural resources in the nine Great Lakes parks, including PIRO (Route and Elias 2006). The GLKN is now in the process of developing 16 long-term monitoring protocols over the next six years for the top 21 vital signs. Some of those monitoring protocols have the potential to address needs we have identified as specific to PIRO. A table comparing our monitoring recommendations with the vital signs monitoring program is included as Table 25.

LaFrancois and Glase (2005) conducted an extensive water resources literature review for Great Lakes National Parks and made numerous recommendations for future monitoring and research specific to PIRO. We concur with many of those and incorporate some of them in the following recommendations. Recommendations are not ordered by priority.

**Water quality and biotic evaluation and monitoring:**

- Water quality data for Lake Superior sites near PIRO should be updated by park staff or through cooperation with other agencies. Regular monitoring is necessary to understand the condition of water resources and to detect and react to changes in a timely manner.
- The abundant and diverse wetland resources, and the potentially ecologically significant vernal pools, need additional study. Wetland biota are largely undocumented for PIRO. The currently funded vernal pool study is important to establish the locations, functions, and biota of PIRO vernal pools.
- A better understanding of PIRO hydrology should be developed by classifying the landscape into hydraulic response areas based on soil moisture regimes, landscape slope, and degree of runoff by overland or subsurface. Such a system would provide a context for understanding and managing water quality and biotic resources. The planned field work to delineate additional first-order streams will be a good addition to the understanding of PIRO hydrology.
- A determination should be made of which beaver ponds or small kettle depressions in PIRO should be considered "lakes", and basic studies should be conducted on the lakes that currently have limited or outdated water quality and biological data, especially in the shoreline zone. Seasonal trends should also be examined to allow adequate characterization of these resources.
- DOC concentrations in PIRO inland waters should be monitored for effects of climate change (LaFrancois and Glase 2005).
- The nutrient status of PIRO inland waters should be monitored, and they should be evaluated for impacts of historical change, especially past logging, on nutrient levels and trophic status. The physical, chemical, and biological impacts of either retaining or removing the remaining low-head dams within PIRO should be assessed.
- An assessment of all PIRO streams and rivers should be conducted using standardized rapid bioassessment techniques to determine existing water quality, and monitoring should continue on a five year basis to document changes and trends in water quality throughout PIRO. Rapid bioassessment screening tools would allow determination of whether or not a stream was supporting its designated aquatic life use as well as potential causes of impairment, through examination of periphyton, benthic macroinvertebrates, and fish assemblages and assessing the quality of the physical habitat structure.
- A determination should be made as to whether the arsenic present in some Alger County wells has implications for PIRO drinking water supplies or other resources.
- Stream sites that had exceedences for lead and cadmium in the 1970s should be resampled during the same seasons for those contaminants so that this concern can be either addressed or eliminated. Similarly, the one instance of elevated mercury in Beaver Lake sediments should be further evaluated.
- Regular assessments of fish species assemblages should be made in Lake Superior and inland waters to detect changes in populations or species composition, and an evaluation of their historic structures should be made where feasible (LaFrancois and Glase 2005). Genetic investigations of coaster brook trout

stocks should be considered, and the need for a locally developed brood stock should be evaluated (Lafrancois and Glase 2005). Populations of native lamprey should be surveyed, and the effect of the sea lamprey control program on these native species should be assessed.

- Populations of unionid mussels should be surveyed in inland waters, and reasons for low recruitment in Grand Sable Lake, including lake trout – yellow perch- mussel population dynamics, should be investigated (Nichols et al. 2001).

- A more detailed assessment should be made of the connections between soil types and properties, landscape morphology, and water quality and quantity in a watershed context.

**Stressor monitoring and evaluation:**

- Surveys for known and encroaching exotic species in PIRO should be expanded, and control programs should be undertaken where feasible. Aquatic invasives are common in western Lake Superior, and their continued spread is a serious threat to park resources and ecosystems.

- Specific pollutants in local and regional air emissions and their potential effects on PIRO inland water resources should be evaluated, and monitoring should be conducted where warranted. Persistent bio-accumulative pollutants are a major stressor for PIRO resources.

- Water and sediment monitoring should be evaluated for heavily-used recreational boating areas for marine engine – related contaminants such as MTBE (methyl tertiary butyl ether), PAHs (polyaromatic hydrocarbons), BTEX (benzene, toluene, ethylbenzene and xylene) and heavy metals such as copper. Recent research in Isle Royale National Park found clear evidence of PAH contamination at significant levels near marinas.

- Locations of stormwater discharges both in and near PIRO should be documented and evaluated for potential impacts. Stormwater contains a number of potentially toxic and damaging substances, and PIRO's neighboring communities are too small to fall under USEPA regulations.

- A risk evaluation for PAH pollution from sealcoated roads should be performed. Coal-tar emulsion sealants have been documented as a major source of PAHs elsewhere.

- The practice of "parking" canoes or boats at campsites on Little Beaver Lake should be evaluated for its potential effects on emergent vegetation and plant, invertebrate, and fish habitat, and appropriate management changes should be implemented.

- Ways to monitor the effects of local land use practices (logging, road building, and residential development) on PIRO inland waters should be developed, especially in steep drainages and in areas identified as being at higher risk in past evaluations. Population trends in the IBZ and watershed should be monitored.

- PIRO staff tracking and oversight of land use changes in the IBZ should continue, and PIRO staff should be allowed to review plans for new and replacement on-site waste disposal systems in the IBZ.

**Planning and Mapping:**

- A plan should be developed to deal with potential fuel spills from tour boats along their tour paths or Great Lakes ships where they pass closest to PIRO. Lake Superior's unpredictable weather and high number of historic shipwrecks show that the threat of a shipping or boating accident is not insignificant. A similar plan could address the slightly less significant threat of a recreational boating fuel spill in inland waters.

- An updated fisheries management plan that incorporates NPS policies into management recommendations is needed.

- A plan should be developed to mitigate impacts of future climate change where feasible strategies can be identified. Risks include changes in water levels, loss of species, and increased pressure from exotic species.

- A more accurate map of land ownership

in the PIRO watershed outside the IBZ is needed to enhance oversight and management decision-making.

**Education**:

- Emphasis should be placed on angler education about the risks of both boat and bait bucket transfer as possible vectors for introduction of exotic species into PIRO inland waters. Boater and angler activity is the largest easily controllable source of pollutants to inland waters.

- Where opportunities exist, efforts should be made to educate the public about the risks that burn barrels and other open burning pose to Lake Superior and other water resources. (One set of education materials can be found at http://www.dnr.state.wi.us/environmentprotect/ob/guides.htm).

# Works Cited


Aiello, C. 2005. Michigan water quality monitoring: Great Lakes tributaries, 2003 report. Michigan Department of Environmental Quality, Surface Water Quality Division. Report MI/DEQ/WB-05/058. (http://www.deq.state.mi.us/documents/deq-wb-swas-03tribreport.pdf). Accessed November 2005.

Alberti, M.A., D.J. Bauer, S.R. Bradt, B. Carlson, S.C. Carlson, W.T. Godkin, S. Greene, J.F. Haney, A. Kaplan, S. Melillo, J.L. Smith (Nowak), B. Ortman, J.E. Quist, S. Reed, T. Rowin, and R.S. Stemberger. 2005. An image-based key to the zooplankton of the northeast (USA), version 2.0. Center for Freshwater Biology, University of New Hampshire, Durham, NH. Online. http://cfb.unh.edu/CFBkey/html/index.html. Accessed December 4, 2006.

Alger County Chamber of Commerce. n.d.. Alger County (factsheet). Munising, MI. (http://www.algercounty.org). Accessed July 2005.

Asplund, T.R. 2000. The effects of motorized watercraft on aquatic ecosystems. Wisconsin Department of Natural Resources, Bureau of Integrated Science Services and University of Wisconsin – Madison, Water Chemistry Program. PUBL-SS-948-00. (http://www.dnr.state.wi.us/org/water/fhp/papers/lakes.pdf). Accessed September 2005.

Baker, E., L. Newman, and B. Kenner. 1999. An action plan for restoring coaster brook trout to the Pictured Rocks National Lakeshore. Multi-agency guidance report for National Park Service, Pictured Rocks National Lakeshore.

Balcom, N.C. 1994. Aquatic immigrants of the northeast, No. 4: Asian clam, *Corbicula fluminea*. Connecticut Sea Grant College Program. 1pp.

Baldwin, N. A., R. W. Saalfeld, M. R. Dochoda, H. J. Buettner, and R.L. Eshenroder. 2002. Commercial fish production in the Great Lakes 1867-2000. (http://www.glfc.org/databases/commercial/commerc.php). Accessed February 2006.

Barbiero, R.P, and M.L. Tuchman. 2001. Results from the U.S. EPA's biological open water surveillance program of the Laurentian Great Lakes: I. Introduction and phytoplankton results. J. Great Lakes Res. 27(2):134–154.

Barbiero, R.P., R.E. Little, and M.L. Tuchman. 2001. Results from the U.S. EPA's biological open water surveillance program of the Laurentian Great Lakes: III. Crustacean Zooplankton. J. Great Lakes Res. 27(2):167–184.

Batzer, D.P., B.J. Palik, and R. Buech. 2004. Relationships between environmental characteristics and macroinvertebrate communities in seasonal woodland ponds of Minnesota. Journal of the North American Benthological Society 23(1):50-68.

Bennett, E.B. 1978. Water budgets for Lake Superior and Whitefish Bay. J. Great Lakes Res. 4 (3-4):331-342.

Bennett, J. P., and M. Bannerjee. 1995. Air pollution vulnerability of 22 midwestern parks. Journal of Environmental Management 44:339-360.

Blewett, W. 1994. Late Wisconsin history of Pictured Rocks National Lakeshore and vicinity. PIRO 94-01, Pictured Rocks National Lakeshore, Munising, MI. (http://www.nps.gov/applications/nature/documents/rrGlacier.pdf). Accessed July 31, 2006.

Boyle, T.P., R. G. Waltermire and G. W. Gustina. 1999. Risk analysis of the aquatic resources in Pictured Rocks National Lakeshore: an ecologically based inventory and estimation of the effects of land use practices. Midcontinent Ecological Science Center, Biological Resources Division, United States Geological Survey. Fort Collins, CO.

Brownlee, S. 2005. "Boat fire forces rescue". The Mining Journal, September 19, 2005.

Burt Township (Michigan) Planning Commission. 1993. Burt Township comprehensive plan. Grand Marais, MI. (http://www.burttownship.com/masterplan.html). Accessed October 2005.

Burt Township, Michigan. 1995 (revised 2005). Burt Township zoning ordinance of the Township of Burt, County of Alger, Michigan. Grand Marais, MI. (http://www.burttownship.com/files/Ordinances/Zoning_Ordinance_2005.pdf). Accessed October 2005.

California Environmental Protection Agency Air Resources Board. 1999. Fact sheet: New regulations for gasoline marine engines. Sacramento, CA. (http://www.arb.ca.gov/msprog/marine/facts.pdf). Accessed September 2005.

Capelli, G.M. 1982. Displacement of northern Wisconsin crayfish by *Orconectes rusticus*. Limnol. Oceanogr. 27:741-745.

Carey, L.M. 1993. Soil Survey of Pictured Rocks National Lakeshore. U.S. Department of Agriculture, Soil Conservation Service. Marquette, MI.

Carlson, R.E. 1977. A trophic state index of lakes. Limnol. Oceanogr. 22:361-369.

Casper, G. 2005. An amphibian and reptile inventory of Pictured Rocks National Lakeshore. Final Report to the National Park Service Great Lakes Inventory and Monitoring Network, Ashland, WI. 46pp.

Central Upper Michigan Planning and Development Regional Commission (CUPPAD). 2000. City of Munising comprehensive plan. CUPPAD, Escanaba, MI. (http://www.cityofmunising.org/cp.htm). Accessed September 2005.

Central Upper Peninsula Planning and Development Regional Commission (CUPPAD). 2004. Comprehensive economic development strategy report. Escanaba, MI.

Charlebois, P.M., M.J. Raffenberg, and J.M. Dettmers. 2001. First occurrence of Cercopagis pengoi in Lake Michigan. J. Great Lakes Res. 27(2): 258-261.

City of Munising Planning Commission. 2004. City of Munising zoning ordinance. Munising, MI. (http://www.cityofmunising.org/pdf/zoningordinance.pdf). Accessed September 2005.

Clements, W., and O. Cox. 2006. An integrated assessment of polycyclic aromatic hydrocarbons (PAHs) and benthic macroinvertebrates of Isle Royale National Park, Michigan, USA. Final report submitted to the National Park Service, Isle Royale National Park.

Code of Federal Regulations. 1899. Refuse act of 1899. 33 USC 407. (http://www4.law.cornell.edu/uscode/html/uscode33/usc_sec_33_00000407----000-.html). Accessed June 2006.

Code of Federal Regulations. 1987. Federal water pollution control act (Clean Water act) (as amended). 33 USC 1251 - 1376, P.L. 845, 62 Stat. 1155 (Fish and Wildlife Service). (http://www.thecre.com/fedlaw/legal14water/fwatrpo.htm). Accessed June 2006.

Colburn, E.A. 2004. Vernal pools: natural history and conservation. The McDonald & Woodward Publishing Company. Blacksburg, Virginia. 426pp.

Cole, G.A. 1983. Textbook of Limnology 3rd Edition. C.V. Mosby Co., St Louis 401 pp.

Copeland, C. 2004. Cruise ship pollution: Background, laws and regulations, and current issues. Congressional Research Service Report RL32450. Congressional Research Service, Library of Congress. (http://www.ncseonline.org/NLE/CRSreports/05feb/RL32450.pdf). Accessed September 2005.

Corbett, J. J., and H. W. Koehler. 2003. Updated emissions from ocean shipping. J. Geophys. Res., 108(D20), 4650. (http://www.ocean.udel.edu/cms/jcorbett/CorbettKoehlerJGR2003.pdf). Accessed September 2005.

Crispin, S.R., V.L. Dunevitz, D. Katz, and K.A. Chapman. 1984. A survey for endangered, threatened, and special concern plant species in Pictured Rocks National Lakeshore, Michigan. Michigan Natural Features Inventory. Lansing, MI. 9pp. + appendices.

Cullis, K.I., and G. E. Johnson. 1988. First evidence of the cladoceran *Bytheothrephes cederstroemi* Schoedler in Lake Superior. J. Great Lakes Res. 14:524-525.

Dahl, B. 2001. Superior Way: the cruising guide to Lake Superior (3rd edition). Lake Superior Port Cities, Inc. Duluth, MN.

de Blij, H.J., and P.O. Muller. 1993. Physical Geography of the Global Environment. John Wiley & Sons, Inc. New York.

DeBruyn, T.D. 1997. Habitat use, food habits and population characteristics of female black bears in the central Upper Peninsula of Michigan: a geographic information system approach. Dissertation. Michigan Technological University, Houghton, MI. 127pp.

DeGuire, L. 1993. The Great Lakes atmospheric deposition program in Michigan. Michigan Department of Natural Resources, Lansing, MI. 16 pp.

Dermott, R., and D. Kerec. 1997. Changes to the deepwater benthos of eastern Lake Erie since the invasion of *Dreissena*: 1979-1993. Can. J. Fish. Aquat. Sci. 54:922-930.

Doepke, P. 1972. Alger County lakes study. Conducted for the Central Upper Peninsula Planning and Development District, Alger County Planning Commission and the National Park Service, Department of Interior. Northern Michigan University, Marquette, MI.

Driscoll, C.T., G.B. Lawrence, A.J. Bulger, T.J. Butler, C.S. Cronan, C. Eagar, K.F. Lambert, G.E. Likens, J.L. Stoddard, and K.C.Weathers. 2001. Acid Rain Revisited: advances in scientific understanding since the passage of the 1970 and 1990 Clean Air Act Amendments. Hubbard Brook Research Foundation. Science Links™ Publication. Vol. 1, no.1. (http://www.hbrook.sr.unh.edu/hbfound/report.pdf) Accessed August 21, 2006.

Duluth Seaway Port Authority. 2004. Port facts. (http://www.duluthport.com/seawayfactsus.html). Accessed September 2005.

Edsall, T. 1960. Age and growth of the whitefish *Coregonus clupeaformis* of Munising Bay, Lake Superior. Transactions of the American Fisheries Society 89:323-332.

Elias, J.E. 2006. Water quality sampling at Pictured Rocks and Sleeping Bear Dunes National Lakeshores, 2005. National Park Service, Great Lakes Inventory and Monitoring Network Report MR/2006/01. Ashland, WI.

Environment Canada and United States Environmental Protection Agency (USEPA). 2005. State of the Great Lakes 2005. ISBN 0-662-41451-9. (http://www.epa.gov/glnpo/solec/). Accessed November 2, 2006.

Farrand, W.R., and C.W. Drexler. 1985. Late Wisconsinan and Holocene history of the Lake Superior Basin. pp. 17-23. In Carrow, T. F., and Calkin, eds. Quaternary evolution of the Great Lakes. Geological Association of Canada Special Paper No. 30.

Flint, R.F. 1957. Glacial and Pleistocene Geology. John Wiley and Sons, Inc., New York. 553 pp.

Futyma, R.P. c.a.1990. Fossil pollen stratigraphy of Twelvemile Bog, Pictured Rocks National Lakeshore, Michigan. Biological Survey, New York State Museum. Albany, NY. 7pp. + appendix.

Garton, D.W. and D.J. Berg. 1990. Occurrence of *Bythotrephes cederstroemi* (Schoedler 1877) in Lake Superior, with evidence of demographic variation within the Great Lakes. J. Great Lakes Res. 16(1):148-152.

Gerovac, P. and R. Whitman. 1995. Fishes of the Pictured Rocks National Lakeshore. Research report to Pictured Rocks National Lakeshore. U.S. Department of the Interior, National Biological Service, Lake Michigan Biological Station, Porter, IN.

Great Lakes Fishery Commission (GLFC), Lake Superior Committee. 2001. Fish community objectives for Lake Superior (public discussion draft). Ann Arbor, MI. (http://www.glfc.org/lakecom/lsc/draftforview2001.pdf). Accessed December 2005.

Grigorovich, I., A. Korniushin, D. Gray, I. Duggan, R. Colautti and H. MacIsaac. 2003a. Lake Superior: an invasion coldspot? Hydrobiologia 499: 191-210.

Grigorovich, I., R. Colautti, E. Mills, K. Holeck, A. Ballert, and H. MacIsaac. 2003b. Ballast-mediated animal introductions in the

Laurentian Great Lakes: retrospective and prospective analyses. Can. J. Fish. Aquat. Sci. 60: 740-756.

Grim, K. 1990a. Status of the fishery resource – 1988, Beaver Lake, Alger County. Michigan Department of Natural Resources, Fisheries Division Report.

Grim, K. 1990b. Status of the fishery resource – 1989, Grand Sable Lake, Alger County. Michigan Department of Natural Resources, Fisheries Division Report.

Gruhn, W. 1976. Series: The trout streams of Michigan. No. 29 – Mosquito River. Michigan Department of Natural Resources, Fisheries Division Technical Report: No. 76-18.

Guiry, M.D., and G.M Guiry. 2006. AlgaeBase version 4.2. National University of Ireland, Galway. Online. http://www.algaebase.org. Accessed December 4, 2006.

Gunderson, J. 2006. Rusty crayfish factsheet. Minnnesota Sea Grant, University of Minnesota. Minneapolis, MN. (http://www.seagrant.umn.edu/exotics/rusty.html) Accessed July 31, 2006

Gunderson, J., and R. Kinnunen (ed). 2004. AIS-HAACP Aquatic invasive species – Hazard analysis and critical control point training curriculum. University of Minnesota, Duluth, MN. (http://www.deq.state.mi.us/documents/deq-ogl-AIS-HACCP%5fmanual.pdf). Accessed December 2005.

Hamblin. W. K. 1958. Cambrian sandstones of Northern Michigan. Michigan Department of Conservation, Geological Survey Division. Lansing, MI. 149pp.

Hamblin, W. K. 1961. Paleogeographic evolution of the Lake Superior region from Late Keweenawan to Late Cambrian time. Geol. Soc. of Am. 17:1-18.

Handy, A., and F. Twenter. 1985. Water resources of Pictured Rocks National Lakeshore, Michigan. Water-Resources Investigations Report 85-4013, U.S. Geological Survey, Lansing, MI.

Hart, S., M. Klepinger, H. Wandell, D. Garling and L. Wolfson. 2000. Integrated pest management for nuisance exotics in Michigan inland lakes. Michigan Department of Environmental Quality and Department of Fisheries and Wildlife, Michigan State University. (http://www.deq.state.mi.us/documents/deq-water-great-lakes-aquatics-exotic4.pdf). Accessed August 7, 2006.

Hausler, R., and G. Peterson. 2001. Water quality best management practices on forest lands. Extension Bulletin E2770. Michigan State University Extension, Lansing, MI. (http://forestry.msu.edu/extension/extdocs/E2770.pdf). Accessed September 2005.

Holtschlag, D.J., and J. R. Nicholas. 1998. Indirect ground-water discharge to the Great Lakes. United States Geological Survey Open-File Report 98-579. Lansing, MI. (http://mi.water.usgs.gov/pdf/glpf.pdf). Accessed September 2005.

Hudson, P. L., and C. A. Bowen, II. 2002. First record of *Neoergasilus japonicus* (Poecilostomatoida: Ergasilidae), a parasitic copepod new to the Laurentian Great Lakes. Journal of Parasitology 88(4): 657-663.

Hughes, J.D. 1968. Unpublished materials for the section on geology of Pictured Rocks National Lakeshore Master Plan. Pictured Rocks National Lakeshore, Munising, MI. 8pp.

Humphreys, C.R., and J. Colby. 1965 Michigan lakes and ponds. Agricultural Experiment Station, Michigan State University. Lansing, MI.

International Joint Commission (IJC). 2003. Climate change and water quality in the Great Lakes basin. Report of the Great Lakes Water Quality Board to the International Joint Commission, August, 2003. (http://www.ijc.org/php/publications/html/climate/index.html). Accessed September 2005.

International Maritime Organization. 1978. International convention for the prevention of pollution from ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78). London, United Kingdom. (http://www.

imo.org/Conventions/contents.asp?doc_id=678&topic_id=258). Accessed June 2006.

IUCN/SSC Invasive Species Specialist Group (ISSG). 2005. Global Invasive Species Database: Hydrocharis morsus-ranae (aquatic plant). (Online). (http://www.issg.org/database/). Accessed August 7, 2006.

Jarnigan, S.T. 1998. Direct and indirect estimates of death rates and predator-mediated dispersal of *Bythotrephes cederstroemi*. Dissertation. Michigan Technological University. Houghton, MI.

Jerome, D.S. 2005. The Landforms of Major Land Resource Area 94B – Eastern Upper Peninsula Sandy Drift. Natural Resources Conservation Service, United States Department of Agriculture. (ftp://ftp-fc.sc.egov.usda.gov/MI/technical/soils/MLRA%2094B%20Eastern-UP%20Landform%20Report.pdf). Accessed September 2005.

Jude, D., E. Stoermer, T. Johengen, and A. Perakis. 2002. Non-indigenous species in the Great Lakes: ecology, interactions, impacts, and future research directions. White Paper prepared for the University of Michigan's Great Lakes Initiative. (http://www.miseagrant.umich.edu/symposium/papers/AQUATI.pdf). Accessed December 2005.

Kamke, K. 1987. Limnology in four lakes in Pictured Rocks National Lakeshore. Thesis. University of Wisconsin – Stevens Point, Stevens Point, WI.

Karamanski, T.J. 1995. The Pictured Rocks: An administrative history of Pictured Rocks National Lakeshore. National Park Service, Omaha, Nebraska. (http://www.nps.gov/piro/adhi/adhi.htm). Accessed September 2005.

Kinnunen, R. 2003. Great Lakes commercial fisheries. Michigan Sea Grant Extension, Marquette, MI. (http://www.miseagrant.umich.edu/downloads/fisheries/GLCommercialFinal.pdf). Accessed December 2005.

Kling, G., K. Hayhoe, L. Johnson, J. Magnuson, S. Polasky, S. Robinson, B. Shuter, M. Wander, D. Wuebbles, D. Zak, R. Lindroth, S. Moser, and M. Wilson. 2003. Confronting climate change in the Great Lakes Region: impacts on our communities and ecosystems. A report of the Union of Concerned Scientists, Cambridge, Massachusetts, and the Ecological Society of America, Washington, D.C. (http://www.ucsusa.org/greatlakes/glchallengereport.html). Accessed November 19, 2006.

LaFrancois, B. Moraska and J. Glase. 2005. Aquatic studies in National Parks of the upper Great Lakes states: past efforts and future directions. Water Resources Division Technical Report, NPS/NRWRD/NRTR-2005/334. National Park Service, Denver, CO.

LaFrancois, B. 2006. US Park Service Proposal – Assess vernal pools of PIRO by determing distribution, abundance, and ecological significance. Project Identification – PMIS 112929.

Lake Carriers' Association. 2004. Map of U.S. and Canadian Great Lakes ports. Lake Carriers Association, Cleveland, OH. (http://www.lcaships.com/Lake%20Carriers%20Map.pdf). Accessed September 2005.

Lake Superior Binational Program (LSBP). 2000. Lake Superior lakewide management plan (LaMP). (http://www.epa.gov/glnpo/lakesuperior/lamp2000/index.html#contents). Accessed September 2005.

Lake Superior Binational Program (LSBP). 2006. Lake Superior Lakewide management plan (LaMP). (http://www.epa.gov/glnpo/lakesuperior/2006/index.html). Accessed May 2006.

Lam, D.C. 1978. Simulation of water circulations and chloride transports in Lake Superior for summer 1973. J. Great Lakes Res. 4(3-4): 343–349.

Lawrie, A.H. 1978. The fish community of Lake Superior. J. Great Lakes Res. 3-4: 513-549.

Ledder, T. 2005. Water quality standards information for the Great Lakes Inventory and Monitoring Network. National Park Service, Great Lakes Inventory and Monitoring Network, Ashland, WI. 54806. Great Lakes Network Technical Report: GLKN/2005/12. (http://www1.nature.nps.

gov/im/units/glkn/WQ%20Standards%20 Report%202005.pdf). Accessed November 2005.

Lehman, J.T. and C.E. Caceres. 1993. Food-web responses to species invasion by a predatory invertebrate: *Bythotrephes* in Lake Michigan. Limnol. and Oceanogr. 38(4):879-891.

Lewin, J. 1991. Acidification mechanisms in a small, clear-water, low pH seepage lake, Upper Peninsula of Michigan. Thesis. Michigan Technological University, Houghton, MI.

Lewin, J.C., L.M. Loope, and R. Stottlemyer. 1990a. Natural acidification of seepage lakes in northern Michigan. Ecological Society of America Bulletin 71(2):229.

Lewin, J.C., L.M. Loope, and R. Stottlemyer. 1990b. Mistaken causes for acidification of sensitive lakes at Pictured Rocks National Lakeshore. Proc. Sixth Conf. on Research and Resource Management in National Parks and Equivalent Reserves. p. 31 (abstr.)

Lillie, R.A., and J.W. Mason. 1983. Limnological characteristics of Wisconsin lakes. WI Dept. Natur. Res. Tech. Bull. No. 138. 116pp.

Limnetics, Inc. 1970. A preliminary survey of the environmental quality of the Pictured Rocks National Lakeshore and Recreational Area, Alger County, Michigan. Prepared for the National Park Service. On file at Pictured Rocks National Lakeshore, Munising, MI.

Lockwood, R. 2000. Sportfishing angler surveys on Michigan inland waters, 1993-99. Michigan Department of Natural Resources. Lansing, MI. (http://www.michigandnr.com/PUBLICATIONS/PDFS/ifr/ifrlibra/technical/reports/2000-3tr/2000-3tr.pdf). Accessed December 2005.

Lodge, D.M., and J.G. Lorman. 1987. Reductions in submerged macrophyte biomass and species richness by the crayfish *Orconectes rusticus*. Can. J. Fish. Aquat. Sci. 44:591-597.

Loope, W. L., and M.P. Holman. 1991. An assessment of stream bed and stream bank characteristics within Pictured Rocks National Lakeshore. Pictured Rocks Resource Report PIR091-1. Munising, MI. (http://data2.itc.nps.gov/nature/documents/rrStreambank%2Epdf). Accessed September 2005.

Loope, W.L. 1993. Evidence of physical and biological change within the Beaver Lake watershed attributable to a turn-of-the-century logging dam. Pictured Rocks Resource Report PIRO 93-2. Munising, MI. (http://data2.itc.nps.gov/nature/documents/rrLogDam%2Epdf). Accessed September 2005.

Loope, L. 1995. Observations of algae and zooplankton from lakes in Pictured Rocks National Lakeshore. Unpublished data, Pictured Rocks National Lakeshore.

Loope, L. 1998a. A review of the limnology of six small lakes in Pictured Rocks National Lakeshore. Pictured Rocks National Lakeshore, Munising, MI.

Loope, W.L., J.B. Anderton, T.G. Fisher, H.M. Joll, and W.L. Blewett. 2001. Landscape-level impacts of late Holocene lake level change along the southeastern shore of Lake Superior. Annual meeting of the North Central Section, Geological Society of America, Abstracts and Program 33(4):A11.

Loope, L. 2004. Aquatic monitoring plan for Pictured Rocks National Lakeshore. Pictured Rocks National Lakeshore, Munising, MI.

Luce-Mackinac-Alger-Schoolcraft District Health Department (LMASDHD). 1998. Superior Environmental Health Code. (http://www.lmasdhd.org/LMASSuperiorCode.pdf). Accessed September 2005.

Ludwig Jr., H., and J. Leitch. 1996. Interbasin transfer of aquatic biota via anglers' bait buckets. Fisheries 21 (7): 14-18.

Mahler, B., P. Van Metre, T. Bashara, J. Wilson, and D. Johns. 2005. Parking lot sealcoat: an unrecognized source of polycyclic aromatic hydrocarbons. Environmental Science and Technology 39 (15): 5560-5566.

Maniero, T., and D. Pohlman. 2003. Air quality monitoring considerations for the

Great Lakes Network Parks. National Park Service, Air Resources Division, for the Great Lakes Inventory and Monitoring Network. Great Lakes Network Technical Report GLKN/2003/06. (http://www1.nature.nps.gov/im/units/glkn/Great%20Lakes%20Air%20Quality%20Monitoring%20Considerations.pdf). Accessed February 2006.

Matheson, D.H., and M. Munawar. 1978. Lake Superior basin and its development. J. Great Lakes Res. 4(3-4): 249-263

McCafferty, W.P. 1981. Aquatic entomology. Jones and Bartett Publ., Inc. Boston, MA. 448pp.

McCarthy, J.J., O.F. Canziani, N.A. Leary, D.J. Dokken, and K.S. White (ed). 2001. Climate Change 2001: impacts, adaptation and vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Press Syndicate of the University of Cambridge. Cambridge, U.K. (http://www.ipcc-wg2.org/index.html). Accessed August 2005.

Michigan Center for Geographic Information. 2005. Michigan Geographic Framework: ver 4b. State of Michigan. Lansing, MI. (http://www.mcgi.state.mi.us/mgdl/). Accessed November 2005.

Michigan Department of Community Health (MDCH) Environmental and Occupational Epidemiology Division. 2004. Michigan 2004 family fish consumption guide. Michigan Department of Community Health. (http://www.michigan.gov/documents/FishAdvisory03_67354_7.pdf). Accessed October 2005.

Michigan Department of Environmental Quality (MIDEQ) Geologic Survey Division. 1987. Template - Bedrock Geology. MIDEQ. Lansing, MI. (http://www.dnr.state.mi.us/spatialdatalibrary/sdl/geology/bedrock/1987_bedrock_geology.exe). Accessed November 2005.

Michigan Department of Environmental Quality (MIDEQ). 1998. Watershed Boundary Data. Lansing, MI. (http://www.mcgi.state.mi.us/mgdl/). Accessed November 2005.

Michigan Department of Environmental Quality (MIDEQ). Surface Water Quality Division. 1999. Administrative rules Part 4: Water quality standards. (http://www.epa.gov/ost/standards/wqslibrary/mi/mi_5_wqs.pdf). Accessed October 2005.

Michigan Department of Environmental Quality (MIDEQ). Surface Water Quality Division. 2000a. Staff Report: A biological survey of selected coastal Lake Superior tributaries in Chippewa, Luce and eastern Alger counties, June 1999. MI/DEQ/SWQ-00/0004. Lansing, MI

Michigan Department of Environmental Quality (MIDEQ). Office of the Great Lakes. 2000b. Great Lakes trends: into the new millenium. Lansing, MI. (http://www.deq.state.mi.us/documents/deq-ogl-gltrends.pdf). Accessed December 2005.

Michigan Department of Environmental Quality (MIDEQ), Surface Water Quality Division. 2001a. National Pollutant Discharge Elimination System permit MI0020044, City of Munising Wastewater Treatment Plant. Marquette, MI.

Michigan Department of Environmental Quality (MIDEQ), Surface Water Quality Division. 2001b. National Pollutant Discharge Elimination System permit MID000892, Kimberly-Clark Corporation Wastewater Treatment Plant. Marquette, MI.

Michigan Department of Environmental Quality (MIDEQ), Drinking Water and Radiological Protection Division, Environmental Health Section. 2001c. The status of the on-site wastewater industry in Michigan Year 2001: A synopsis of the regulation of on-site wastewater treatment and disposal in Michigan. (http://www.deq.state.mi.us/documents/deq-swq-onsitewastewater.doc). Accessed September 2005.

Michigan Department of Environmental Quality (MIDEQ). 2002a. Michigan turfgrass environmental stewardship program. (http://www.michigan.gov/printerFriendly/0,1687,%207-135-3585_4129_4191-11044--,00.html). Accessed September 2005.

Michigan Department of Environmental

Quality (MIDEQ). 2002b. Director's order. Designated trout streams for the state of Michigan. FO-210.03. Lansing, MI.

Michigan Department of Environmental Quality, (MIDEQ), Office of the Great Lakes. 2002c. Michigan's aquatic nuisance species state management plan update: prevention and control in Michigan waters. Lansing, MI. (http://www.deq.state.mi.us/documents/deq-ogl-ANSPlan2002.pdf). Accessed December 2005.

Michigan Department of Environmental Quality (MIDEQ). 2004a. Water withdrawals for self-supplied industrial manufacturing in Michigan 2004. Lansing, MI. (http://www.deq.state.mi.us/documents/deq-wd-wurp-Industrial04.pdf). Accessed October 2005.

Michigan Department of Environmental Quality (MIDEQ). Water Division. 2004b. Water quality and pollution control in Michigan: 2004 sections 303(d) and 305(b) integrated report. MI/DEQ/WD-04/029. (http://www.michigan.gov/deq/1,1607,7-135-3313_3686_3728-12711--,00.html). Accessed October 2005.

Michigan Department of Environmental Quality (MIDEQ). Water Bureau. 2004c. 2003 annual report on Michigan public water systems violations. (http://www.michigan.gov/deq/0,1607,7-135-3313_3675_3691-96721--,00.html). Accessed November 2005.

Michigan Department of Environmental Quality (MIDEQ). Water Bureau. 2005a. Staff report: Michigan beach monitoring year 2003 annual report. MI/DEQ/WD-04/062. (http://www.deq.state.mi.us/documents/deq-wb-beach-2003annualreport.pdf). Accessed October 2005.

Michigan Department of Environmental Quality (MIDEQ). Water Bureau. 2005b. Staff Report: A biological survey of the Chocolay, Au Train and selected tributaries to Lake Superior located in Marquette and Alger counties, June 11-17, 2000. MI/DEQ/WB-05/051. Lansing, MI.

Michigan Department of Environmental Quality (MIDEQ). 2005c. Michigan Safe Drinking Water Act, Act 399, PA 1976, as amended, and the administrative rules. EQC2050. (http://www.deq.state.mi.us/documents/deq-wd-water-fos-tsu-Act399.pdf). Accessed November 2005.

Michigan Department of Environmental Quality (MIDEQ). Water Bureau. 2005d. 2004 annual report on Michigan public water systems violations. (http://www.michigan.gov/deq/0,1607,7-135-3313_3675_3691-62960--,00.html). Accessed November 2005.

Michigan Department of Environmental Quality (MIDEQ). Water Bureau. 2005e. Water quality maps for Michigan by county (online). (http://www.michigan.gov/deq/0,1607,7-135-3313_3675_3690-76500--,00.html). Accessed December 2005.

Michigan Department of Environmental Quality (MIDEQ). 2005f. Public Act 148: Groundwater Inventory and Map Project. Lansing, MI. (http://gwmap.rsgis.msu.edu/). Accessed December 2005.

Michigan Department of Environmental Quality (MIDEQ). 2005g. Wellogic -Statewide Wells. Lansing, MI. (http://gwmap.rsgis.msu.edu/). Accessed October 2005.

Michigan Department of Natural Resources (MIDNR). 1981. Pictured Rocks National Lakeshore Draft Fisheries Management Plan. Michigan Department of Natural Resources Report to National Park Service, Pictured Rocks National Lakeshore.

Michigan Department of Natural Resources (MIDNR) Watershed Council. 2000. Geographic Information Systems database. Lansing, MI.

Michigan Department of Natural Resources (MIDNR) Forest, Mineral and Fire Management Division, Resource Mapping and Aerial Photography. 2001. Michigan (Upper Peninsula) GAP land stewardship coverage, version 1.0. Lansing, MI. (http://www.mcgi.state.mi.us/mgdl/). Accessed November 2005.

Michigan Department of Natural Resources (MIDNR) Forest, Mineral, and Fire Management Division. 2003. IFMAP/GAP Upper Peninsula land cover. (http://

www.mcgi.state.mi.us/mgdl/). Accessed November 2005.

Michigan Department of Natural Resources (MIDNR). 2004. Munising – Bayshore Marina (online). (http://www.michigan.gov/printerFriendly/0,1687,7-153-10365_10884_18317-44333--,00.html). Accessed April 2006.

Michigan Department of Natural Resources (MIDNR). Forest, Mineral and Fire Management Division. 2005a. DNR ownership and project boundaries. (http://www.michigan.gov/cgi/0,1607,7-158-12540_13817_13818-31021--.00.html). Accessed October 27, 2005.

Michigan Department of Natural Resources (MIDNR). 2005b. Great Lakes charter and creel charter tables (online). (http://www.michigandnr.com/PUBLICATIONS/PDFS/fishing/Charter/Site190_Marquette_03CharterHarv_3-23-04_ST.pdf). Accessed December 2005.

Michigan Natural Features Inventory and Michigan Department of Natural Resources (MNFI and MIDNR). 1998. Template - Quaternary Geology, edition 2.0. Lansing, MI. (http://www.mcgi.state.mi.us/mgdl/). Accessed June 2006.

Michigan State Climatologists Office. n.d.. Climate of Munising. Michigan State University, East Lansing, MI. (http://climate.geo.msu.edu/stations/5690/). Accessed September 2005.

Minnesota Pollution Control Agency and Metropolitan Council (MPCA). 2002. Ground water quality beneath Twin Cities metropolitan communities served by individual sewage treatment systems. (http://www.pca.state.mn.us/water/groundwater/gwmap/rpt-metroists-02.pdf). Accessed September 2005.

Minnesota Sea Grant. 2006a. Zebra mussels threaten inland waters: an overview. Duluth, MN. (http://www.seagrant.umn.edu/exotics/zmoverview.html). Accessed August 1, 2006.

Minnesota Sea Grant. 2006b. A field guide to aquatic exotic plants and animals. Duluth, MN. (http://www.seagrant.umn.edu/exotics/fieldguide.html). Accessed August 1, 2006.

Momot, W.T. 1992. Further range extensions of the crayfish *Orconectes rusticus* in the Lake Superior basin of northwestern Ontario. Can. Field-Nat. 106(3):397-399.

Mullen, G. 1988. An evaluation of standard timber harvest practices on stream dynamics in the Pictured Rocks National Lakeshore Inland Buffer Zone. Thesis. Michigan Technological University. Houghton, MI. as cited in Boyle, T.P., R. G. Waltermire and G. W. Gustina. 1999. Risk analysis of the aquatic resources in Pictured Rocks National Lakeshore: an ecologically based inventory and estimation of the effects of land use practices. Midcontinent Ecological Science Center, Biological Resources Division, United States Geological Survey. Fort Collins, CO.

Munawar, M. and I.F. Munawar. 1978. Phytoplankton of Lake Superior 1973. J. Great Lakes. Res., 4(3-4): 415–442.

National Atmospheric Deposition Program (NADP). 2006. Hydrogen ion concentration as pH from measurements made at the field laboratories, 2004 (map). NADP Program Office, Illinois State Water Survey, Champaign, IL. (http://nadp.sws.uiuc.edu/isopleths/maps2004/phfield.pdf). Accessed August 21, 2006.

National Center for Manufacturing Sciences, Environmentally Conscious Manufacturing Strategic Initiative Group. 2004. Wood products: impacts, risks and regulations. (http://ecm.ncms.org/ERI/new/IRRwood.htm). Accessed August 2005.

National Climatic Data Center (NCDC). 2005. NCDC TD 9641 Clim 81 1961-1990 Normals, 1961-1990. National Oceanic and Atmospheric Administration, U.S. Department of Commerce. Cited at World Climate (online) (http://www.worldclimate.com/). Accessed August 1, 2006.

National Oceanic and Atmospheric Administration (NOAA). Office of Coast Survey. 2004a. 14962 Lake Superior St. Mary's River to Au Sable (electronic navigation chart). (http://chartmaker.ncd.noaa.gov/). Accessed August 2005.

National Oceanic and Atmospheric Administration (NOAA). Office of Coast

Survey. 2004b. 14963 Grand Marais to Big Bay Point (electronic navigation chart). (http://chartmaker.ncd.noaa.gov/). Accessed August 2005.

National Oceanic and Atmospheric Administration (NOAA). Office of Coast Survey. 2004c. 14969 Munising Harbor and approaches including Grand Island (electronic navigation chart). (http://chartmaker.ncd.noaa.gov/). Accessed August 2005.

National Oceanic and Atmospheric Administration (NOAA). Office of Coast Survey. 2005. 14961 Lake Superior (electronic navigation chart). (http://chartmaker.ncd.noaa.gov/). Accessed August 2005.

National Oceanic and Atmospheric Administration (NOAA), National Ocean Service. 2006. United States Coast Pilot 6: Great Lakes: Lakes Ontario, Erie, Huron, Michigan, and Superior and St. Lawrence River (36th edition). Washington, D.C. (http://nauticalcharts.noaa.gov/nsd/coastpilot6.htm). Accessed April 2006

National Park Service (NPS). 1995. Baseline water quality data inventory and analysis: Pictured Rocks National Lakeshore. Water Resources Division. Fort Collins, CO. Technical Report NPS/NRWRD/NRTR-95/57. (http://nrdata.nps.gov/PIRO/nrdata/water/baseline_wq/docs/PIROWQAA.pdf). Accessed October 2005.

National Park Service (NPS). 1996. Pictured Rocks National Lakeshore, Michigan. (park map/brochure). Munising, MI.

National Park Service (NPS). 2002. Pictured Rocks National Lakeshore personal watercraft use environmental assessment. Pictured Rocks National Lakeshore, Munising, MI. (http://www.nps.gov/piro/pwc/PIRO_EA_9_July_02_maps.pdf). Accessed September 2005.

National Park Service (NPS). 2003. Pictured Rocks National Lakeshore resource management plan 2003 (draft). Pictured Rocks National Lakeshore, Munising, MI.

National Park Service (NPS). 2004a. Pictured Rocks: A brief Lakeshore history. Pictured Rocks National Lakeshore, Munising, MI. (http://www.nps.gov/piro/LakeshoreHistory.pdf). Accessed September 2005.

National Park Service (NPS). 2004b. Final general management plan wilderness study environmental impact statement, Pictured Rocks National Lakeshore. Munising, MI. (http://www.nps.gov/piro/gmp/gmp.htm). Accessed May 2006.

National Park Service (NPS). 2005a. Final Vegetative Cover (digital data). Pictured Rocks National Lakeshore. Munising, MI.

National Park Service (NPS). 2005b. A brief account of the geology and geomorphology of Pictured Rocks National Lakeshore (online). (http://www2.nature.nps.gov/geology/parks/piro/index.cfm). Accessed February 2006.

National Park Service (NPS). 2005c. Environmental assessment, Pictured Rocks National Lakeshore, wildland fire management plan. Pictured Rocks National Lakeshore, MI. (http://data2.itc.nps.gov/parks/piro/ppdocuments/PRNL%20Fire%20Mgt%20Plan%20Environmental%20Assessment.pdf). Accessed September 2005.

National Park Service (NPS). 2005d. Pictured Rocks National Lakeshore facts (online). (http://www.nps.gov/piro/pphtml/facts.html). Accessed July 2005.

National Park Service (NPS). 2005e. Climate change: What does the future hold for Great Lakes National Parks? Pictured Rocks National Lakeshore. Munising, MI.

National Park Service (NPS). 2005f. Roads and Hydrologic Features (digital data). Pictured Rocks National Lakeshore. Munising, MI.

National Park Service (NPS). 2005g. Park Zones (digital data). Pictured Rocks National Lakeshore. Munising, MI.

National Park Service (NPS). 2005h. Digital Elevation Model (DEM). Pictured Rocks National Lakeshore. Munising, MI.

National Park Service (NPS). 2006. Land ownership in the IBZ (digital data). Pictured Rocks National Lakeshore. Munising, MI.

National Sea Grant Law Center. 2005. "Michigan passes ballast water laws." (http://www.olemiss.edu/orgs/SGLC/ballastfact(1).pdf). Accessed February 2006.

National Small Flows Clearinghouse (NSFC). 2001. Septic system information. Morgantown, WV. (http://www.nesc.wvu.edu/nsfc/nsfc_septicnews.htm). Accessed September 2005.

Newman, L. 2003. Inventory of nearshore fish and mud puppy (amphibian) in Lake Superior, Pictured Rocks National Lakeshore. U.S. Fish and Wildlife Service, Ashland, WI.

Newman. L.E. 2005. Fish species inventory of inland waters of Pictured Rocks National Lakeshore, Mich. National Park Service, Great Lakes Inventory and Monitoring Network, Ashland, WI. 54806. Great Lakes Network Technical Report: GLKN/2005/04 13 pp. (http://www1.nature.nps.gov/im/units/glkn/Pictured%20Rocks%20Inland%20Fish.pdf). Accessed November 18, 2006.

Nichols, S.J. 1993. Appendix A: Life history and ecological requirements of the Zebra Mussel – North American Experience through 1992. *In*: Reid, D. F. *et al*. Zebra-Mussel-Specific Containment Protocols. NOAA Great Lakes Environmental Research Laboratory Contribution No. 890. p. 24-27.

Nichols, S., E. Crawford, J. Amberg, G. Kennedy, G. Black, and J. Allen. 2001. Status of freshwater unionid populations at Pictured Rocks National Lakeshore, 1999-2000. Final report to National Park Service, Pictured Rocks National Lakeshore, U.S. Geological Survey, Great Lakes Science Center, Ann Arbor, MI.

Nuhfer, A. 1988. Chapel Lake gill net survey, August 9-10, 1988. Michigan Department of Natural Resources Report.

Ocean Conservancy. 2001. Good Mate recreational boating and marina manual. The Ocean Conservancy, Washington, D.C.

Ocean Conservancy. 2006. Federal court orders U.S. EPA to regulate ships dumping ballast water. Online. (http://www.oceanconservancy.org/site/News2?abbr=press_&page=NewsArticle&id=8797). Accessed November 2, 2006.

Pepin, J. 2005. Ban lifted in parts of Pictured Rocks; Jet Skis OK. The Mining Journal, October 29, 2005.

Pictured Rocks Cruises, Inc. 2004. Official home of Pictured Rocks Cruises (online). (http://www.picturedrocks.com/). Accessed October 2005.

Pictured Rocks National Lakeshore and Michigan Department of Natural Resources (PIRO and MIDNR). 1995. Fisheries management plan for Pictured Rocks National Lakeshore. Pictured Rocks National Lakeshore, Munising, MI

Pigg, R. 2001. Domestic supply well baseline study report. Michigan Department of Agriculture Groundwater Monitoring Program, Lansing, MI. (http://www.michigan.gov/documents/MDA_FullBaselineStudyReport_98224_7.pdf). Accessed November 2005.

Rayburn, T., A. Whelan, M. Jaster and R. Wingrove. 2004. Net environmental benefit analysis for Isle Royale National Park. Final Report. Proceedings from the Workshop held January 6-8, 2004 in Duluth, Minnesota. Great Lakes Commission, Ann Arbor, MI. (http://www.glc.org/irps/irps/docs/NEBA-final.pdf). Accessed September 2005.

Reaser, J. K. 2000. Amphibian declines: an issue overview. Federal Taskforce on Amphibian Declines and Deformities, Washington, D.C. 32pp.

Remaley, T. 2005. Fact sheet: Eurasian watermilfoil (online). (http://www.nps.gov/plants/alien/fact/pdf/mysp1.pdf). Accessed August 7, 2006.

Reeves, M. E. 1996. Techniques for the protection of the Great Lakes from infection by exotic organisms in ballast water, Ninth Coast Guard District. Article reprinted from "Zebra Mussels and Other Aquatic Nuisance Species." Frank D'itri [ED.]. 1996. Ann Arbor Press.

Rose, R. 1997. Overview of Cambrian sandstone environments of deposition. National Park Service, Pictured Rocks

National Lakeshore Resource Report #9. (http://data2.itc.nps.gov/nature/documents/rrBedrock%2Epdf). Accessed September 2005.

Route, B., and J. Elias. 2004. Phase II Report: Progress toward designing a long-term ecological monitoring program. Great Lakes Inventory and Monitoring Network, National Park Service, Ashland, WI.

Route, B. and J. Elias (editors). 2006. Phase III Report: Long-term Ecological Monitoring Plan for the Great Lakes Network. U.S. National Park Service, Great Lakes Inventory and Monitoring Network. Technical Report GLKN/2006/02. (http://www1.nature.nps.gov/im/units/glkn/index.htm). Accessed November 2, 2006.

Schwenner, C. 2003. Soil Survey of Alger County, Michigan, Interim Report - May 2003. Vol. 1-3. Natural Resources Conservation Service. Marquette, MI.

Shaw, B., C. Mechenich, and L. Klessig. 1996. Understanding lake data. University of Wisconsin-Extension, Madison, WI. Publication G3582. (http://dnr.wi.gov/org/water/fhp/lakes/under/). Accessed December 2005.

Sheffy, T. 1984. Interpreting acid rain research findings in Wisconsin: what does it all mean? Wisconsin Natural Resource 8:6, pp 29-32.

Sherfy, M. and J. Thompson. 2001. Potential risk of aquatic invasive species introductions due to international trade in live bait. In North American Commission for Environmental Cooperation, Preventing the introduction and spread of aquatic invasive species in North America, workshop proceedings, 28-30 March 2001, p 12-14. Montreal, Quebec. (http://www.cec.org/files/pdf/BIODIVERSITY/aquatic-invasives_en.pdf). Accessed December 2005.

Skoglund, B. 2004. Golf swings "fore" the environment. Minnesota Environment, Winter, 2004. (http://www.pca.state.mn.us/publications/mnenvironment/impaired-waters-edition/golf.html). Accessed February 2006.

Smith, B.R., J J. Tibbles, and B.G.H. Johnson. 1974. Control of the Sea Lamprey (*Petromyzon marinus*) in Lake Superior, 1953-1970. Technical Report No. 26. Great Lakes Fishery Commission. Ann Arbor, MI.

Snyder, F.L., M.B. Hilgendorf, and D.W. Garton. 1997. Zebra mussels in North America. OHSU-FS-045. Ohio Sea Grant College Program. 4pp.

Spillman, B. 2006. "Developers covet areas surrounding national parks." USA Today, March 21, 2006.

Sreenivasan, A. and J. Leonard. 2003. Comparison of growth parameters between migrant and resident strains of brook trout. Progress Report for Pictured Rocks National Lakeshore, Northern Michigan University, Marquette, MI.

Stackpoole, S. 1997. Purple loosestrife in Michigan. Bulletin E-2632, Michigan Sea Grant. MICHU-SG-97-501. 6pp.

State of Michigan, State Office of Administrative Hearings and Rules. 1979. Michigan Administrative Code Supplement 7, R 299.6002 Eff. June 26, 1981. (http://www.state.mi.us/orr/emi/admincode.asp?AdminCode=Single&Admin_Num=29906001&Dpt=EQ&RngHigh=). Accessed November 2005.

Steuer, J., W. Selbig, N. Hornewer, and J. Prey. 1997. Sources of contamination in an urban basin in Marquette, Michigan and an analysis of concentrations, loads, and data quality. United States Geological Survey Water-Resources Investigations Report 97-4242. (http://pubs.er.usgs.gov/pubs/wri/wri974242). Accessed February 2006.

Stockel, J. A. and P. M. Charlebois. 2001. *Daphnia lumholtzi*: The next Great Lakes exotic? Illinois-Indiana Sea Grant College Program, Illinois Natural History Survey, Dept. of Nat. Res. and Env. Sci. UIUC. (http://www.misegrant.org/pubs/online/msg99-500.html)

Stottlemyer, R. 1982a. The neutralization of acid precipitation in watershed ecosystems of the Upper Peninsula of Michigan. Pages 261-274 *in* F. D'Itri, editor. Acid precipitation: effects on ecological systems. Ann Arbor Science Publishers, Ann Arbor, MI.

Stottlemyer, R. 1982b. Variation in ecosystem sensitivity and response to anthropogenic atmospheric inputs, Upper Great Lakes Region. International Symposium on Hydrometeorology, American Water Resources Association June:79-83.

Stottlemyer, R. 1989. Effects of atmospheric acid deposition on watershed/lake ecosystems of Isle Royale and Michigan's Upper Peninsula. NAPAP Progress Report through 1989, Great Lakes Area Studies Unit Report #41, National Park Service and Great Lakes Area Resource Studies Unit, Houghton, MI

Stottlemyer, R. and D. Rutkowski. 1990. Multi-year trends in snowpack ion accumulation and loss, Northern Michigan. Water Resources Research 26(4):721-737.

Thayer, S. 2005. Charter boat fishing effort and harvest from the Michigan waters of the Great Lakes, 2004. Michigan Department of Natural Resources, Fisheries Division. Charlevoix, MI. (http://www.michigan.gov/documents/2004report_125898_7.pdf). Accessed December 2005.

Trout Unlimited. 2005. Background and History – The Coaster Brook Trout (online). (http://www.tu.org/site/pp.asp?c=7dJEKTNuFmG&b=295201). Accessed February 2006.

U.S. Census Bureau. 2005. United States Census 2000. (http://www.census.gov/main/www/cen2000.html). Accessed September 2005.

United States Department of Agriculture (USDA), National Agricultural Statistics Service. 2002. 2002 Census of Agriculture. (http://www.nass.usda.gov/census/). Accessed September 2005.

United States Department of Agriculture (USDA) Forest Service. 2004. Hiawatha National Forest ownership. (http://www.fs.fed.us/r9/forests/hiawatha/maps/gis/). Accessed November 2006.

United States Department of Agriculture, Natural Resources Conservation Service (USDA NRCS). 1994. State soil geographic (STATSGO) data base for Michigan. Fort Worth, TX. (http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/). Accessed June 2006.

United States Department of Agriculture, Natural Resources Conservation Service (USDA NRCS). 2006. PLANTS Profile for *Myriophyllum spicatum* L. Eurasian watermilfoil (online). (http://plants.usda.gov/java/profile?symbol=MYSP2). Accessed August 7, 2006.

United States Environmental Protection Agency (USEPA) and Government of Canada. 1995. The Great Lakes: An Environmental Atlas and Resource Book. USEPA Great Lakes National Program Office, Chicago, IL. (http://www.epa.gov/glnpo/atlas/index.html). Accessed September 2005.

United States Environmental Protection Agency (USEPA). 2000. Ambient water quality criteria recommendations: Information supporting the development of state and tribal nutrient criteria for lakes and reservoirs in nutrient ecoregion VIII. EPA 822-B-00-010. (http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/lakes/lakes_8.pdf). Accessed December 2005.

United States Environmental Protection Agency (USEPA). 2001a. Deer Lake Area of Concern (online). (http://www.epa.gov/glnpo/aoc/drlake.html). Accessed September 2005.

United States Environmental Protection Agency (USEPA). 2001b. Ambient water quality criteria recommendations: Information supporting the development of state and tribal nutrient criteria for rivers and streams in nutrient ecoregion VIII. EPA 822-B-01-015. (http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/rivers_8.pdf). Accessed December 18, 2006.

United States Environmental Protection Agency (USEPA). 2003. Response of surface water chemistry to the Clean Air Act amendments of 1990. EPA 620/R-03/001. Research Triangle Park, NC. (http://www.epa.gov/ord/htm/CAAA-2002-report-2col-rev-4.pdf). Accessed December 2005.

United States Environmental Protection Agency (USEPA). 2005a. Envirofacts Data

Warehouse. (online) (http://www.epa.gov/enviro/). Accessed September 2005.

United States Environmental Protection Agency (USEPA). 2005b. Envirofacts - Safe Drinking Water Information System (online). (http://oaspub.epa.gov/enviro/ef_home2.water). Accessed October 2005.

United States Environmental Protection Agency (USEPA). 2005c. Vessel sewage discharge program. (online) (http://www.epa.gov/owow/oceans/regulatory/vessel_sewage/). Accessed September 2005.

United States Environmental Protection Agency (USEPA). 2005d. BEACON: Beach advisory and closing on-line notification: Alger County beaches with beach data (online). (http://oaspub.epa.gov/beacon/beacon_county_page.main?p_county_fips=003&p_state_fips=26). Accessed December 2005.

United States Environmental Protection Agency (USEPA). 2005e. Invasive species (online). (http://www.epa.gov/owow/invasive_species/). Accessed December 2005.

United States Environmental Protection Agency (USEPA). 2006. National emission inventory (NEI) database for criteria and hazardous air pollutants (online). (http://www.epa.gov/air/data/neidb.html). Accessed November 18, 2006.

United States Environmental Protection Agency Region 5 (USEPA Region 5). 2000. Inland sensitivity atlas: Upper Peninsula of Michigan mapping area. USEPA Region 5, Chicago, IL.

United States Fish and Wildlife Service (USFWS) National Wetlands Inventory. 1994. National wetlands inventory data. St. Petersburg, FL.

United States General Accounting Office (USGAO). 2000. Marine pollution: Progress made to reduce marine pollution by cruise ships, but important issues remain. GAO/RCED-00-48. (http://www.gao.gov/new.items/rc00048.pdf). Accessed September 2005.

United States Geological Survey (USGS). Great Lakes Science Center. 2000. Round goby: an exotic fish in the Great. Ann Arbor, MI. (http://www.glsc.usgs.gov/_files/factsheets/2000-1%20Round%20Goby.pdf). Accessed August 2, 2006.

United States Geological Survey (USGS). Great Lakes Science Center. 2004. Eurasian ruffe (online). (http://www.glsc.usgs.gov/main.php?content=research_invasive_ruffe&title=Invasive%20Fisho&menu=research_invasive_fish). Accessed August 2, 2006.

United States Geological Survey (USGS). 2005. Water science for schools. Water Q and A: water use at home (online). (http://ga.water.usgs.gov/edu/qahome.html). Accessed October 2005.

Vanlier, K.E. 1963. Reconnaissance of the ground-water resources of Alger County, Michigan. Water Investigation 1. State of Michigan Department of Conservation Geological Survey Division and Geological Survey, U.S. Department of the Interior. Lansing, MI. (http://www.deq.state.mi.us/documents/deq-ogs-gimdl-WI01.PDF). Accessed September 2005.

Vogel, J. 2000. History of fish and fisheries in the Pictured Rocks National Lakeshore. Pictured Rocks Resource Report PIRO-2000-1. Munising, MI. (http://www.nps.gov/applications/nature/documents/rrFish%2Epdf). Accessed December 2005.

Ward, J.L. and J.R. Hodgson. 1997. The presence of the Asian clam *Corbicula sp*., from Lake Superior. J. Freshwater Ecol. 12(1):167-169.

Watson, N.H.F., and J.B. Wilson. 1978. Crustacean zooplankton of Lake Superior. J. Great Lakes Res. 4(3-4): 481-496

Weeks, D.P. and R.J. Andrascik. 1998. Voyageurs National Park, Minnesota, Water Resources Scoping Report. Technical Report NPS/NRWRS/NRTR-98/201. Water Resources Division, National Park Service, Department of the Interior. Denver, CO.

White, D. S., M. H. Winnell, and D. J. Jude. 1984. Discovery of the Asiatic clam, *Corbicula fluminea*, in Lake Michigan. J. Great Lakes Res. 10:329-331.

Whitman, R.L., M.B. Nevers, L.L. Last, T.G. Horvath, M.L. Goodrich, S.M. Mahoney, and J.A. Nefczyk. 2002. Status and trends of selected inland lakes of the Great Lakes cluster National Parks. USGS, Great Lakes Science Center, Ann Arbor, MI. (http://www.glsc.usgs.gov/_files/reports/InlandLakesReport.pdf). Accessed August 21, 2006.

Wiese, F. 2002. Seabirds and Atlantic Canada's ship-source oil pollution: impacts, trends and solutions. World Wildlife Fund Canada, Toronto, Canada. (http://wwf.ca/AboutWWF/WhatWeDo/ConservationPrograms/RESOURCES/PDF/SeabirdsReport.pdf). Accessed September 2005.

Wikipedia contributors. 2005. SS Edmund Fitzgerald. Wikipedia, the Free Encyclopedia. (http://en.wikipedia.org/wiki/Edmund_Fitzgerald). Accessed September 2005.

Williams, D.D. 1996. Environmental constraints in temporary fresh waters and their consequences for the insect fauna. Journal of the North American Benthological Society 15(4):634-650.

Wisconsin Sea Grant. 2002. White perch (online). (http://www.seagrant.wisc.edu/greatlakesfish/fwhiteperch1.html). Accessed August 2, 2006.

Wood, V. (webmaster). 2001. Shipwreck dive tours. (online) (http://www.exploringthenorth.com/scuba/diving.html). Accessed September 2005.

Wood, V. (webmaster). 2004. Scuba dive or snorkel the shipwrecks of Lake Superior in the Alger Underwater Preserve. (online) (http://www.exploringthenorth.com/shiptour/dive.html). Accessed September 2005.

World Wildlife Fund Canada. 1997. Terrestrial and aquatic protected areas representation analysis: Lake Superior basin. Draft report. 26 pp. Cited in Lake Superior Binational Program. 2000. Lake Superior Lakewide Management Plan (LaMP) 2000. (http://www.epa.gov/glnpo/lakesuperior/lamp2000/LS%20chapter%206a.pdf). Accessed December 2005.

Zhuikov, M. 1997. Fish with a bad haircut. May 1997 "Seiche" newsletter, Minnesota Sea Grant (online). (http://www.seagrant.umn.edu/exotics/stickleback.html). Accessed August 7, 2006.

**Personal Communications**

Persons who provided personal communications used in the preparation of this report.

Beek, Mike. Manager, Burt Township Department of Public Works, Grand Marais, MI. (906) 494-2411.

Bovin, Doug. Munising City Manager, Munising, MI. (906) 387-2095 dbovin@cityofmunising.org

Dell, Daniel. Michigan Department of Environmental Quality. (517) 335-4130. delld@michigan.gov.

Elias, Joan. Aquatic Ecologist, NPS Great Lakes Inventory and Monitoring Network. (715)682-0631, ext. 24. Joan_Elias@nps.gov

Fitzner, Craig. Air Toxics Supervisor, Michigan Department of Environmental Quality, Lansing, MI. (517) 373-7044. fitzner@michigan.gov

French, Peggy. Director Environmental Health, Luce-Mackinac-Alger-Schoolcraft District Health Department, Manistique, MI. pfrench@lmasdhd.org

Hach, Larry. Chief Ranger, Pictured Rocks National Lakeshore, Munising, MI. (906) 387-2607. larry_hach@nps.gov

Kinnunen, Ron. Sea Grant-Michigan State Extension, Marquette, MI. (906) 226-3687. kinnune1@msu.edu

LaFrancois, Brenda Moraska. Aquatic Ecologist, NPS Midwest Regional Office. (651) 433-5953. brenda_moraska_lafrancois@nps.gov.

Leutscher, Bruce. Biologist, Pictured Rocks National Lakeshore, Munising, MI. (906) 387-2680 Bruce_Leutscher@nps.gov

Loope, Lora. Aquatic Ecologist, Pictured Rocks National Lakeshore, Munising, MI. (906) 387-2650. lora_loope@nps.gov

Moseley, Tom. Sanitarian, Luce-Mackinac-Alger-Schoolcraft District Health Department, Alger County office. (906) 387-2297. tmoseley@lmasdhd.org

Niemi, Mike. Public Works Director, Munising Water and Sewer Department, Munising, MI. (906) 387-2246.

Northup, Jim. Superintendent, Pictured Rocks National Lakeshore, Munising, MI. (906) 387-2607. Jim_Northup@nps.gov

Ochman, John. Maintenance Supervisor, Pictured Rocks National Lakeshore, Munising, MI. (906) 387-3110. John_Ochman@nps.gov

Ring, Margie. Michigan Department of Environmental Quality, Waste and Hazardous Materials Division, Gwinn, MI. (906) 346-8523. RINGM@michigan.gov

Ringuette, Lindsey. Environmental Quality Analyst, Michigan Department of Environmental Quality, Water Bureau, Gwinn, MI. (906) 346-8518. ringuetl@michigan.gov

Schultz, Greg. U.S. Coast Guard. Gschultz@msoduluth.uscg.mil. Also available at http://www.glc.org/irps/irps/docs/jan17meeting.pdf.

Shauver, John. Munising Township Zoning Administrator. (906) 892-8257.

Smith, Carl. District Geologist, Waste and Hazardous Materials Division, Michigan Department of Environmental Quality, Gwinn, MI. (906) 346-4480. smithcl@michigan.gov

Spencer, Jeff. Michigan Clean Marina Program, Michigan Department of Environmental Quality, Lansing, MI. (517) 241-5719. SPENCEJL@michigan.gov

Taft, William. Aquatic Biologist, Water Bureau, Michigan Department of Environmental Quality. (517) 335-4205. taftw@michigan.gov

# Appendices

**Appendix A. Sources of data for base map and explanation of map terminology.**

All maps and associated geoprocessing were done with the ArcGIS 9.1 software by Environmental Systems Research Institute, Inc. (ESRI). Maps are shown in the NAD 1983 UTM Zone 16N coordinate system. Spatial data obtained in other datums or coordinate systems were re-projected using ArcGIS. GIS data obtained from the Michigan Center for Geographic Information Data Library were typically in the Michigan GeoRef coordinate system based on the NAD 1983 datum and an oblique mercator projection.

The base map features shown in Figure 1, and used on many of the other maps, were obtained as follows:

The roads and hydrologic (rivers and lakes) features in the area of Pictured Rocks National Lakeshore were obtained directly from the National Park Service via a data CD from Pictured Rocks staff (NPS 2005f). Roads and hydrologic features in the adjacent areas of Alger and Schoolcraft Counties were obtained from the Michigan Center for Geographic Information (2005) as part of the Michigan Geographic Framework, version 4b. The county and city boundaries were also part of the Michigan Geographic Framework.

NPS also provided the National Lakeshore shoreline and inland buffer zone boundaries (NPS 2005g) and a 10-meter digital elevation model (DEM) layer (NPS 2005h). The ¼ mile lakeshore boundary on Lake Superior was created by buffering the shoreline zone, and the elevation hillshade shown in Figure 1 was developed from the DEM layer.

The Midwest regional location map frame in Figure 1 utilized lake, state, county, and province data obtained from ESRI, 1999, ESRI Data & Maps Series. County boundaries in the Upper Peninsula of Michigan area locator map frame were from the Michigan Geographic Framework.

Data sources are listed for the specific content of the other maps. Digital versions (GIS ready) of the source data were used when possible; the symbolization represents our interpretation or application of the data. Where only images of spatial data were available, the images were geo-referenced and digitized on-screen to develop the map content. Image data sources were qualified with "after" in the source listing, such as for the State Forest boundary in Figure 3, landforms in Figure 9, glacial deposits in Figure 15, and groundwater data points in Figure 27.

In some cases, various geoprocessing tools were applied to cited data sources to derive new map features. These sources were qualified with "derived from," as in Figure 4 and Figure 12. In Figure 4, the watershed zone upgradient of the inland buffer zone was derived by merging the Lake Superior drainage sub-watersheds (MIDEQ 1998), and subtracting the area of the park zones. The depth contour used to define the Alger Bottomland Preserve in Figure 4, and the bathymetry in Figure 12, were derived by interpolating depth soundings and depth contours from electronic navigation charts (NOAA 2004a, 2004b, 2004c, 2005).

**Appendix B. List of additional references.**

Additional PIRO Resources:


Armichardy, D. and J. Leonard. 2003. Seasonal movements of resident and Lake Superior anadromous fishes in the Beaver Lakes basin Pictured Rocks National Lakeshore, MI, USA. Research update report to Pictured Rocks National Lakeshore Aquatic Ecologist.

Bowerman, W., IV. 1991. Factors influencing breeding success of bald eagles in Upper Michigan. Thesis. Northern Michigan University, Marquette, MI.

Daniels, J. 2000. European frogbit: What is it? Should we be worried? Michigan Sea Grant College Program. Upwellings 22(4).

Farrell, J., and J. Hughes. 1984. Wave erosion and mass wasting at Pictured Rocks National Lakeshore. Final Report, National Park Service, Contract Number CX-6000-2-0073, Northern Michigan University, Department of Geography, Earth Science and Conservation, Marquette, MI.

Fisher, T., and R. Whitman. 1998. Sedimentologic and stratigraphic analysis of Beaver Lake sediment cores, Pictured Rocks National Lakeshore, Michigan. Report to Pictured Rocks National Lakeshore, by Indiana University Northwest, Gary, IN, and the U.S. Geological Survey Lake Michigan Ecological Research Station, Porter, IN.

Fisher, T., and R. Whitman. 1999. Deglacial and lake level fluctuation history recorded in cores, Beaver Lake, Upper Peninsula, Michigan. Journal of Great Lakes Research 25:263-274.

Gerovac, P., R. Whitman, L. Last, and M. Becker. 1996. Surficial sediment characteristics of Beaver Lake, Pictured Rocks National Lakeshore, Michigan. Final Report to Pictured Rocks National Lakeshore. U.S. Geological Survey, Lake Michigan Ecological Research Station, Porter, IN.

Hansen, M. (ed). 1996. A lake trout restoration plan for Lake Superior. Great Lakes Fish Comm. 34 p. (http://www.uwsp.edu/water/mhansen/1996_Hansen.pdf). Accessed February 2006.

Heindorf, M., J. Morgan, and C. Simon. 2002. The development of an air toxics monitoring strategy for Michigan. Michigan Department of Environmental Quality, Air Quality Division. (http://www.deq.state.mi.us/documents/deq-aqd-toxics-peerRVstrategy.pdf). Accessed February 2006.

Hoff, M. 1996. Substrate survey of Beaver Lake, Pictured Rocks National Lakeshore, with special reference to natural reproduction of walleye. Final Report to Pictured Rocks National Lakeshore. Lake Superior Biological Station, Ashland, WI.

Hoffman, J., M. Smith, and J. Lehman. 2001. Perch or plankton: top-down control of Daphnia by yellow perch (*Perca flavescens*) or *Bythotrephes cederstroemi* in an inland lake. Freshwater Biology 46:759-775.

Jarnigan, S., B. Swan, and W. Kerfoot. 2000. Fish as vectors in the dispersal of *Bythotrephes cederstroemi*: diapausing eggs survive passage through the gut. Freshwater Biology 43:579-589.

Ledder, T. 2003. Water resource information and assessment report for the Great Lakes Inventory and Monitoring Network. National Park Service, Great Lakes Inventory and Monitoring Network, Ashland, WI. 54806. Great Lakes Network Technical Report: GLKN/2003/05. 42p. (http://www1.nature.nps.gov/im/units/glkn/Final%20Water%20Q%20report.pdf). Accessed October 2005.

Loope, W. 1983. Lamprey control plan: Picture Rocks National Lakeshore. Draft plan for Pictured Rocks National Lakeshore, Munising, MI.

Loope, W. 1986. Environmental assessment: grayling reintroduction, Pictured Rocks National Lakeshore. U.S. Department of the Interior, National Park Service memo to Michigan Department of Natural Resources district fisheries biologist.

Loope, W. and S. Scott. 1987. A reintroduction of grayling (*Thymallus arcticus*) to the inland waters of Picture Rocks National Lakeshore, Michigan. U.S. Department of the Interior, National Park Service and Michigan Department of Natural Resources report to Pictured Rocks National Lakeshore.

Loope, W. 1992. Shoreline dynamics and issues of shoreline protection at PIRO. PIRO 092-2, Pictured Rocks National Lakeshore, Munising, MI.

Loope, L. 1998b. Spiny water flea and its presence at Pictured Rocks National Lakeshore. Pictured Rocks National Lakeshore, Munising, MI.

Loope, L. 2001b. Wetland types in Pictured Rocks National Lakeshore. Pictured Rocks National Lakeshore, Munising, MI.

Loope, W., T. Fisher, H. Jol, R. Goble, J. Anderton, and W. Blewett. 2004. A Holocene history of dune-mediated landscape change along the southeastern shore of Lake Superior. Geomorphology 61:303-322.

MacKinnon, W.A. 2004. Species collected during the 2003 field season for Pictured Rocks National Lakeshore. Agency Report, McMillan, MI.

Massachusetts Natural Heritage and Endangered Species Program. 2000. Vernal pool fact sheet and certification criteria. Massachusetts Division of Fisheries and Wildlife. (http://www.mass.gov/dfwele/dfw/nhesp/vpcert.pdf) .

Merritt, R.W., and Cummins, K.W. 1984. An introduction to the aquatic insects of North

America, 2nd ed. Kendall/Hunt Publishing Co. Dubuque, Iowa. 722pp.

Michigan Department of Natural Resources. 1989. Michigamme project: Grand Sable Lake, Alger County (data only). Data report to Pictured Rocks National Lakeshore, Michigan Department of Natural Resources, Lansing, MI.

Michigan Department of Natural Resources. 1991. Assessment of mercury contamination in selected Michigan Lakes, 1987-1990: Historical trends, environmental correlates, and potential sources. Staff report, Surface Water Quality Division, Michigan Department of Natural Resources, Lansing, MI.

Michigan Department of Natural Resources. 1992. Fish contaminant data for Grand Sable Lake. Letter to Pictured Rocks National Lakeshore, Lansing, MI.

Michigan Technological University (MTU). 1979. The ecosystems of Pictured Rocks National Lakeshore: their attributes and limitations for visitor use. Department of Biological Sciences, Michigan Technological University, Houghton, MI.

Momot, W.T. 1984. Crayfish production: a reflection of community energetics. J. Crustacean Biol. 4:35-54

Morgan, J., E. Swain, and M. Allan. 2003. Identification of atmospheric mercury sources in the Great Lakes states through an ambient monitoring program: final report. Michigan Department of Environmental Quality, Air Quality Division, Minnesota Pollution Control Agency, Environmental Outcomes Division, and Wisconsin Department of Natural Resources, Bureau of Air Management. (http://www.deq.state.mi.us/documents/deq-aqd-toxics-Hgfinalreport.pdf). Accessed February 2006.

National Park Service (NPS). 1994. Resource Management Plan. Pictured Rocks National Lakeshore, Munising, MI.

Nevers, M.B. and R. Whitman. 2004. Characterization and comparison of phytoplankton in selected lakes of five Great Lakes area National Parks. Aquatic Ecosystem Health and Management 7:515-528.

Newman, L. E. 2001. Stream assessment of Pictured Rocks National Lakeshore, 1988. U.S. Fish and Wildlife Service Report to Pictured Rocks National Lakeshore. Ashland Fishery Resources Office Report, Ashland, WI. 18 pp.

Newman, L. and R. Dubois (eds). 1996. Status of Brook Trout in Lake Superior. Prepared for the Lake Superior Technical Committee by the Brook Trout Subcommittee. (http://www.fws.gov/midwest/ashland/brook/index.html). Accessed February 2006.

Paton, P.W.C., B. Timm, and T. Tupper. 2003. Monitoring pond-breeding amphibians: a protocol for the Long-term Coastal Ecosystem Monitoring Program at Cape Cod National Seashore. Final Report to the Cape Cod National Seashore, Wellfleet, MA.

Pawlak, E.M. 1998. Remote sensing and vernal pools. Our Hidden Wetlands: The Proceedings of a Symposium on Vernal Pools in Connecticut, p. 20-21.

Pennak, R.W. 1989. Fresh-water invertebrates of the United States, 3rd Ed. John Wiley & Sons, Inc. New York, NY. 628pp.

Preisser, E L., J.Y. Kefer, and J.D. Lawrence. 2000. Vernal pool conservation in Connecticut: an assessment and recommendations. Environmental Management 26(5):503-513.

Premo, D. and J. Davis. 1990. A survey of herpetofauna along the proposed Beaver Rim Road in the Pictured Rocks National Lakeshore. Final Report to Pictured Rocks National Lakeshore. White Water Associates, Inc., Amasa, MI.

Roman, C.T., N.E. Barrett, and J.W. Portnoy. 2004. Vegetation along upland-to-wetland gradients of vernal wetlands and kettle ponds: predicting vegetation response to hydrologic alteration. Final Technical Report to the National Park Service Water Resources Division, Fort Collins, CO.

Roman, C.T., N.E. Barrett, and J.W. Portnoy. 2001. Aquatic vegetation and trophic condition of Cape Cod (Massachusetts, U.S.A.) kettle ponds. Hydrobiologia 443:31-42.

Snodgrass, J.W., M.J. Komoroski, A.L. Bryan, Jr., and J. Burger. 2000. Relationships among isolated wetland size, hydroperiod, and amphibian species richness: implications for wetland regulations. Conservation Biology 14(2):414-419.

Sprules, W.G.; H.P. Riessen; and E.H. Jin. 1990. Dynamics of the *Bythotrephes* invasion of the St. Lawrence Great Lakes. J. Great Lakes Res. 16(3):346-351.

Stone, J. 1992. Vernal pools in Massachusetts: Aerial photographic identification, biological and physical characteristics, and state certification criteria. Thesis. University of Massachusetts, Amherst, MA.

Waldwick, R. 1997. Effects of forestry practices on amphibian populations in eastern North America. Herpetological Conservation 1:191-205.

Werner, J. 1989. Amphibian/reptile survey of Sand Point area, Pictured Rocks National Lakeshore. Final Report, National Park Service Contract Number PX6320-9-0080, Northern Michigan University, Marquette, MI

Yan, N., A. Blukacz, W. Sprules, P. Kindy, D. Hackett, R. Girard, and B. Clark. 2001. Changes in zooplankton and the phenology of the spiny water flea, Bythotrephes, following its invasion of Harp Lake, Ontario, Canada. Canadian Journal of Fisheries and Aquatic Sciences. 58:2341-2350.

Zedler, P.H. 2003. Vernal pools and the concept of isolated wetlands. Wetlands 23(3):597-607.

Selected Symposium and Conference Proceedings – Lake Superior

Auer, M.T., and T.C. Johnson (guest eds.) 2004. Lake Superior. J. Great Lakes Res. 30 (supplement).

Billingsley, L.W. (scientific editor). 1981. Stock Concept International Symposium (STOCS). Canadian Journal of Fisheries and Aquatic Sciences, Vol. 38, No. 12.

Christie, W.J., and G. R. Spangler. 1987. International Symposium on Stock Assessment and Yield Prediction (ASPY). Canadian Journal of Fisheries and Aquatic Sciences, Vol. 44, Supplement 2.

(editor unknown). 1977. Percid International Symposium (PERCIS). Canadian Journal of Fisheries and Aquatic Sciences, Vol. 34, No. 10.

(editor unknown). 1980. Proceedings of the Sea Lamprey International Symposium (SLIS). Canadian Journal of Fisheries and Aquatic Sciences, Vol. 37, No. 11.

Jones, M.L., C.H Olver and J.W. Peck (guest eds.). 2003. Sea Lamprey International Symposium (SLIS II). Journal of Great Lakes Research, Vol. 29, Supplement 1.

Kendall, R.L. (ed.). 1978. A Symposium on Selected Coolwater Fishes of North America. American Fisheries Society, Special Publication 11.

Loftus, K.H., and H.A. Regier. 1972. Proceedings of the 1971 Symposium on Salmonid Communities in Oligotrophic Lakes (SCOL). J. Fish. Res. Bd. Canada. 29 (6): 611-986.

Munawar, M. (ed). 1978. Limnology of Lake Superior. J. Great Lakes Res. 3-4.

Selgeby, J.H., R. L. Eshenroder, C. C. Krueger, J. E. Marsden and R. L. Pycha (guest eds.). 1995. International Conference on Restoration of Lake Trout in the Laurentian Great Lakes (RESTORE). Journal of Great Lakes Research, Vol. 21, Supplement 1.

**Appendix C. National Wetlands Inventory classifications and acreages for Pictured Rocks National Lakeshore.**

| System | Subsystem | Class | Subclass | Water | Shoreline zone (ha) | IBZ (ha) | Park (ha) |
|---|---|---|---|---|---|---|---|
| Lacustrine | | | | | 751.06 | 99.05 | 850.12 |
| | Littoral | | | | 110.78 | 0 | 110.78 |
| | | Unconsolidated bottom | | | 108.01 | 0 | 108.01 |
| | | Beach/bar | | | 2.77 | 0 | 2.77 |
| | Limnetic | Unconsolidated bottom | | Permanently flooded | 640.28 | 99.05 | 739.33 |
| Palustrine | | | | | 1536.21 | 2019.00 | 3555.21 |
| | | Emergent | | | 20.13 | 68.66 | 88.79 |
| | | | | Intermittently exposed | 0 | 5.77 | 5.77 |
| | | | | Saturated | 0 | 1.20 | 1.20 |
| | | | | Saturated/semipermanent | 14.96 | 48.61 | 63.57 |
| | | | | Seasonally flooded | 1.68 | 4.46 | 6.15 |
| | | | | Semipermanently flooded | 3.48 | 8.61 | 12.10 |
| | | Forested | | | 1374.15 | 1807.85 | 3182.00 |
| | | | | Saturated | 906.05 | 1417.07 | 2323.13 |
| | | | | Saturated/semipermanent | 466.04 | 388.89 | 854.93 |
| | | | | Seasonally flooded | 2.05 | 0.32 | 2.38 |
| | | | | Seasonally flooded/saturated | 0 | 1.56 | 1.56 |
| | | | Broad-leaved Deciduous | | 0 | 9.44 | 9.44 |
| | | | Needle-leaved Evergreen | | 728.05 | 1036.33 | 1764.38 |
| | | Scrub-Shrub | | | 107.43 | 109.99 | 217.43 |
| | | | | Saturated | 14.73 | 15.71 | 30.44 |
| | | | | Saturated/semipermanent | 75.94 | 71.06 | 147.00 |
| | | | | Seasonally flooded | 16.76 | 22.89 | 39.65 |
| | | | | Semipermanently flooded | 0 | 0.33 | 0.33 |
| | | | Broad-leaved Deciduous | | 40.08 | 27.11 | 67.19 |
| | | | Needle-leaved Evergreen | | 0 | 0.13 | 0.13 |
| | | Unconsolidated bottom | | | 34.49 | 32.49 | 66.98 |
| | | | | Intermittently flooded | 1.42 | 10.06 | 11.48 |
| | | | | Permanently flooded | 33.07 | 22.18 | 55.26 |
| | | | | Semipermanently flooded | 0 | 0.24 | 0.24 |
| Uplands | | | | | 9836.09 | 13208.13 | 23044.22 |
| Total | | | | | 12123.33 | 15326.21 | 27449.54 |

**Appendix D. Classifications and scientific and common names of species listed in this report.**

**Phytoplankton (Guiry and Guiry 2006)**

| Kingdom | Phylum | Class | Order | Family | Genus | Species | Common name |
|---|---|---|---|---|---|---|---|
| Monera | Cyanophyta | Cyanophyceae | Nostocales | Nostocaceae | *Aphanizomenon* | *flos-aquae* | Blue-green algae |
| | | | Synechococcales | Merismopediaceae | *Aphanocapsa* | *rivularia* | |
| | | | Chroococcales | Chroococcaceae | *Chroococcus* | *limneticus* | |
| | | | Oscillatoriales | Oscillatoriaceae | *Lyngbya* | *birgei* | |
| Plantae | Bacillariophyta | Fragilariophyceae | Fragilariales | Fragilariaceae | *Asterionella* | *formosa* | Diatoms |
| | | | | | *Fragilaria* | *intermedia* | |
| | | | Tabellariales | Tabellariaceae | *Tabellaria* | *fenestrata* | |
| | | Coscinodiscophyceae | Aulacoseirales | Aulacoseiraceae | *Aulacoseira* | *islandica* | |
| | Charophyta | Charophyceae | Charales | Characeae | *Chara* | sp. | Green algae |
| | | | | | *Nitella* | sp. | |
| | | Zygnematophyceae | Zygnematales | Zygnemataceae | *Spirogyra* | spp. | |
| | Chlorophyta | Chlorophyceae | Oedogoniales | Oedogoniaceae | *Bulbochaete* | sp. | |
| | | Ulvophyceae | Ulotrichales | Ulotrichaceae | *Ulothrix* | spp | |
| | Chrysophyta | | | | | | Yellow-brown algae |
| | Pyrrophyta | | | | | | Dinoflagellates |
| | Rhodophyta | Florideophyceae | Nemalionales | Batrachospermaceae | *Batrachospermum* | sp. | Red algae |

**Zooplankton (Alberti et al. 2005)**

| Phylum | Class | Subclass | Order | Suborder | Family | Genus | Species | Common name |
|---|---|---|---|---|---|---|---|---|
| Rotifera | Monogononta | | Ploima | | Brachionidae | *Keratella* | spp. | Rotifer |
| Arthropoda | | | Anostraca | | Chirocephelidae | *Eubranchipus* | sp. | Fairy shrimp |
| Arthropoda | Crustacea | Malacostraca | Amphipoda | Gammaridea | Pontoporeiidae | *Diporeia* | *affinis* | Amphipod |
| | | | Mysidacea | | Mysidae | *Mysis* | *relicta* | Opossum shrimp |
| Arthropoda | Crustacea | | | Cladocera | Bosminidae | *Bosmina* | *longirostris* | Cladoceran |
| | | | | | Cercopagididae | *Bythotrephes* | *longimanus*** | Spiny water flea |
| | | | | | | *Cercopagis* | *pengoi**** | Fishhook water flea |
| | | | | | Chydoridae | *Eurycercus* | *lamellatus* | Cladoceran |
| | | | | | | *Pseudochydorus* | *globosus* | |
| | | | | | Daphniidae | *Daphnia* | *galeata mendotae* | Cladoceran |
| | | | | | | *Daphnia* | *lumholtzi**** | |
| | | | | | Holopedidae | *Holopedium* | gibberum | Cladoceran |
| Arthropoda | Crustacea | Copepoda | Cyclopoida | | Cyclopidae | *Cyclops* | *scutifer* | Cyclopoid copepod |
| | | | | | | *Cyclops* | *vernalis* | |
| | | | | | | *Diacyclops* | *thomasi // bicuspidatus thomasi* | |
| | | | | | Ergasilidae | *Neoergasilus* | *japonicus**** | Parasitic copepod |
| | | | Calanoida | | Diaptomidae | *Diaptomus* | *sicilis* | Calanoid copepod |
| | | | | | | *Skistodiaptomus* | *oregonensis* | |
| | | | | | Temoridae | *Epischura* | *lacustris* | Calanoid copepod |

**invasive exotic species found in PIRO
*** invasive exotic species believed to be encroaching on PIRO

**Benthos (after PIRO, Lora Loope, Aquatic Ecologist, pers. comm. 2005)**

| Phylum | Class | Order | Family | Genus | Species | Common name |
|---|---|---|---|---|---|---|
| Coelenterata | Hydrozoa | Hydroida | | *Hydra* | | Hydra |
| Platyhelminthes | Turbellaria | | | | | Planaria |
| Porifera | | | | | | Freshwater sponges |
| Annelida | Hirudinea | | | | | Leeches |
| | Oligochaeta | | | | | Segmented worms |
| | Polychaeta | | | | | Bristle worms |
| Bryozoa | | | | | | Moss animalcules |
| | Phylactolaemata | Plumatellida | Pectinatellidae | *Pectinatella* | *magnifica* | Bryozoan |
| Mollusca | Bivalvia (Pelecypoda) | Veneroida | Corbiculidae<br>Dreissenidae<br>Sphaeriidae | *Corbicula*<br>*Dreissena*<br>*Dreissena*<br>*Sphaerium* | *fluminea****<br>*bugensis****<br>*polymorpha****<br>sp. | Asian clam<br>Quagga mussel<br>Zebra mussel<br>Clam |
| | | Unionoida | Unionidae | *Elliptio*<br>*Lampsilis* | sp.<br>sp. | Clam |
| | Gastropoda | Prosobranchia | Hydrobiidae | *Amnicola* | *limnosa* | Clam |
| | | | Valvatidae | *Valvata* | sp. | Clam |
| | | Pulmonata | Planorbiidae | *Helisoma* | *anceps* | Mollusk |
| | | Basommatophora | Lymnaeidae | *Lymnaea* | *palustris* | Snail |
| Arthropoda | Crustacea | Amphipoda | Gammaridae | *Gammarus* | *lacustris* | Scud |
| | | | Talitridae | *Hyallela* | *azteca* | Scud |
| | | Isopoda | | | | Aquatic sow bugs |
| | | Ostracoda | | | | Seed shrimp |
| | | Decapoda | Cambaridae | *Orconectes* | *rusticus**** | Rusty crayfish |
| | Insecta | Ephemeroptera | | | | Mayflies |
| | | Plecoptera | | | | Stoneflies |
| | | Odonata | Zygoptera | | | Damselflies |
| | | | Anisoptera | | | Dragonflies |
| | | Trichoptera | | | | Caddisflies |
| | | Lepidoptera | | | | Moths, butterflies |
| | | Coleoptera | Elmidae | *Dubiraphia*<br>*Macronychus*<br>*Optioservus*<br>*Stenelmis* | spp.<br>glabratus<br>*fastiditus*<br>*crenata* | Riffle beetles |
| | | Diptera | Chironomidae | | | Midges |
| | | Hemiptera | | | | True bugs |

***** invasive exotic species believed to be encroaching on PIRO**

**Aquatic Macrophytes (after PIRO, Lora Loope, Aquatic Ecologist, pers. comm. 2005)**

| Family | Genus | Species | Common name |
|---|---|---|---|
| Alismaceae | *Alisma* | sp. | Water plantain |
| Hydrocharitaceae | *Anarchis (Eleodea)* | spp. | Canadian waterweed |
| Butomaceae | *Butomus* | *umbellatus**** | Flowering rush |
| Callitrichaceae | *Callitriche* | *hermaphroditica* | Water starwort |
| Cyperaceae | *Carex* | spp. | Sedges |
| Ceratophyllaceae | *Ceratophyllum* | *demersum* | Coon's tail |
| Equisetaceae | *Equisetum* | spp. | Horsetails |
| Eriocaulaceae | *Eriocaulon* | *septangulare* | Sevenangle pipewort |
| Lythraceae | *Lythrum* | *salicaria**** | Purple loosestrife |
| Hydrocharitaceae | *Hydrocharis* | *morsus-ranae**** | European frog-bit |
| Haloragidaceae | *Hippurus* | *vulgaris* | Mare's tail |
| | *Myriophyllum* | *alterniflorum* | Alternate flower watermilfoil |
| | *Myriophyllum* | *farwellii* | Farwell's milfoil |
| | *Myriophyllum* | *spicatum**** | Eurasian watermilfoil |
| | *Myriophyllum* | spp. | Watermilfoils |
| Nymphaeaceae | *Nuphar* | spp. | Pond lilies |
| Potamogetonaceae | *Potamogeton* | *crispus**** | Curly-leaf pondweed |
| | *Potamogeton* | *gramineus* | Variableleaf pondweed |
| | *Potamogeton* | *praelongus* | Whitestem pondweed |
| | *Potamogeton* | spp. | Pondweed |
| Cyperaceae | *Scirpus* | spp. | |
| Typhaceae | *Typha* | *latifolia* | Broadleaf cattail |
| | *Typha* | spp. | Cattails |
| Lentibulariaceae | *Utricularia* | spp. | Bladderworts |
| Hydrocharitaceae | *Vallisneria* | spp. | Eelgrasses |

***** invasive exotic species believed to be encroaching on PIRO**

**Terrestrial and wetland plants.**

| Scientific name | Common name |
|---|---|
| *Aegopodium podagraria*** | Bishopsweed |
| *Alnus viridis ssp. crispa* | Green alder |
| *Alnus incana ssp. rugosa* | Mountain alder |
| *Ammophilia brevigulata brevigulata* | Beach grass |
| *Andromeda glaucophylla* | Bog rosemary |
| *Artemisia campestris var. caudata* | Beach wild wormwood |
| *Aster nemoralis** | Bog aster |
| *Botrychium spp.* | Moonworts, grape-ferns |
| *Calypso bulbosa* | Calypso orchid |
| *Centaurea maculosa*** | Spotted knapweed |
| *Chamaedaphne calyculata* | Leatherleaf |
| *Cirsium pitcheri* | Pitcher's thistle |
| *Crataegus douglasii* | Douglas' hawthorn |
| *Cypripedium arietinum* | Ram's head orchid |
| *Drepanocladus aduncus* | Drepanocladus moss |
| *Elymus canadensis* | Canada wild rye |
| *Elymus glaucus* | Blue wild rye |
| *Elymus trachycaulus* | Slender wheat grass |
| *Empetrum nigrum* | Black crowberry |
| *Kalmia polifolia* | Bog rosemary |
| *Larix laricina* | Tamarack |
| *Lathyrus japonicus var. maritimus* | Beach pea |
| *Ledum groenlandicum* | Labrador tea |
| *Leymus mollis* | Dune grass |
| *Oenothera biennis* | Common evening primrose |
| *Picea mariana* | Black spruce |
| *Pinguicula vulgaris* | Butterwort |
| *Primula mistassinica* | Bird's eye primrose |
| *Prunus pumila* | Sand cherry |
| *Salix spp.* | Willow |
| *Sorbus decora* | Showy mountain ash |
| *Sphagnum spp.* | Sphagnum moss |
| *Stellaria longipes* | Stitchwort |
| *Tanacetum huronense* | Lake Huron tansy |
| *Vaccinium macrocarpon* | Cranberries |
| *Vaccinium oxycoccos* | Cranberries |
| *Vaccinium spp.* | Blueberries |
| *Vallisneria spp.* | Eelgrass |
| *Vinca minor*** | Periwinkle |

***species believed to be in PIRO but not found in survey**

****invasive exotic species found in PIRO**

**Fish (after GLFC 2001).**

| Family | Scientific name | Common name |
|---|---|---|
| Petromyzontidae | *Ichthyomyzon unicuspis** | Silver lamprey |
| | *Petromyzon marinus*** | Sea lamprey |
| Acipenseridae | *Acipenser fulvescens* | Lake sturgeon |
| Clupeidae | *Alosa pseudoharengus*** | Alewife |
| Cyprinidae | *Couesius plumbeus* | Lake chub |
| | *Cyprinus carpio** | Common carp |
| | *Hybognathus hankinsoni* | Brassy minnow |
| | *Notropis atherinoides* | Emerald shiner |
| | *N. heterolepis* | Blacknose shiner |
| | *N. hudsonius* | Spottail shiner |
| | *N. volucellus* | Mimic shiner |
| | *Phoxinus neogaeus* | Finescale dace |
| | *Rhinichthys atratulus* | Blacknose dace |
| | *R. cataractae* | Longnose dace |
| | *Semotilus margarita** | Pearl dace |
| Catostomidae | *Catostomus catostomus* | Longnose sucker |
| | *C. commersoni* | White sucker |
| | *Moxostoma anisurum** | Silver redhorse |
| | *M. macrolepidotum** | Shorthead redhorse |
| Ictaluridae | *Ictalurus natalis** | Yellow bullhead |
| | *Ictalurus spp.* | Bullheads |
| Esocidae | *Esox lucius* | Northern pike |
| Osmeridae | *Osmerus mordax* | Rainbow smelt |
| Salmonidae | *Coregonus artedi* | Lake herring |
| | *C. clupeaformis* | Lake whitefish |
| | *C. hoyi* | Bloater |
| | *C. kiyi* | Kiyi |
| | *C. spp.* | Deepwater ciscoes |
| | *Oncorhynchus kisutch* | Coho salmon |
| | *O. gorbuscha* | Pink salmon |
| | *O. mykiss* | Rainbow trout |
| | *O. tshawytscha* | Chinook salmon |
| | *Prosopium coulteri* | Pygmy whitefish |
| | *P. cylindraceum* | Round whitefish |
| | *Salmo trutta* | Brown trout |
| | *Salvelinus fontinalis* | Brook trout |
| | *Salvelinus fontinalis x namaycush* | Splake |
| | *S. namaycush* | Lake trout |
| | *S. namaycush* | Siscowet |
| | *Thymallus arcticus** | Arctic grayling |
| Percopsidae | *Percopsis omiscomaycus* | Trout perch |
| Gadidae | *Lota lota* | Burbot |
| Gasterosteidae | *Culaea inconstans* | Brook stickleback |
| | *Gasterosteus aculeatus**** | Threespine stickleback |
| | *Pungitius pungitius* | Ninespine stickleback |
| Cottidae | *Cottus bairdii* | Mottled sculpin |
| | *Cottus cognatus* | Slimy sculpin |
| | *Myoxocephalus thompsoni* | Deepwater sculpin |
| Moronidae | *Morone americana**** | White perch |
| Centrarchidae | *Ambloplites rupestris* | Rock bass |
| | *Lepomis gibbosus* | Pumpkinseed |
| | *L. macrochirus* | Bluegill |
| | *Micropterus dolomieu* | Smallmouth bass |
| Percidae | *Etheostoma nigrum* | Johnny darter |
| | *Gymnocephalus cernuus**** | Ruffe |
| | *Perca flavescens* | Yellow perch |
| | *Percina caprodes* | Logperch |
| | *Sander vitreus* | Walleye |
| Gobiidae | *Neogobius melanostomus**** | Round goby |
| Umbridae | *Umbra limi* | Central mudminnow |

***species believed to be in PIRO but not found in survey**
****invasive exotic species found in PIRO**
***** invasive exotic species believed to be encroaching on PIRO**

**Amphibians**

| Scientific name | Common name |
|---|---|
| *Ambystoma laterale* | Spotted salamander |
| *Ambystoma maculatum* | Blue-spotted salamander |
| *Bufo americanus americanus* | American toad |
| *Hemidactylium scutatum* | Four-toed salamander |
| *Hyla versicolor* | Eastern gray treefrog |
| *Necturus maculosus maculosus** | Mud puppy |
| *Notophthalmus viridescens* | Eastern newt |
| *Plethodon cinereus* | Red-backed salamander |
| *Pseudacris crucifer crucifer* | Northern spring peeper |
| *Rana clamitans melanota* | Green frog |
| *Rana pipiens** | Northern leopard frog |
| *Rana septentrionalis** | Mink frog |
| *Rana sylvatica* | Wood frog |

**Reptiles**

| Scientific name | Common name |
|---|---|
| *Chelydra serpentina serpentine* | Eastern snapping turtle |
| *Chrysemys picta* | Painted turtle |
| *Diadophis punctatus edwardsii** | Northern ring-necked snake |
| *Glyptemys insculpta* | Wood turtle |
| *Nerodia sipedon sipedon* | Northern watersnake |
| *Opheodrys vernalis* | Smooth greensnake |
| *Storeria occipitomaculata occipitomaculata* | Northern red-bellied snake |
| *Thamnophis sirtalis sirtalis* | Eastern gartersnake |

**Other**

| Scientific name | Common name |
|---|---|
| *Ursus americanus* | Black bear |
| *Lymantria dispar*** | Gypsy moth |

***species believed to be in PIRO but not found in survey**
****invasive exotic species found in PIRO**

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

NPS D-124, December 2006

**National Park Service**
**U.S. Department of the Interior**

**Water Resources Division**
**Natural Resource Program Center**
1201 Oak Ridge
Fort Collins, CO  80525

EXPERIENCE YOUR AMERICA