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Assessment of Coastal Water Resources and Watershed Conditions at Apostle Islands National Lakeshore (Wisconsin)

Natural Resource Technical Report NPS/NRWRD/NRTR—2007/367






Cover photos:

Top Left:	Outer Island Lighthouse, NPS Photo
Top Center:	Sand River Estuary, Mainland Unit, Eric Epstein
Top Right:	Sea Caves East of Meyers Beach, Mainland Unit, Dave Mechenich
Bottom Left:	Outer Island Sand Spit, Eric Epstein
Bottom Center:	Stockton Island Tombolo Interdunal Pool, Emmet Judziewicz
Bottom Right:	Lake Superior from Trail East of Meyers Beach, Dave Mechenich

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Executive Summary

Apostle Islands National Lakeshore (APIS) is located at the tip of the Bayfield Peninsula in northern Wisconsin. It includes 21 of the 22 Apostle Islands in Lake Superior, a strip of the mainland, and the waters of Lake Superior out to 0.4 km from the islands' shores. The lakeshore encompasses 17,017 ha of land and 11,057 ha of Lake Superior, only 15% of the archipelago's total water area. APIS was designated and placed under the management of the National Park Service (NPS) by an act of Congress in 1970 and further strengthened by designation of about 80% of its land area as the Gaylord Nelson Wilderness in 2004.

Key features of APIS include Lake Superior, the largest and one of the cleanest freshwater lakes in the world. APIS also includes some of the most pristine sandscapes left in the Great Lakes region, including sand spits, cuspate forelands, tombolos, a barrier spit, and numerous beaches; many of these sandscapes are recognized as Wisconsin State Natural Areas. Other outstanding features include colorful sandstone cliffs and sea caves, old-growth forests, and the largest collection of lighthouses in the National Park System. In 2001, approximately 48,000 visitors used private motorboats, kayaks, or sailboats to tour the islands. The NPS provides 20 docks, and nearly all the islands have natural anchorage areas that provide shelter from storm winds and opportunities for recreational activities. Inland surface water resources include lagoons on Michigan, Stockton, and Outer Islands, unnamed perennial streams on Stockton and Oak Islands, and the Sand River Estuary. Bogs, beaver ponds, and wetlands are common, and APIS has more kilometers of intermittent streams than any other Great Lakes national park.

The APIS area has long, cold winters and short, moderately warm summers, made somewhat more maritime by proximity to Lake Superior. APIS is located at the northern limit of the hemlock-white pine-northern hardwood forest and the southern limit of the boreal forest and is 96% forested. Much of adjoining Bayfield County is also forested. Major landowners on the Peninsula include the Wisconsin Department of Natural Resources, the USDA - Forest Service, and Bayfield County. The north and northeastern tip of the Peninsula is the Red Cliff Band of Lake Superior Chippewa Indian Reservation.

APIS includes a number of regionally rare habitats, including old-growth forest, boreal forest, five types of northern forests, forest seep, clay bluff communities, sandstone cliff communities, lagoon and bog communities, forested ridge and swale, coastal fen, Great Lakes barrens, and dune communities. It is officially home to five current Wisconsin-endangered plant species (including satiny willow, *Salix pellita*) and 12 current Wisconsin-threatened plant species [including coast sedge (*Carex exilis*), lenticular sedge (*Carex lenticularis*), Michaux's sedge (*Carex michauxiana*), drooping sedge (*Carex prasina*), broad-leaved twayblade (*Listera convallarioides*), flat-leaved willow (*Salix planifolia*), and narrow false oats (*Trisetum spicatum*)], as well as 23 plant species of special concern. APIS is also home to the federally endangered piping plover (*Charadrius melodus*) and the federally threatened bald eagle (*Haliaeetus leucocephalus*), as well as 11 bird species of special concern in Wisconsin. Other species of special concern include four-toed salamanders (*Hemidactylium scutatum*) and several types of aquatic and terrestrial insects.

Lake Superior has been classified as an ultra-oligotrophic lake, and its phytoplankton and zooplankton communities reflect that status. Diatoms and phytoflagellates contribute most of the lakewide phytoplankton biomass. The zooplankton community is dominated by large calanoid copepods, with cladocerans also present (and perhaps becoming more numerous in western Lake Superior). The fish community includes as many as 96 species, including some of commercial importance, such as lake trout (*Salvelinus namaycush*), lake whitefish (*Coregonus clupeaformis*), and lake herring (*C. artedi*). The conditions of Lake Superior bays in the mainland unit and surrounding the islands generally mirror the open water conditions. The three major lagoons in the park on Outer, Stockton, and Michigan Islands also generally reflect oligotrophic conditions. Less is known about the biota of Sand River and Saxine Creek in the mainland unit, the many ephemeral and a few permanent streams on the islands, or the vernal pools that may provide important habitat for amphibians and other species.

Potential sources of pollution to APIS 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 better-regulated, but the potential impact on APIS of permitted local and regional emissions is unknown.

Point sources of water pollution to Lake Superior near APIS include five small municipal wastewater treatment plants, an electrical power generating facility, and a fish hatchery. Nonpoint sources include Great Lakes shipping activities, tour boats and private boats, marinas, and stormwater discharges. Great Lakes cargo ships travel within 8 km of Devils and Sand Islands, 6 km of Michigan Island, and 1 km of Long Island, and may come closer during storms. These have the potential to accidentally spill cargoes or fuel, or discharge bilge water or ballast water that could contain exotic species. Bayfield Peninsula municipalities are all too small to be covered by United States Environmental Protection Agency (USEPA) stormwater regulations. Potential sources of water pollution to the APIS mainland unit's streams and bays include on-site wastewater treatment systems, logging, and road building.

APIS's surface waters have generally been determined to be of high quality. Lake Superior waters continue to be notable for their clarity, but runoff from Peninsula streams sometimes creates sediment plumes that extend well into the islands. These sediments are mainly clay particles and are sometimes high in phosphorus, but to date, excessive phosphorus levels have not been found in routine Lake Superior monitoring. Some data indicate that nitrate has been increasing lakewide over the period of record, perhaps related to atmospheric deposition. Only a few exceedences of aquatic freshwater life or human health criteria have been recorded. Many fish species from Lake Superior have fish consumption advisories, especially for women and children, because of polychlorinated biphenyl (PCB), mercury or dioxin contamination. Limited data indicate that the quality of APIS groundwater resources is good, with a few aesthetic problems for domestic use related to iron and manganese.

Population growth in Ashland and Bayfield Counties has been slow since 1990, and population is much lower than the peak experienced around 1920. Ashland County's population is declining; Bayfield County is experiencing population growth around small unincorporated towns along major roads, rural towns around Ashland, and in the Town of Russell associated with the Red Cliff Indian Reservation. Housing growth is outpacing population growth, largely because of second home development. Development and population pressures should be observed for possible impact on APIS resources.

Six aquatic invasive species are currently known to exist in the APIS vicinity: the sea lamprey (*Petromyzon marinus*), the Eurasian ruffe (*Gymnocephalus cernuus*), the threespine stickleback (*Gasterosteus aculeatus*), the spiny water flea (*Bythotrephes longimanus*), the Eurasian watermilfoil (*Myriophyllum spicatum*), and purple loosestrife (*Lythrum salicaria)*. Other aquatic invasives that are known to exist in Lake Superior and may be considered to be encroaching on APIS include the alewife (*Alosa pseudoharengus)*, New Zealand mudsnail (*Potamopyrgus antipodarum*), zebra mussel (*Dreissenia polymorpha*), Asian clam (*Corbicula fluminea*), round goby (*Neogobius melanostomus*), and white perch (*Morone americana*). Primary vectors for introducing exotic species to Lake Superior are the bilge and ballast water of commercial ships, boating, and angler activity.

Climate change could have major impacts on APIS resources, both by altering the habitats that enable certain rare species to survive as well as by allowing exotic species to compete more successfully. Some of the projected impacts include warmer inland waters with less dissolved oxygen and more phosphorus and mercury release from sediments, changes in fish communities away from coldwater species, and reductions in the size of wetland habitats. Climate change could change Lake Superior water levels with potentially severe effects on APIS sandscapes and on the configuration of the islands themselves. Sandscapes are also sensitive to trampling caused by human foot traffic.

The potential for degradation of APIS water resources is shown in Table i. Documented problems include water clarity issues related to phosphorus-laden sediment loss from Bayfield Peninsula watersheds; fish consumption advisories related to mercury, polychlorinated biphenyl and dioxin contamination; regional air pollution; visitor use intensity, especially on sandscapes; and aquatic invasive species.

Recommendations detailed in the report include the following:

Water quality and biotic evaluation and monitoring

- Routine water quality monitoring should continue as outlined in GLKN protocols and Axler et al. (2006).
- The potentially ecologically significant vernal pools and the abundant and diverse wetland resources need additional study and long-term monitoring.
- An assessment of all APIS 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 APIS.
- Intermittent streams at APIS need further water quality and biological investigation and monitoring.
- Continued cooperation with WDNR, USFWS, and the tribes is encouraged to ensure that resource protection goals for APIS fish populations are met.

Table i. Potential for degradation of water resources in Apostle Islands National Lakeshore.

Stressor/ Environmental Indicator	**Lake Superior open waters**	**Mainland Unit Lake Superior coastline and bays**	**Mainland Unit streams**	**Islands Lake Superior coastline and bays**	**Islands inland waters and wetlands**
Water quality indicators					
Water clarity	OK	PP	EP	EP	NA
Nutrients	PP	PP	EP	PP	PP
Dissolved oxygen	OK	OK	OK	PP	EP
Fecal bacteria	OK	OK	NA	PP	OK
Sediment	OK	PP	EP	EP	NA
Biological indicators					
Zooplankton populations	PP	PP	NA	PP	PP
Fish consumption advisories	EP	EP	EP	EP	EP
Land use-related stressors					
Regional atmospheric deposition and air pollution	EP	EP	EP	EP	EP
Local air pollution sources	PP	PP	PP	PP	PP
Wastewater discharges covered by NPDES permits	OK	NA	NA	PP	NA
Stormwater	OK	OK	OK	PP	NA
Agriculture	OK	OK	OK	OK	NA
Landfills	OK	PP	PP	OK	NA
Septic systems	OK	PP	PP	OK	OK
Residential development	OK	PP	PP	PP	NA
Road building	OK	PP	PP	NA	NA
Logging	OK	PP	PP	NA	NA
Recreational and commercial use					
Land-based visitor use intensity	NA	PP	OK	EP	OK
Recreational boating	PP	PP	NA	PP	NA
Commercial tour boating	PP	OK	OK	PP	NA
Commercial fishery	OK	OK	NA	OK	NA
Great Lakes shipping	EP	PP	NA	PP	NA
Invasive species	EP	EP	EP	EP	EP
Climate change	PP	PP	PP	PP	PP

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

shaded =limited data; NA= not applicable.

- The genetic makeup of coaster brook trout stocks around the islands should be investigated, and the need for a locally developed brood stock more appropriate to the islands should be evaluated (Lafrancois and Glase 2005).

Stressor monitoring, evaluation, and management

- Surveys for known and encroaching aquatic invasive species in APIS should be expanded, and control programs should be undertaken where feasible.
- Specific pollutants in local and regional air emissions and their potential effects on APIS water resources should be evaluated, and monitoring should be conducted where warranted.
- Water level fluctuations should be monitored at unique island habitats such as splash pools and temporary beach habitats, and habitat losses should be documented.
- Water and sediment monitoring should be evaluated for heavily-used recreational boating areas, including Presque Isle Bay, 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.
- Locations of stormwater discharges on the Bayfield Peninsula should be documented and evaluated for potential impacts.
- The WDNR’s proposal to quantify the effects of erosion control practices on Lake Superior tributaries by monitoring suspended solids and flow should be supported, and the results should be examined for possible impacts or mitigation opportunities for mainland unit streams.
- Population trends in the watershed of the mainland unit should be monitored, and ways to monitor the effects of local land use practices (logging, road building, and residential development) on APIS mainland unit waters should be developed and implemented in proportion to increased use.
- Effects of recreation on shoreline habitat and shoreline processes should continue to be monitored at heavily visited sites. In particular, physical damage to sensitive shoreline resources from boat wakes, groundings or other recreational boating impacts need to be assessed and monitored.
- The town of Russell landfill should be discussed with WDNR specialists to define whether or not it is in the Sand River basin and to determine if further investigation of the site is warranted.

Planning

- A plan should be developed to mitigate impacts of future climate change where feasible strategies can be identified.

Education

- Emphasis should be placed on boater education about current regulations and risks posed by fuel spills, human waste discharge, or discharge of bilge water or bait buckets into nearshore Lake Superior waters.

Acknowledgements

We would like to thank the many people who assisted us in the preparation of this report. Greg Schultz of the U.S. Coast Guard provided information on fuels and oils carried on Great Lakes ships, and Dave Strzok shared specific information about the Apostle Island Cruise Services fleet. Many WDNR staff were very helpful in providing data and local information, including Jennifer Filbert, Terry Koehn, Candy Schrank, and Sheri Snowbank. Jim Nepstad of APIS provided park use statistics. Ulf Gafvert of GLKN provided valuable GIS information. Joan Elias of GLKN pointed out water quality reports and provided information on Lake Superior habitat zones. Greg Fischer and Matt Symbal explained the workings of the wastewater treatment systems at the UW-Stevens Point Aquaculture Facility and Red Cliff Fish Hatchery, respectively. Becky Sapper of the Nature Conservancy gave permission for use of a watershed map for Chequamegon Bay. Eric Epstein of WDNR and Emmet Judziewicz of UW – Stevens Point gave permission for some of their photos to be used in this report. Lora Loope of Pictured Rocks National Lakeshore provided species lists that were helpful in organizing the species data for APIS as well.

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Commonly Used Abbreviations

AMSL	above mean sea level
APIS	Apostle Islands National Lakeshore
BP	before present
C	Celsius
CAA	Clean Air Act
CAAA	Clean Air Act Amendments
cm	centimeter
DO	dissolved oxygen
g	gram
GLFC	Great Lakes Fishery Commission
GLKN	Great Lakes Inventory and Monitoring Network
GLSC	Great Lakes Science Center
ha	hectare
Hg	mercury
kg	kilogram
km	kilometer
L	liter
LLC	limited liability company
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
MDNR	Minnesota Department of Natural Resources
mg/L	milligram per liter
NADP	National Atmospheric Deposition Program
ng/L	nannograms per liter
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NPS	National Park Service
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System (USGS)
NWRPC	Northwest Regional Planning Commission
OLIS	Wisconsin Office of Land Information Systems
PCBs	polychlorinated biphenyls
ppm	part per million
SIC	Standard Industrial Classification
µg/L	microgram per liter (part per billion)
USEPA	United States Environmental Protection Agency
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
UWEX	University of Wisconsin - Extension
WDNR	Wisconsin Department of Natural Resources

Introduction and Park Description

Size, Boundaries, Location, and Regional Setting

Apostle Islands National Lakeshore (APIS) is located at the tip of the Bayfield Peninsula of northern Wisconsin (Figure 1). It includes 21 of the 22 Apostle Islands in Lake Superior, as well as a 19 kilometer (km) strip along the shore of the mainland (NPS 2004a). The islands range in size from 1.4 hectare (ha) Gull Island to 4,003 ha Stockton Island (WDNR 2005j). APIS encompasses 28,074 ha; 17,017 ha of land and 11,057 ha of Lake Superior extending 0.4 km from shore, only 15% of the archipelago's total water area. The lake bed is under the jurisdiction of the State of Wisconsin. NPS general regulations under 36 CFR 1.2 (3) establish authority over waters subject to U.S. jurisdiction, without regard to the ownership of submerged lands.

APIS was established by an act of Congress in 1970, to "conserve and develop for the benefit, inspiration, education, recreational use, and enjoyment of the public certain significant islands and shoreline of the United States and their related geographic, scenic, and scientific values" (NPS 1989). It included 20 islands and a portion of the mainland; Long Island was added in 1986. In 2004, 13,557 ha, or about 80% of the land base of APIS, were permanently protected as wilderness (NPS 2004b) (Figure 2).

APIS is part of the Lake Superior Lake Plain landscape ecosystem that covers nearly 320 km of Lake Superior shoreline in Michigan, Minnesota, and Wisconsin (Albert 1995). It is also located entirely within the United States Geological Survey's (USGS) Hydrologic Unit 04010301 (Beartrap-Nemadji; USGS 2006). The Sand River, Raspberry River, and Red Cliff Creek watersheds contribute 66% of the runoff area from the Bayfield Peninsula between Squaw Point (now Mawikwe Point) and the city of Bayfield and are the three main streams discharging to the Lakeshore area of Lake Superior for all but Long Island (Rose 1988).

APIS lands include areas in Ashland and Bayfield Counties in Wisconsin (Figure 3). Though the majority of islands lie in Ashland County, the Bayfield County portion contains the mainland unit of the Lakeshore as well as the mainland unit's watershed. Nearly 48% of Bayfield County land is publicly owned, and approximately 85% is forested (Laumann 2003). The northern and northeastern tip of the Bayfield Peninsula is the Red Cliff Band of Lake Superior Chippewa Indian Reservation, which is held in trust by the U.S. government (Laumann 2003). Much of the north central part of the Peninsula, including much of the mainland unit's watershed, is county-owned forest. Other major landowners in the Bayfield Peninsula include the Wisconsin Department of Natural Resources (WDNR) and the USDA - Forest Service (Figure 4). Much of the northern part of Ashland County, directly south of APIS, is the Bad River Band of Lake Superior Chippewa Indian Reservation and also held in trust by the U.S. government (Stable Solutions 2005a).

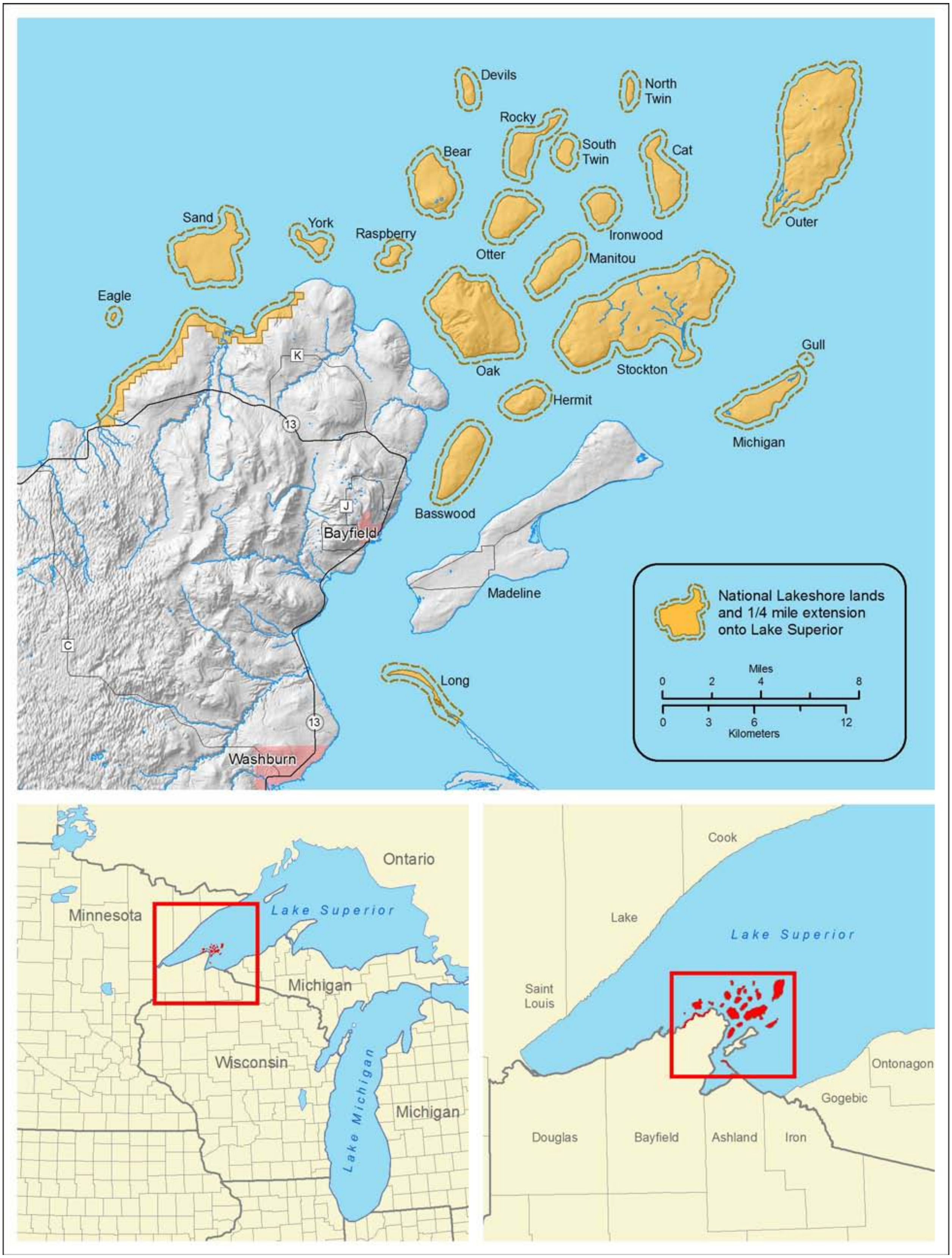


Figure 1. Location of Apostle Islands National Lakeshore in the upper Great Lakes region of the United States (see Appendix A for sources).

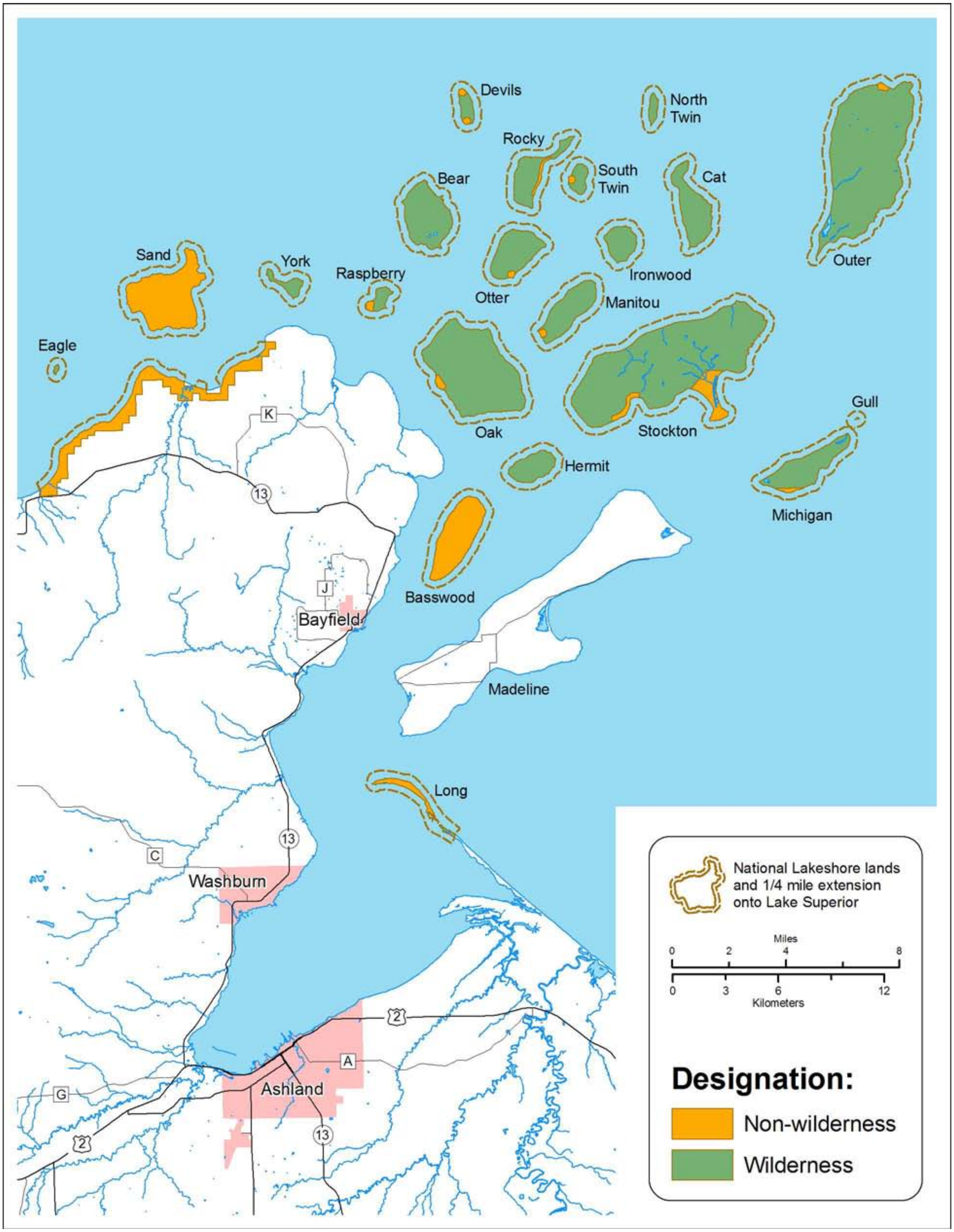


Figure 2. Wilderness areas of the Apostle Islands National Lakeshore (after NPS 2006b).

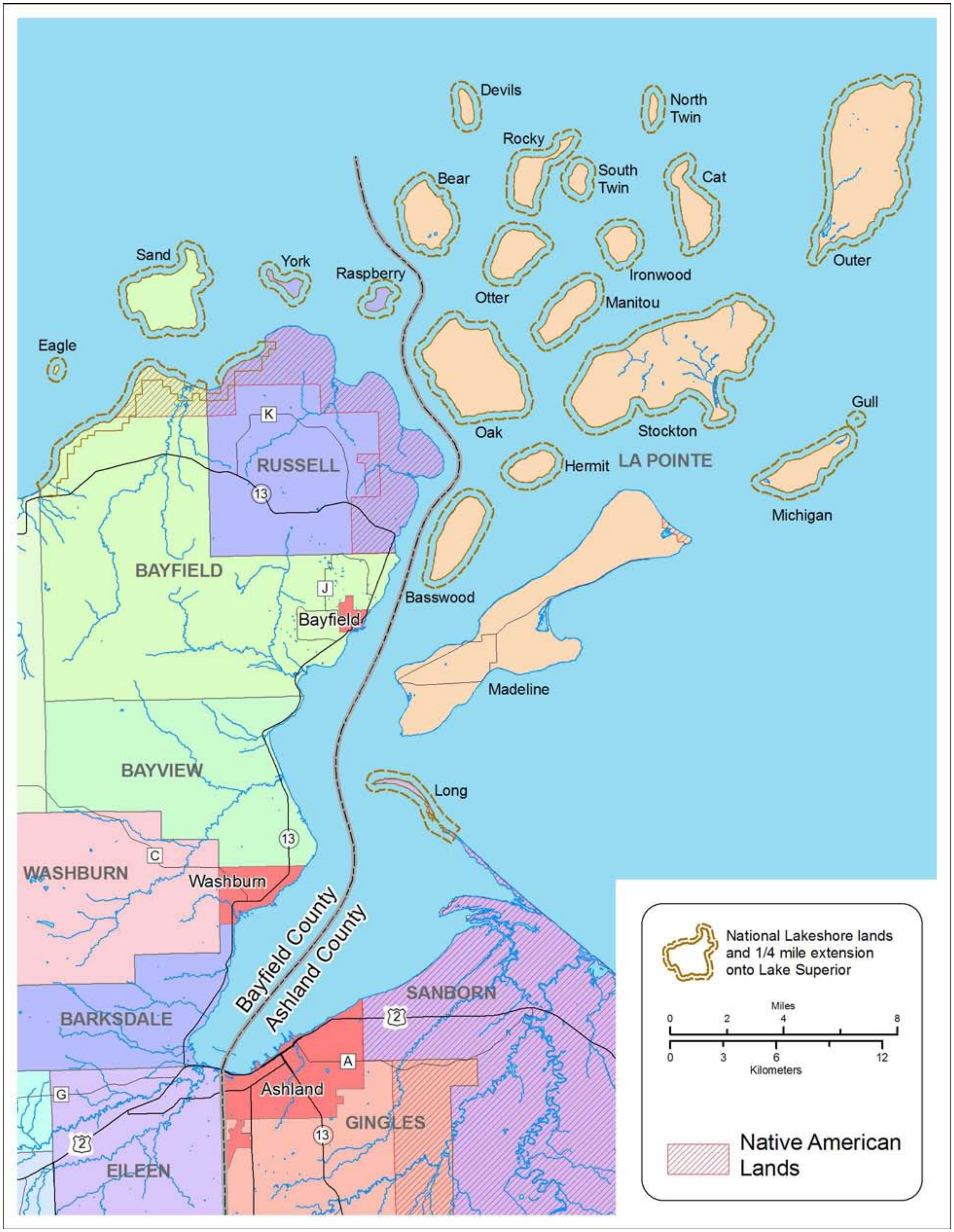


Figure 3. Municipal units in the Apostle Islands area
(OLIS 1999, 2000).

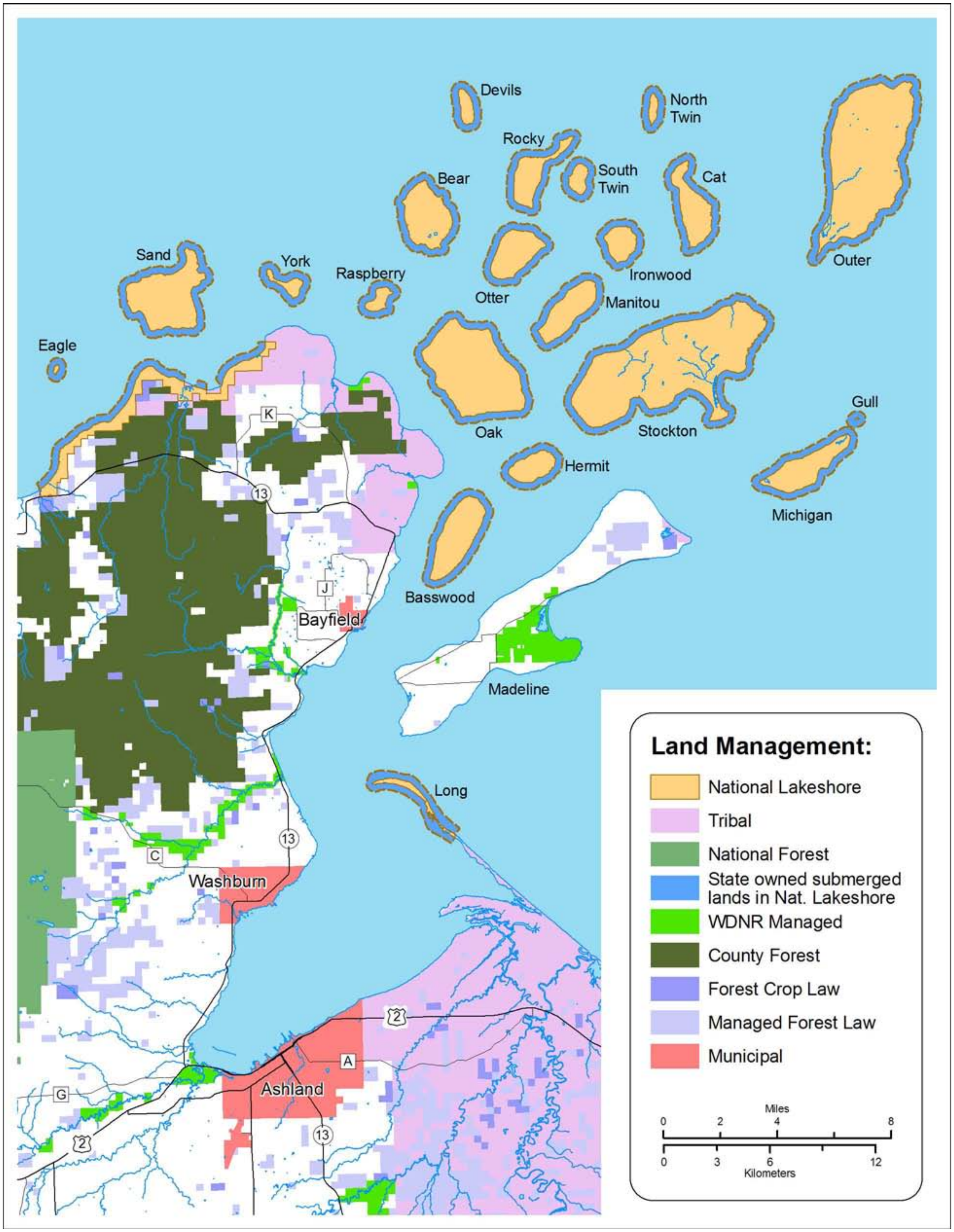


Figure 4. Land management in the Apostle Islands area
(OLIS 1999, 2000; USDA - Forest Service 2001; NPS 2001; WDNR 2005k, l, m, n).

Key Features

APIS is located in and along the shore of Lake Superior, which has the greatest surface area of any freshwater lake in the world. The lake is 560 km long and 260 km wide at its longest and widest points, respectively, and it contains 10% of Earth's fresh surface water. Its cold temperatures, large size, and watershed's low population density result in it being one of the cleanest lakes in the world (NPS 2002a).

APIS includes some of the most pristine sandscapes left in the Great Lakes region, such as sand spits, cuspate forelands, tombolos, a barrier spit (Long Island), and numerous beaches. Sand spits are long, narrow sand deposits that extend outward from the mouth of a bay or a tip of land. Cuspate forelands are similar to sand spits but are more wedge-shaped. Tombolos are sand deposits that connect islands to each other or to the mainland (NPS 2002b). Other outstanding features include colorful sandstone cliffs and sea caves, some pristine old-growth forests, and the largest collection of lighthouses in the National Park System (NPS 2004b, 2005b) (Figure 5). The WDNR Natural Heritage Inventory Program has designated four types of state natural areas within APIS: maritime forest, sandscape, maritime cliff, and critical species areas (NPS 2005a; WDNR 2006f).

APIS's inland surface water resources are not abundant, but include lagoons on Stockton, Michigan, and Outer Islands; Sand River and Saxine Creek on the mainland, and unnamed perennial streams on Stockton and Oak Islands; and the Sand River estuary (Van Stappen 1999). Bogs, beaver ponds, and wetlands occur on many of the islands, and APIS includes more kilometers of intermittent streams than any other Great Lakes national park (Lafrancois and Glase 2005).

Climate

The region encompassing APIS has a humid continental climate characterized by long, cold winters and rather short, moderately warm summers. Bayfield County has an average temperature of 5^{o}C, and on average receives 71 centimeters (cm) of precipitation, which includes 127-191 cm of snow (Laumann 2003). However, the climate of the islands, and to some extent the mainland unit of APIS, is moderated by Lake Superior, and hence is more maritime (Table 1). In comparison to the mainland, the islands experience warmer winters, a later spring arrival, cooler summers, and a longer fall, though the more outlying islands, e.g., Devils and Outer, are cooler than those more inland (NPS 2005a).

In Bayfield County, prevailing winds are westerly from early fall through early spring and easterly the remainder of the year (Laumann 2003). In APIS, when storms occur, the prevailing winds blow from the northwest, north, and northeast (NPS 2005a).

Even in a severe winter, the ice coverage on Lake Superior is normally limited to 40-50%, although it may briefly reach 80-90% (NOAA 2006). Chequamegon Bay is usually icebound from December until April (Laumann 2003). In the west end of the lake, 10-15 cm of fast ice builds northeast from Duluth as far as APIS. Rafting and ridging may make ice as thick as 1.2 m in navigation areas (NOAA 2006).

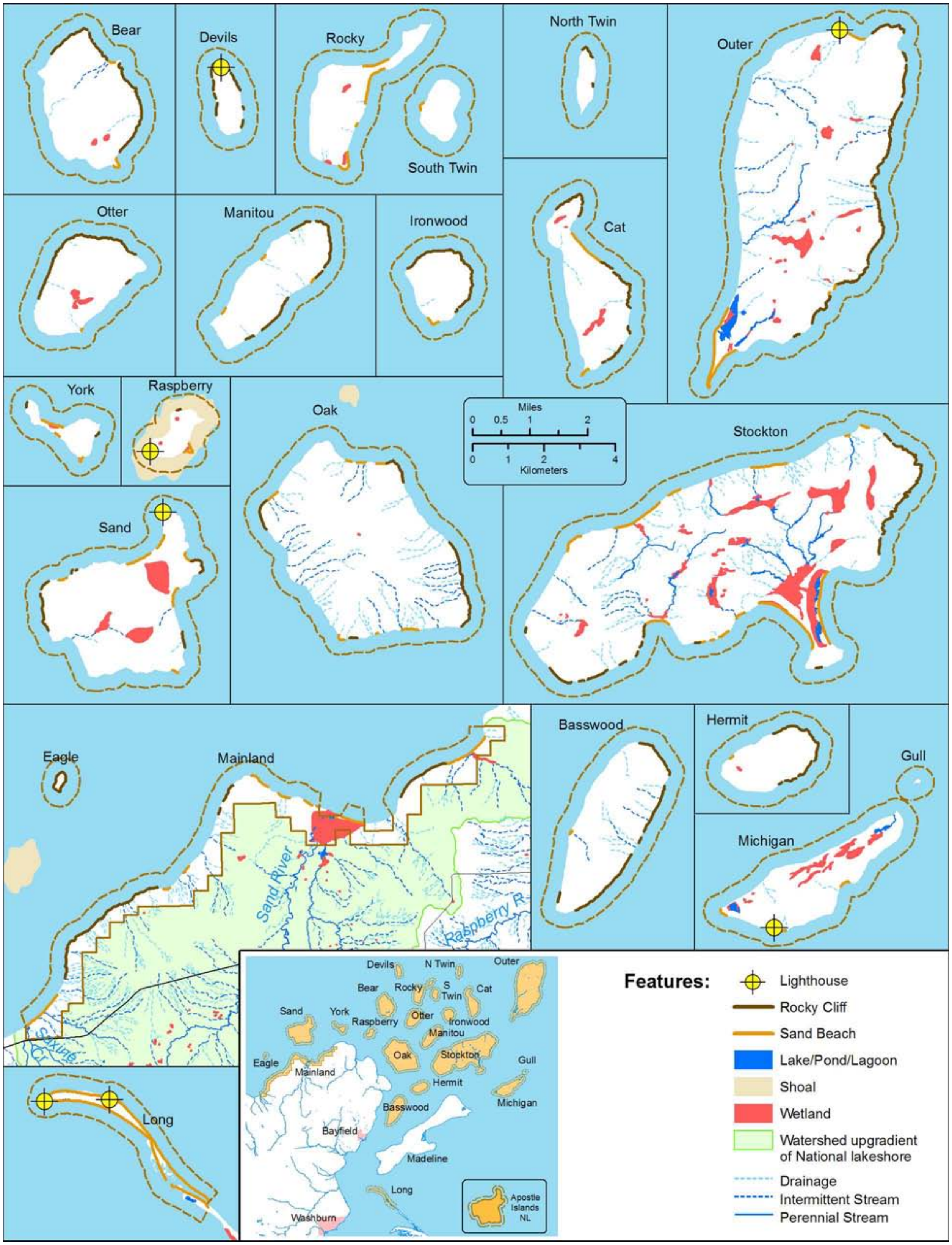


Figure 5. Key features and water resources of Apostle Islands National Lakeshore (NPS 1999b, c; USEPA 2000; NPS 2005d; NRCS 2005).

Table 1. Climate data for the inland Ashland Experimental Farm compared to Madeline Island and Bayfield 6 North, which are affected by proximity to Lake Superior (Wisconsin State Climatology Office 2004).

	Ashland Experimental Farm	Madeline Island	Bayfield 6 North
January mean temperature (°C)	-12.3	-11.0	-11.1
July mean temperature (°C)	19.6	18.7	19.1
Recorded extremes (°C)	-41 to 42	-37 to 39	-37 to 40
Median number of days in growing season (>0°C)	115	129	135
Annual precipitation (cm)	76.3	84.3	85.0
Annual snowfall (cm)	147.3	187.7	247.9

Land Use and Vegetative Cover

APIS is located at the contact zone between the hemlock-white pine-northern hardwood forest and the boreal forest. Before human settlement, about 90% of the islands were covered by an upland mixed coniferous/hardwood forest dominated by hemlock (*Tsuga canadensis*), white pine (*Pinus strobus*), sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), and white birch (*Betula papyrifera*) (NPS 2005a). Boreal forest species include white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), tamarack (*Larix laricina*), white cedar (*Thuja occidentalis*), white birch, and trembling aspen (*Populus tremuloides*) (Van Stappen 1999). Additional plant communities include those of sandscapes (dunes, pine savanna and forest, and bogs), alder thickets and beaver flowages, clayscapes, rockscapes, and disturbed areas (Judziewicz and Koch 1993).

APIS's monitoring plan (Van Stappen 1999) lists 13 habitat types largely defined by their vegetative cover (Table 2). Conifer forests dominated by white cedar and northern hardwood sugar maple forests are the two most common types, followed by aspen-birch forests and northern hardwood mixed forests. In all, over 96% of APIS is classified as forest habitat.

Similarly, the Wisconsin Land Cover Grid (WDNR 1998) classifies 91.3% of the islands as forest, and an additional 3.6% as forested wetlands (Table 3). In the mainland unit, 88.5% is classified as forest, 2.5% as forested wetlands, and 5.2% as wetlands with deciduous shrubs. The watershed that contributes to the mainland unit is also similar, with 86.7% forest, 1.6% as forested wetlands, and 10.2% as grassland (Figure 6).

In all, more than 800 plant species occur within APIS (Judziewicz and Koch 1993), including five state-endangered species, 12 state-threatened species, and 23 species of special concern in Wisconsin (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2007). Some of APIS's habitats are regionally rare, including old-growth forest, boreal forest, five types of northern forests, forest seep, clay bluff communities, sandstone cliff communities, lagoon and bog communities, forested ridge and swale, coastal fen, Great Lakes barrens, and dune communities (NPS 2005a).

Table 2. Vegetation types by habitat in Apostle Islands National Lakeshore (after Van Stappen 1999).

Habitat type	**Dominant species**	**% of APIS**	**Where found**
Conifer forests	White cedar	21.9	Western islands, mainland unit
Northern hardwood sugar maple forests	Sugar maple	21.7	Not specified
Aspen/birch forests	Trembling aspen, white birch	16.8	Coasts of most islands
Northern hardwood mixed forests	Yellow birch, red maple (*Acer rubrum*), balsam fir, sometimes Canada yew (*Taxus canadensis*)	15.8	Not specified
Northern hardwood hemlock forests	Hemlock	10.8	Bear, Oak, Outer, and Stockton Islands
Boreal forests	White spruce, black spruce (*Picea mariana*), balsam fir, tamarack, white cedar, white birch, trembling aspen	3.1	Devils, North Twin, Raspberry, South Twin, York, Rocky, and Sand Islands
Old-growth northern hemlock forest	Hemlock, yellow birch, Canada yew	3.0	Outer Island
Oak forests	Northern red oak (*Quercus rubra*), northern pin oak (*Quercus ellipsoidalis*)	3.0	Oak and Long Islands
Bog wetlands	Not specified	1.9	Many islands, especially Devils, Outer, and Stockton Islands
Pine forests	White pine, red pine (*Pinus resinosa*), Jack pine (*Pinus banksiana*)	0.6	Stockton Island tombolo, Long Island
Clearings or open areas	Not specified	0.3	Areas of historic logging, farming, quarrying, and lighthouses
Dunal features	Beach grass (*Ammophila breviligulata*), beach pea (*Lathyrus japonicus*), speckled alder (*Alnus incana* subsp. *rugosa*), trembling aspen, white birch	Not specified	Not specified
Old-growth conifer forest	Balsam fir, white cedar, white spruce, black spruce, white birch, white pine, yellow birch, Canada yew	Not specified	Devils and Raspberry Islands

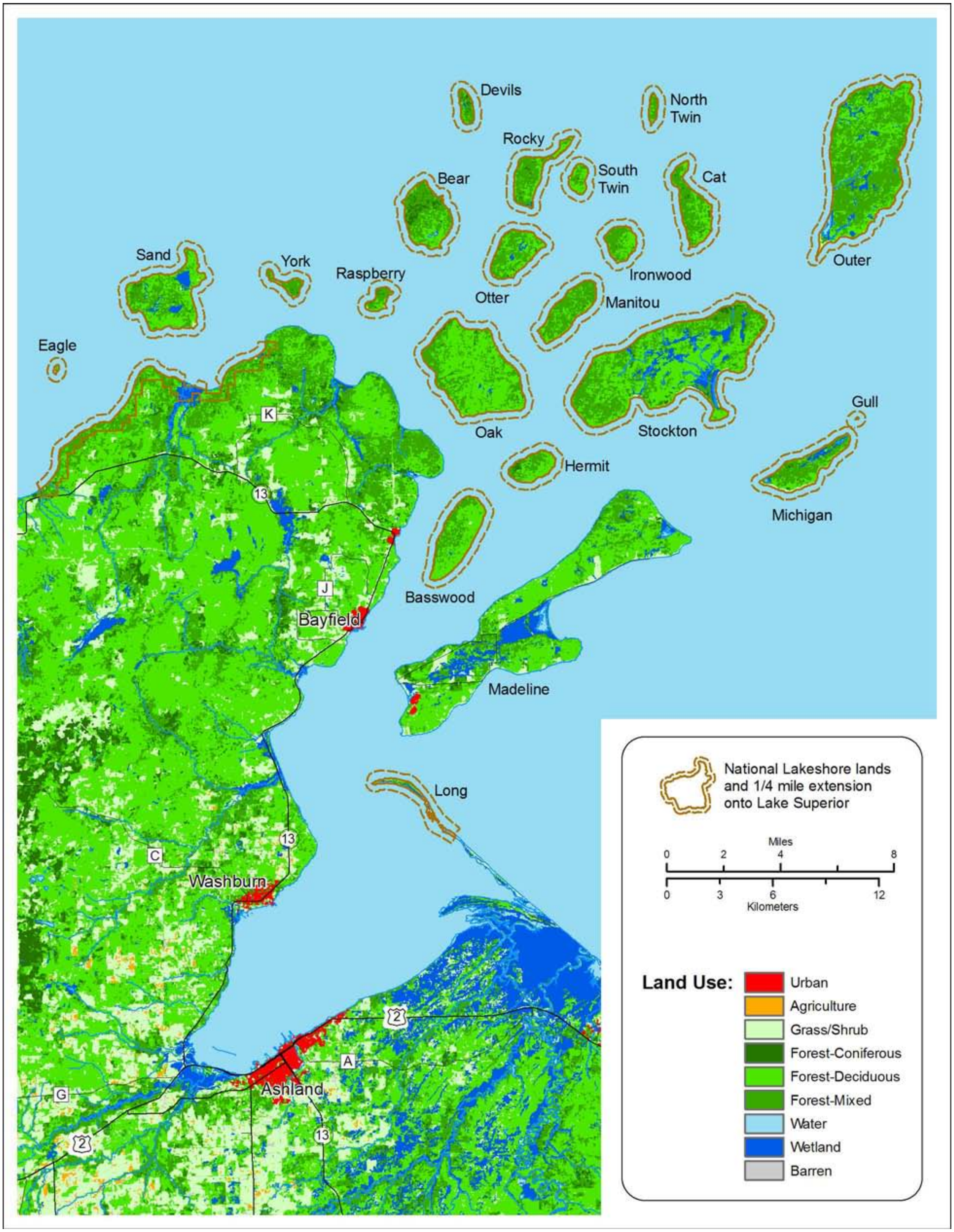


Figure 6. Land cover in the Apostle Islands National Lakeshore area (WDNR 1998).

Table 3. Wisconsin Land Cover Grid land cover for Apostle Islands National Lakeshore islands, mainland unit, and land in the mainland unit's watershed (WDNR 1998).

Land Cover Type		APIS Islands		APIS Mainland		APIS Watershed upgradient of Mainland	
		ha	**%**	**ha**	**%**	**ha**	**%**
150	Grassland	163	1.0	7	0.7	1,328	10.2
163	Forest-Red Pine	80	0.5	7	0.7	381	2.9
173	Forest-Mixed Conifers	312	2.0	20	1.9	151	1.2
176	Forest-Aspen	2,822	17.9	177	17.5	3,368	25.9
187	Forest-Mixed Deciduous	3,778	23.9	106	10.4	4,536	34.9
190	Forest-Mixed Conifer/Deciduous	7,433	47.0	587	57.9	2,834	21.8
	Total Forest	**14,425**	**91.3**	**897**	**88.5**	**11,271**	**86.7**
200	Water	388	2.5	21	2.0	5	<0.1
211	Wetland-Emergent/ Wet Meadow	98	0.6	11	1.1	20	0.2
218	Wetland-Shrub Deciduous	137	0.9	52	5.2	170	1.3
219	Wetland-Shrub Evergreen	22	0.1	0	0	0	<0.1
223	Wetland-Forest Deciduous	154	1.0	8	0.8	79	0.6
229	Wetland-Forest Coniferous	223	1.4	10	0.9	58	0.4
234	Wetland-Forest Mixed Deciduous/ Coniferous	192	1.2	8	0.8	75	0.6
	Total Wetland	**826**	**5.2**	**89**	**8.8**	**403**	**3.1**
	Totals	**15,802**	**100**	**1,013**	**100**	**13,007**	**100**

Historic and Current Human Uses

APIS may have been occupied at least seasonally by native peoples as early as Paleoindian times, 9,000 to 12,000 years before present (BP) (NPS 2005a). For the last 400 years, the Apostle Islands have been used in some manner by the Lake Superior Ojibwe (Chippewa) and their ancestors.

The European history of the Apostle Islands area began in 1659, when the French explorers and fur traders Pierre Radisson and Sieur des Groseilliers built a temporary outpost on the shores of Chequamegon Bay (Jordahl 1994). A military post was established by 1693 on Madeline Island. The Ojibwe became resident in the Chequamegon region sometime in the 1700s. By 1835, La Pointe became the commercial center for the western half of Lake Superior, and both Catholics and Protestants had active missions there. By contrast, today’s major mainland cities in the region, such as Ashland, Superior, and Duluth, were not settled until after the Sault Locks were opened, around 1854. Anticipating the eventual decline of fur trading, a commercial fishing venture was begun among the islands at this time. It was the earliest such venture on Lake

Superior, but started off poorly because of the difficult economic times, only to become successful again around 1870 (Jordahl 1994).

In the 1840s, minerals such as copper and iron were discovered in the Upper Peninsula of Michigan. The U.S. government, wishing to acquire mineral lands, ordered the Ojibwe to relocate to Minnesota, but eventually assigned them to lands on the mainland at the location of their present-day reservations east and south of Ashland and on the Bayfield Peninsula. Also in the 1840s, logging operations began with the building of a small sawmill. As shipping on the lake increased in importance, the U.S. Lighthouse Service built lighthouses on Michigan Island in 1857 and on Chequamegon Point in 1858 (Jordahl 1994).

Between 1868 and 1898, four sites in the Apostle Islands hosted seven separate brownstone quarry operations. Basswood Island was the first, followed by Stockton and Hermit Islands. The quarries eventually closed because of national economic problems, changes in architectural fashion, and the development of new types of building materials (NPS 2002c).

In 1865, the first homesteader made his home and began to farm on Basswood Island. Rocky, South Twin, Ironwood, Michigan, and Sand Islands also saw farms established, but most did not last past the end of the 19th century, and by World War II farming was no longer practiced on any of the islands (NPS 2002f). The late 1800s also saw the growth of tourism in the region, and the establishment of permanent settlements on Madeline and Sand Islands (Jordahl 1994).

By the late 1920s, the prime timber species in the region were essentially exhausted, although some areas had escaped commercial logging. These included North Twin, Eagle, Gull, Devils, and Raspberry Islands, and the lighthouse reservations on Outer and Sand Islands (NPS 2005a). By 1940, the year-round community on Sand Island had disbanded. In the 1950s, the fishing industry began to collapse because of overfishing, pollution, introduction of competing exotic species, and sea lamprey depredation (Jordahl 1994).

In the 1950s, conservationists and the Wisconsin Legislative Council Conservation Committee pushed for public acquisition of the islands. In 1959, Stockton, Oak, and Basswood Islands were purchased to form an Apostle Islands State Forest. The area had been previously considered for National Park status in the 1930s, but the devastating effects of logging and fires caused it to be rejected. However, by the 1960s, many of the worst scars on the land had healed, and with the help of U.S. Senator and former Wisconsin governor Gaylord Nelson, APIS was established in 1970 (Jordahl 1994).

Geology and Soils

The basement rock for all of APIS is Precambrian sandstone of the Bayfield Group of the Keweenawan Supergroup. At approximately 600 million years old, it is the youngest Precambrian sedimentary rock in the Lake Superior region (USGS 2005). The Keweenawan Supergroup is up to 15 km thick; its upper members, the Oronto Group, Bayfield Group, and Jacobsville sandstone are together approximately 7 km thick (Cannon et al. 1999b). The Bayfield Group includes (from youngest to oldest) the Cheqaumegon, Devils Island, and Orienta Formations, which have thicknesses of up to 150 m, 90 m, and 550 m respectively

(Nuhfer and Dalles 1987). The Chequamegon is a generally thickly bedded, reddish-brown, and feldspathic sandstone, and is present on the majority of the islands (Figure 7) (Cannon et al. 1999b). The underlying Devils Island formation is pink and white quartz with many ripple marks. It is thinly bedded and easily erodible, and is the formation in which most APIS sea caves are formed. It is the uppermost bedrock unit on Devils Island, part of Sand Island, and the western portion of the mainland unit. The Orienta is a red, brown, and white feldspathic sandstone which underlies all of APIS but is exposed only on a part of Sand Island and on Eagle Island (Nuhfer and Dalles 1987).

Atop the Precambrian rock lie till, lacustrine, and shore deposits of Pleistocene and Recent epochs. Tills originated during the glaciations that ended about 12,000 BP. Following the retreat of the glacier, APIS was first deeply submerged as lake levels rose to 329 m above mean sea level (AMSL) around 11,000 BP, then exposed as lake levels fell to 114 m AMSL about 8,000 BP. Lake levels rebounded until about 5,500 BP, when they were within a meter of today's Lake Superior elevation of 182 m AMSL (Cary et al. 1979). Fluctuating lake levels have had multiple influences on APIS surficial geology. During periods of deep submergence, lacustrine clays were deposited in parts of APIS, while during periods of falling lake levels, surficial materials were reworked by wave action, creating the sandy to cobbly beach deposits that extend well into the interior of the islands and mainland. More modern lake levels have eroded some shorelines while creating beaches, spits, and dunes in others.

The influence of Lake Superior is still seen today in the surficial geology of the islands and mainland unit (Figure 8, Table 4). Most islands display wave-planed topography, except for the westernmost islands (Raspberry, York, Sand, and Eagle) which display lake-modified glacial topography (Clayton 1984). Postglacial deposits include well-sorted sand and gravel shoreline sediments on Michigan, Outer, Rocky, and Stockton Islands and all of Long Island, and stream sediments at the outlet of the Sand River in the mainland unit (Clayton 1984). Clayton (1984) made particular note of organic sediments on Sand and Stockton Islands, but all islands with substantial wetlands have organic sediments.The mainland unit is part of the Bayfield Lake-Modified Till Plain ecological unit of Wisconsin, whose characteristic landform is hilly modified lacustrine moraine with deep v-shaped ravines (WDNR et al. 1999).

Sandy shore deposits dominate the surficial geology of Outer, Devils, Rocky, South Twin, Otter, Basswood, Raspberry, Otter, and Manitou Islands, while lacustrine clays dominate on Sand, York, Cat, Eagle, Gull, Ironwood, North Twin, Michigan, and Hermit Islands. Stockton, Madeline, and Bear Islands have both. Oak Island and the mainland unit have a surficial geology consisting of lake clay and stratified sand and gravel end moraine (Young and Skinner 1974).

The thickness of these deposits is variously reported to be from 1.5 - 15 m on Basswood Island, from 1.5 - 30 m on parts of Sand, Stockton, and Madeline Islands, and from 15 - 30 m in the mainland unit (WDNR et al. 1999), and up to 46 m on part of Madeline Island and up to 61 m in the mainland unit (Young and Skinner 1974). Islands without thick till cover include Devils, North Twin, Eagle, and Gull (Nuhfer and Dalles 1987).

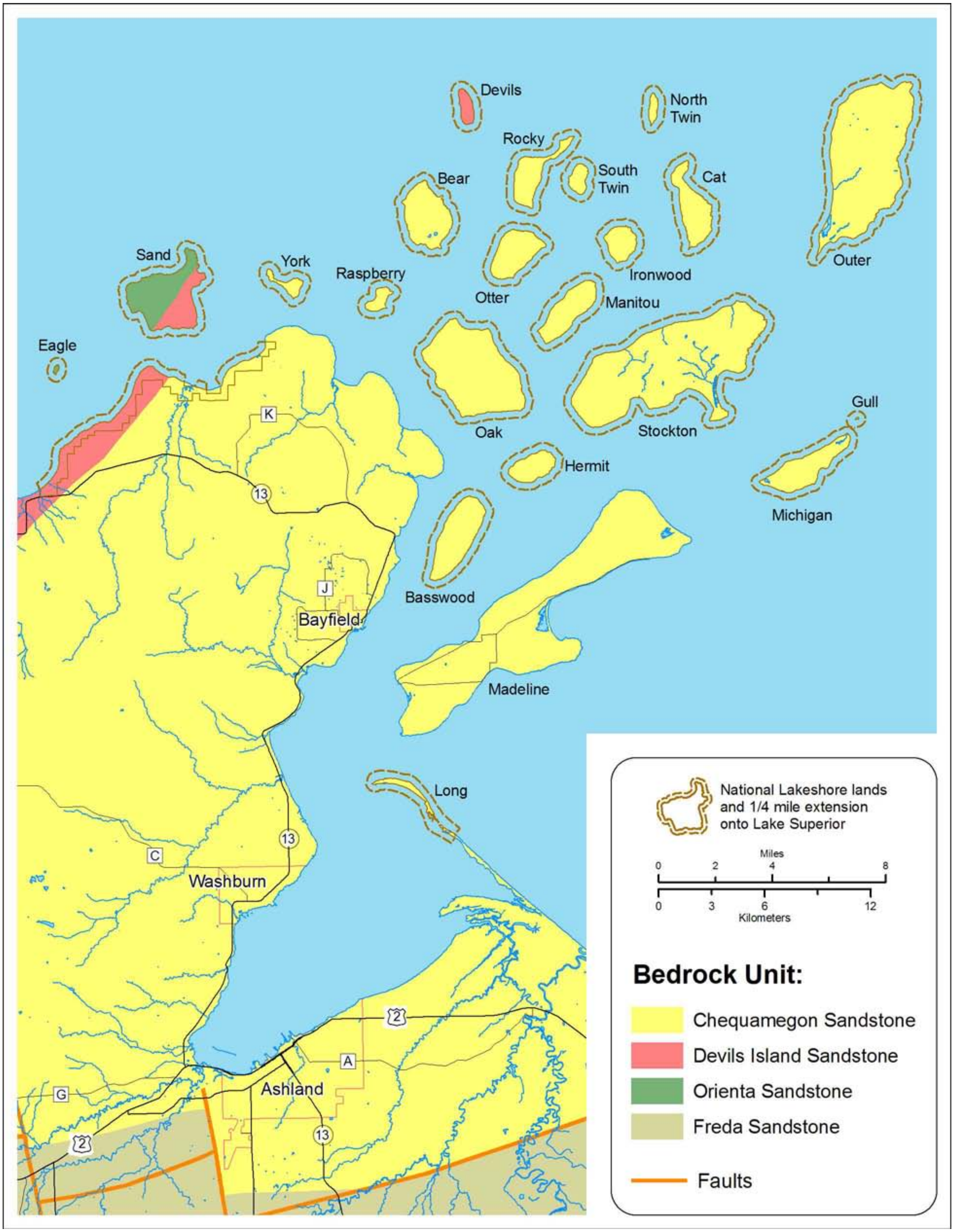


Figure 7. Bedrock geology of the Apostle Islands area
(derived from Cannon et al. 1999a, b; Nicholson et al. 2004).

Table 4. Pleistocene Geology of Apostle Islands National Lakeshore (after Clayton 1984).

	Postglacial deposits			**Miller Creek Formation**		**Bedrock**	**Landforms**	
	Shoreline sediment	**Stream sediment**	**Organic sediment**	**Lake-modified glacial topography**	**Wave-planed topography**	**Pre-Pleistocene rock**	**Abandoned beaches and wave-cut bluffs**	**Drumlins**
Mainland unit		Sand River outlet		Present	Most of the unit		Present	Present
Basswood					Entire island			
Bear				Present	Present	Present		
Cat					Entire island			Present
Devils					Entire island			Present
Eagle				Entire island				
Gull*								
Hermit					Entire island		Present	
Ironwood					Entire island			
Long	Entire island							
Manitou					Entire island			
Michigan	Present				Most of the island			Present
North Twin					Entire island			
Oak				Present	Most of the island		Present	
Outer	Present				Most of the island		Present	
Otter					Entire island			
Raspberry				Entire island				
Rocky	Present			Present	Present	Present		
Sand			Present	Most of the island				
South Twin					Entire island			
Stockton	Present		Present	Present	Present		Present	Present
York				Entire island				

*unable to determine at scale of map

Table 4. Pleistocene Geology of Apostle Islands National Lakeshore (continued).

KEY

Shoreline sediment: Well sorted sand and gravel (no more than a few metres above the present level of Lake Superior). Deposited after about 5,000 BP.

Stream sediment: Sand and gravel (channel deposits); generally more than 1 m thick. In many places overlain by silt and clay (overbank deposits) or peat. Floodplains of modern streams. Most deposited since about 10,000 BP.

Organic sediment. Peat; less than 1 m thick in some areas, but typically probably a few meters thick. Low-lying, flat swamps, bogs, and marshes. Most deposited since about 10,000 BP.

Lake-modified glacial topography. Topography subdued as the result of wave action or as the result of being deposited in a water-logged state during high stages of Lake Superior. Low-relief, hummocky collapse topography in most places, but drumlinized in some areas. Till is typically 1 to 20 m thick.

Wave-planed topography. Occurs on higher and steeper parts of the Superior lowland than map unit gl, where waves have been more active. In some areas Miller Creek till is overlain by a thin (typically 1 m) layer of near-shore sand, and in some areas the Miller Creek till has been eroded away, exposing underlying Copper Falls till, stream sediment, or shoreline sediment.

Pre-Pleistocene bedrock. Middle Proterozoic lithic sandstone, mudstone, and conglomerate of the Oronto Group and Late Proterozoic or Cambrian quartz sandstone of the Bayfield Group at the surface in much of the area, but till or stream sediment may be a few metres or more thick in many areas.

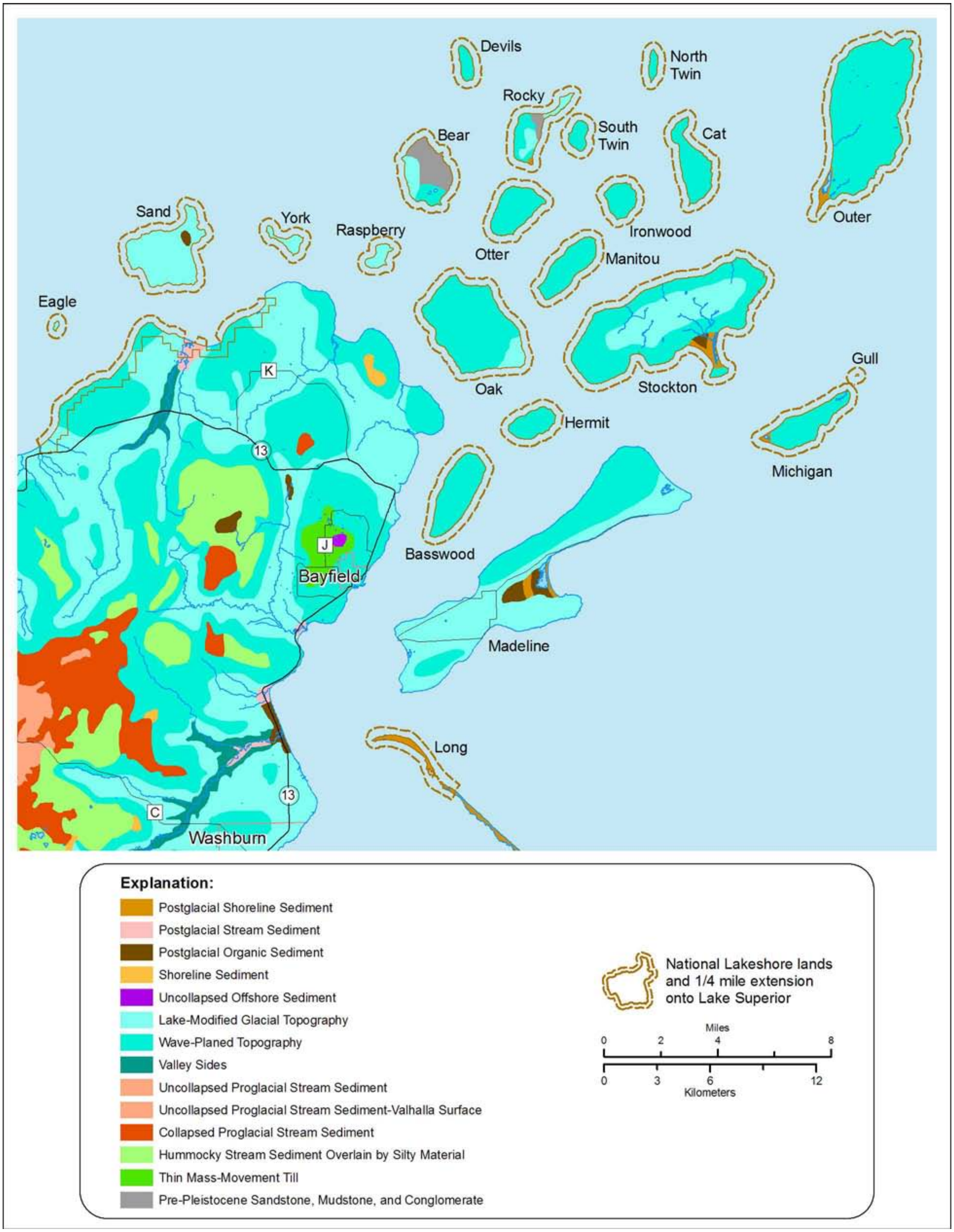


Figure 8. Pleistocene Geology of the Apostle Islands area (after Clayton 1984).

Soils in APIS have been mapped by a number of workers at various levels of detail (e.g., Whitson et al. 1914, 1929; Anderson et al. 1979, 1980; Milfred and Anderson 1985). The Ecological Landscapes of Wisconsin report (WDNR et al. 1999) describes island soils as "moderately well drained, somewhat poorly drained, and well drained loamy, clayey, and sandy soils with a sandy loam, clay loam or loamy sand surface over calcareous clay till, non-calcareous sand beach deposits, sandstone, or a combination of each." Similarly, mainland soils are described as "well drained, moderately well drained, and somewhat poorly drained clayey and sandy soils with a silt loam, loamy fine sand or sand surface over calcareous clay till or non-calcareous beach deposits or both."

Soil surveys for both Ashland and Bayfield Counties were published in 2006 (NRCS 2006a, 2006b). Island soils ranged from sandy to clayey, and some new series were needed to define soils unique to the islands. Overall, island soils have thicker humus/organic matter surfaces than those found on the mainland (NPS 2004a). The number of soil mapping units found on each island varies from one on Eagle and Gull Islands to 27 on Outer Island and 31 on Stockton Island (Appendix C).

The four most common soil mapping units in the APIS mainland unit account for 60.6% of all soils (Portwing-Herbster Complex, 19.1%; Kellogg-Allendale Complex, 15.5%; Udorthents, Ravines, and Escarpments, 16.9%; and Cornucopia Silt Loam, 7.5%) (Table 5). Similarly, for the watershed upgradient of the mainland unit, four soil mapping units account for 60.4% of all soils (Portwing-Herbster Complex, 26.9%; Kellogg-Allendale Complex, 15.6%; Udorthents, Ravines, and Escarpments, 9.1%; and Superior-Sedgwick Complex, 8.8%). Among the islands, there is slightly greater variability: six soil mapping units account for 58.8% of all soils (Kellogg-Allendale Complex, 15.6%; Superior-Sedgwick Complex, 14.7%; Morganlake Loamy Sand, 8.7%; Sedgwick-Munuscong Complex, 7.6%; Portwing-Herbster Complex, 6.4%; and Udorthents, Ravines, and Escarpments, 5.8%). Detailed tables of the soils for each island are included as Appendix C.

Table 5. Soil mapping units and areas for Apostle Islands National Lakeshore mainland watershed, mainland unit, and islands (NRCS 2006a, 2006b).

Soil Mapping Units			Number of Hectares			
Number	Name	% Slope	Mainland Watershed	Mainland Unit	Islands	Park
1385B	CUBLAKE-KEWEENAW, STONY COMPLEX	0-6	4.0	0.0	104.8	104.8
174	RUBICON SAND	0-60	41.7	0.8	0.0	0.8
2015	PITS		9.5	0.0	0.0	0.0
203	WAKEFIELD FINE SANDY LOAM, STONY	1-18	35.5	0.0	341.9	341.9
226A	ALLENDALE LOAMY FINE SAND	0-3	9.2	0.0	275.6	275.6
319A	TONKEY SANDY LOAM	0-2	0.0	0.0	46.7	46.7
3276A	AU GRES LOAMY SAND	0-3	0.0	9.4	0.0	9.4
339D	ROUSSEAU LOAMY FINE SAND	15-30	6.6	0.0	0.0	0.0
3403A	LOXLEY, BESEMAN, AND DAWSON SOILS	0-1	0.0	0.0	275.6	275.6
3423A	RIFLE PEAT	0-1	8.1	38.6	93.3	131.8
3512D	MENOMINEE LOAMY SAND	15-30	5.0	0.0	1.3	1.3
3608	DEERTON-BROWNSTONE COMPLEX,VERY STONY	0-15	29.0	44.4	854.6	898.9
3609C	ABBAYE LOAMY SAND	6-15	22.2	42.2	59.0	101.2
375A	ROBAGO FINE SANDY LOAM, LAKE TERRACE	0-3	1.5	0.0	0.0	0.0
376B	TULA FINE SANDY LOAM, STONY	1-6	36.8	0.0	86.0	86.0
3826B	ALLENDALE-WAKELEY-KINROSS COMPLEX	0-6	374.5	35.4	185.2	220.6
405A	LUPTON, CATHRO, AND TAWAS SOILS	0-1	125.0	39.5	168.3	207.8
475	RUBICON-SAYNER COMPLEX	0-30	195.4	0.0	0.0	0.0
479A	LERCH-HERBSTER COMPLEX	0-3	643.0	11.4	80.8	92.2
480B	PORTWING-HERBSTER COMPLEX	0-6	3499.4	192.7	1011.7	1204.5
481	CORNUCOPIA SILT LOAM	6-45	786.4	75.1	115.3	190.4
500B	CROSWELL SAND	0-6	0.0	1.5	10.5	12.0
509B	GOGEBIC FINE SANDY LOAM, VERY STONY	1-6	0.0	0.0	59.8	59.8
514B	IOSCO LOAMY SAND	0-4	0.0	0.0	657.3	657.3
517	ANNALAKE FINE SANDY LOAM, LAKE TERRACE	2-15	9.4	10.3	0.0	10.3
526A	FLINK SAND	0-3	17.7	3.7	0.0	3.7
574E	SAYNER LOAMY SAND	15-45	145.3	0.0	0.0	0.0
579B	PARKFALLS SANDY LOAM, VERY STONY	0-4	3.7	0.0	0.0	0.0
597A	MEEHAN SAND, BEACHES	0-2	0.0	0.0	70.6	70.6
598A	WURTSMITH SAND, BEACHES	0-3	0.0	0.0	79.4	79.4

Table 5. Soil mapping units and areas for Apostle Islands National Lakeshore mainland watershed, mainland unit, and islands (continued).

Soil Mapping Units			**Number of Hectares**			
Number	**Name**	**% Slope**	**Mainland Watershed**	**Mainland Unit**	**Islands**	**Park**
599C	GRAYLING SAND, BEACHES	2-12	0.0	0.0	81.7	81.7
5A	ARNHEIM MUCKY SILT LOAM, FREQUENTLY FLOODED	0-1	56.3	2.3	63.1	65.4
603B	REDRIM VERY COBBLY SAND, VERY STONY	0-6	0.0	17.1	99.9	117.0
605B	LAPOIN LOAM	0-6	10.4	26.5	9.3	35.8
610B	ZEBA SANDY LOAM, VERY STONY	0-6	4.0	0.0	289.6	289.6
611B	ABBAYE-LAPOIN COMPLEX	0-6	28.3	22.4	442.1	464.5
614B	ABBAYE-ZEBA COMPLEX, VERY STONY	0-6	0.0	0.0	220.5	220.5
674	SULTZ SAND	0-45	105.5	0.8	0.0	0.8
6A	MOQUAH FINE SANDY LOAM, FREQUENTLY FLOODED	0-3	111.8	2.7	0.0	2.7
705	CUBLAKE-CROSWELL-ASHWABAY COMPLEX	0-15	959.5	35.5	763.7	799.2
712	MORGANLAKE LOAMY SAND	0-15	84.4	0.0	1374.9	1374.9
713	KELLOGG-ALLENDALE-ASHWABAY COMPLEX	2-15	2033.2	156.0	2463.4	2619.4
753B	SEDGWICK-MUNUSCONG COMPLEX	0-6	138.0	1.0	1202.3	1203.3
756	SUPERIOR-SEDGWICK COMPLEX	0-15	1145.7	40.3	2323.9	2364.2
7C	BEACHES	2-12	0.0	6.9	142.3	149.2
805E	SULTZ-ASHWABAY-RUBICON COMPLEX	15-45	422.0	7.1	229.7	236.8
813E	MANISTEE-KELLOGG-ASHWABAY COMPLEX	15-45	258.6	8.6	196.9	205.6
874	KEWEENAW, STONY-RUBICON COMPLEX	0-30	453.6	0.0	346.9	346.9
92F	UDORTHENTS, RAVINES, AND ESCARPMENTS	25-60	1181.6	170.6	914.8	1085.3
M-W	MISCELLANEOUS WATER		0.0	0.0	2.3	2.3
W	WATER		4.4	4.6	24.5	29.1
	TOTALS		13012.2	1007.2	15769.6	16776.8
	Most common mapping units highlighted in gray					

General Hydrology and Water Budget

Data from the weather station on Madeline Island indicates that APIS receives approximately 84 cm of precipitation each year (Wisconsin State Climatology Office 2004). No specific water budget has been done for APIS, but a number of studies provide general insight on water budget and hydrology. The Wisconsin portion of the Lake Superior basin, which encompasses APIS, has an average water budget that includes an input of 79 cm of precipitation, and outputs of 45 cm evapotranspiration, 32.5 cm stream runoff (both overland and baseflow), and 1.3 cm groundwater underflow directly to Lake Superior (Table 6) (Young and Skinner 1974).

According to Laumann (2003) Bayfield County receives 71 cm of precipitation annually, of which runoff accounts for 33 cm (46%). A model developed for the Whittlesey Creek watershed in Ashland County estimated that in 1992-93, 67% (63.5 cm) of the 94.7 cm of annual precipitation was lost as evapotranspiration, 18.4% (17.5 cm) became surface water runoff, and 9.8% (9.4 cm) infiltrated to recharge groundwater. The remaining 4.8% (4.6 cm) was attributed to a change in soil moisture storage during the modeling period (Lenz et al. 2003).

Table 6. Hydrologic budget for the Wisconsin portion of the Lake Superior basin, 1931-1960 (Young and Skinner 1974).

	Precipitation (cm)	**Runoff (cm)**	**Change in storage (cm)**	**Underflow (cm)**	**Evapotranspiration (cm)**
Dry year (1963)	55.5	22.4	-2.8	1.3	34.5
Average (1931-60)	78.7	32.5	0	1.3	45.0
Wet year (1951)	112.8	62.7	+1.5	1.3	47.2

Bennett (1978) proposed a water budget for Lake Superior with inputs of direct precipitation (69.6 cm) and land drainage (65.7 cm), and outputs of evaporation (47.0 cm) and outflow through the St. Mary’s River (88.3 cm). Similarly, Holtschlag and Nicholas (1998) estimate that approximately 56% of the lake’s water arrives as direct precipitation on the lake surface, 11% enters as runoff from adjacent land surfaces, and 33% arrives as indirect groundwater discharge, defined as the groundwater component of streamflow (Holtschlag and Nicholas 1998). Direct groundwater discharge to Lake Superior has not been measured, but it is estimated to be low to negligible in APIS’s vicinity because of the low permeability of the aquifers (Grannemann and Weaver 1998).

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 at its longest and widest points, respectively, and its shoreline length is 4,800 km, including islands. Its volume is 12,100 km^3, 10% of the world's fresh surface water (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).

The Apostle Islands ecoregion of Lake Superior is characterized by relatively shallow water (generally <100 m) (Figure 9), sandy substrates, considerable habitat complexity because of the numerous islands, reefs, and sandbars, and relatively diffuse anthropogenic influences (Johnson et al. 2004). The islands are separated by pre-glacial valleys that are now submerged (Collie 1901).

Lake Superior's currents and circulation influence water temperatures, sediment transport, ice cover, distribution of nutrients and oxygen, and dispersal of planktonic organisms, and so are important to the aquatic community (LSBP 2006). Harrington's 1895 study of the lake's currents has recently been reviewed, and new observations are generally consistent with his data (Beletsky et al. 1999). The lake has both epilimnetic and hypolimnetic currents, which flow in a counter-clockwise direction in most of the lake, including the eastern side of APIS (LSBP 2006). However, in the relatively shallow western Lake Superior basin, beginning on the west side of the Bayfield Peninsula, the current flow is clockwise (Harrington 1895). Overall, currents on the south side of the lake are strongest (Matheson and Munawar 1978). Current speeds are low and uniform with depth in the spring. As temperatures warm, currents accelerate in the epilimnion, reaching a maximum in early September, while currents in the hypolimnion decelerate, 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 2006). Lake Superior experiences seiches, which are internal gravity waves that form in response to wind or to changes in barometric pressure (LSBP 2000).

In 1993, the National Oceanic and Atmospheric Administration (NOAA) identified and mapped 15 shoreline types in APIS as part of a USEPA assessment of shoreline vulnerability to oil spills (Table 7, Figure 10) (USEPA Region 5 2000). APIS's shoreline types can be roughly described as rocky cliffs or bedrock shores (32%); human-made structures (1%); or sand, sand and gravel, or gravel beaches, sometimes with shelving bedrock (64%). In addition, 3% of APIS shoreline is classified as wetlands, including parts of the mainland unit and Long and Stockton Islands, and approximately 0.1% is classified as sheltered, vegetated low banks, all part of the mainland unit (USEPA Region 5 2000). A breakdown of Table 7 for each island and the mainland unit is included as Appendix D.

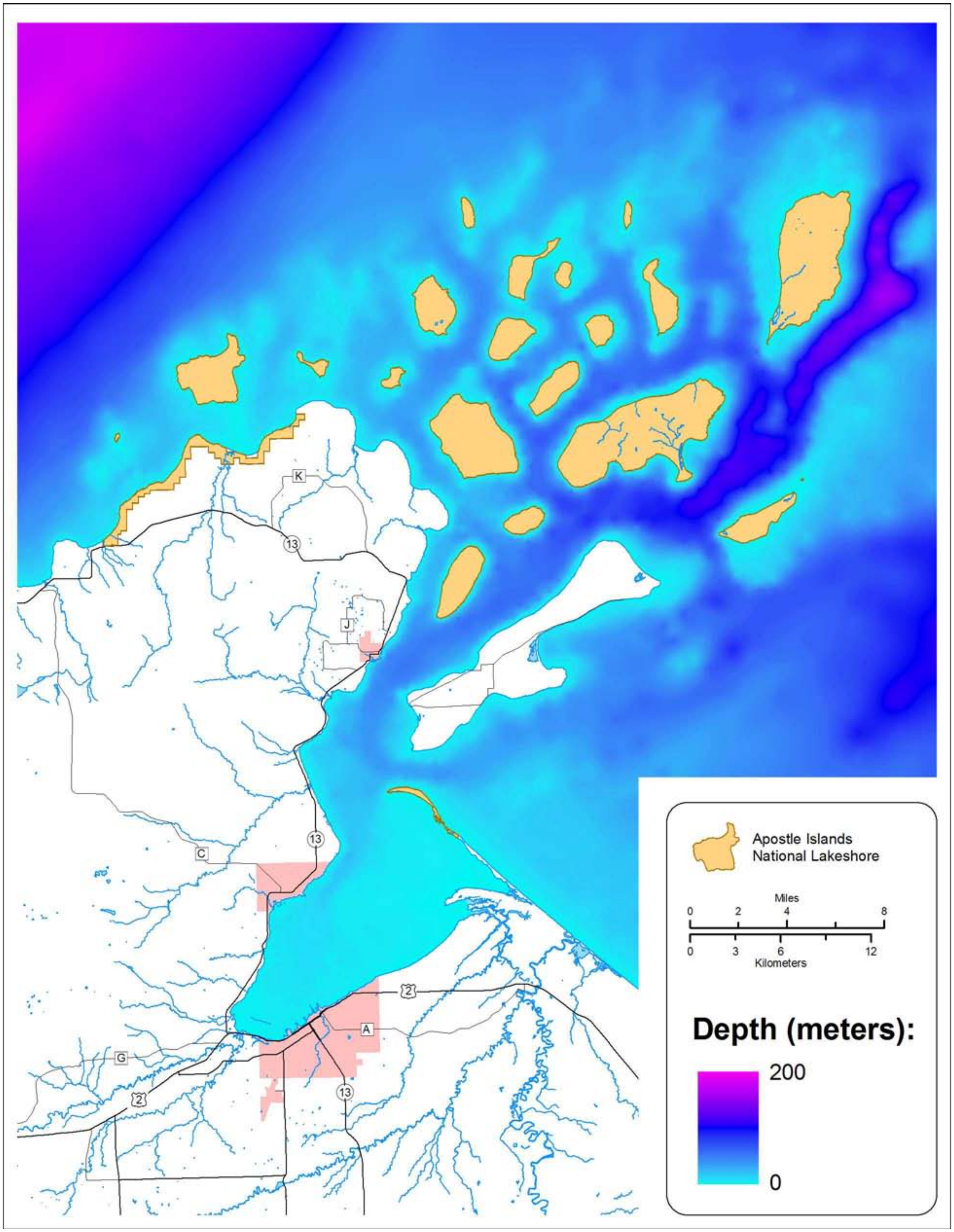


Figure 9. Lake Superior bathymetry in the vicinity of Apostle Islands National Lakeshore (derived from NOAA 2004, 2005a, b, c).

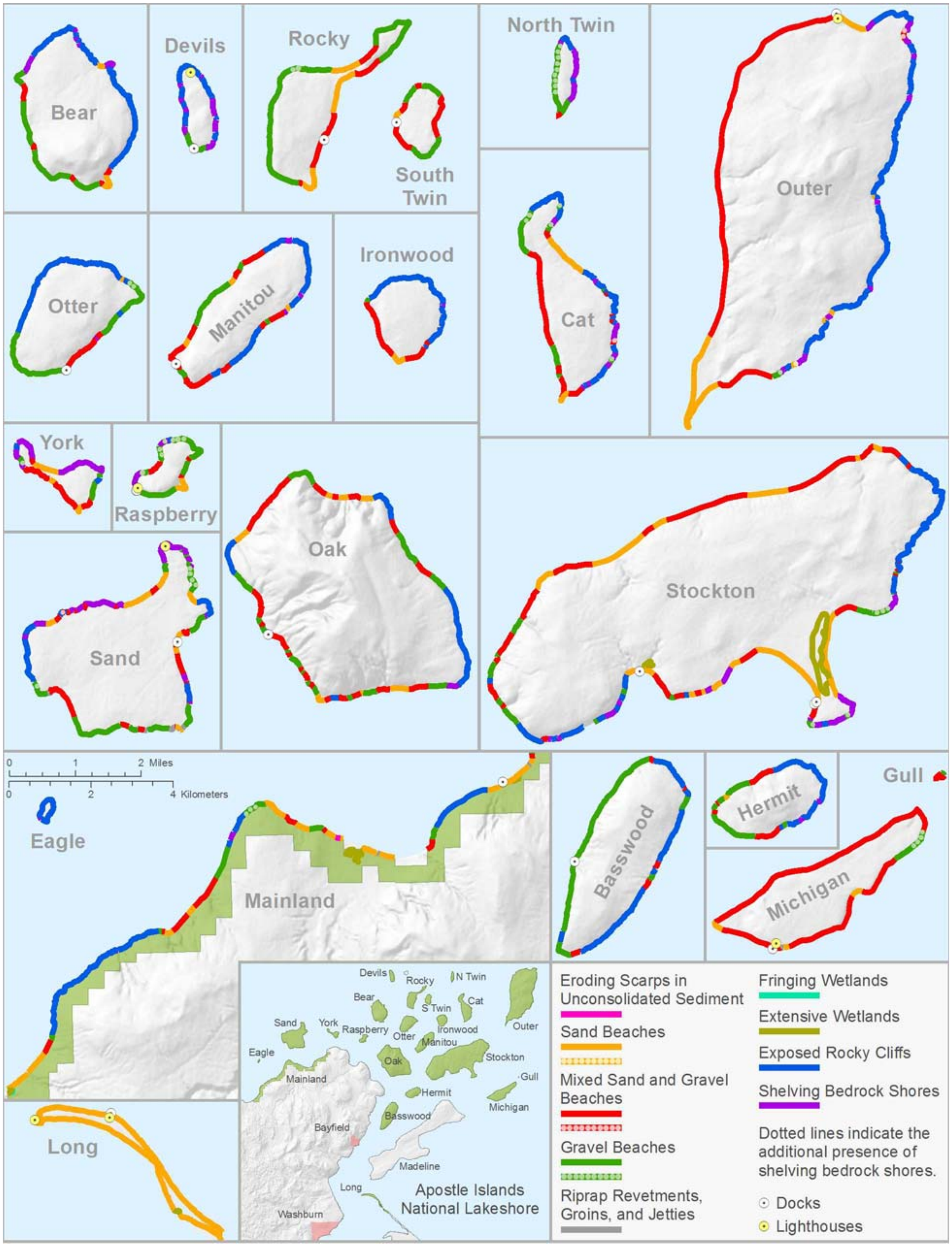


Figure 10. Shoreline types for Apostle Islands National Lakeshore (USEPA Region 5 2000).

Table 7. Lake Superior shoreline types, lengths, and USEPA shoreline sensitivity classification for Apostle Islands National Lakeshore (USEPA Region 5 2000).

Shoreline Type	Number of Kilometers	% of APIS	NOAA ESI Shoreline Classification	USEPA Shoreline Sensitivity Classification
Exposed Rocky Cliffs	66.80	25.62	1A	Low
Exposed, Solid Man-made Structures	0.13	0.05	1B	Low
Shelving Bedrock Shores	18.04	6.92	2	Low
Riprap Revetments, Groins, and Jetties	0.92	0.35	6B	Low
Subtotal	**85.89**	**32.94**		
Eroding Scarps in Unconsolidated Sediments	0.13	0.05	3	Low-Medium
Sand Beaches	45.00	17.26	4	Low-Medium
Sand Beaches/Shelving Bedrock Shores	0.16	0.06	4/2	Low-Medium
Mixed Sand and Gravel Beaches	68.98	26.45	5	Low-Medium
Mixed Sand and Gravel Beaches/Shelving Bedrock Shores	0.50	0.19	5/2	Low-Medium
Gravel Beaches	46.56	17.85	6A	Low-Medium
Gravel Beaches/Shelving Bedrock Shores	5.76	2.21	6A/2	Low-Medium
Subtotal	**166.95**	**64.07**		
Sheltered, Solid Man-made Structures	0.06	0.02	8B	Medium-High
Sheltered, Vegetated Low Banks	0.19	0.07	9A	Medium-High
Subtotal	**0.26**	**0.09**		
Fringing Wetlands	0.21	0.08	10A	High
Extensive Wetlands	7.35	2.82	10B	High
Subtotal	**7.56**	**2.90**		
Total	**260.78**			

For purposes of describing aquatic communities, the U.S. Fish and Wildlife Service (USFWS) divides Lake Superior waters into three zones: a “nearshore” of < 9 m depth, an “inshore” of 9-73 m depth, and an “offshore” of greater than 73 m depth (Newman 2003). An alternative, but similar classification has been proposed by the Lake Superior Technical Committee (LSTC), which defines a "nearshore" of less than 80 m depth (including both USFWS’s “nearshore” and “inshore”) and an "offshore" of greater than 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 10 m depth, but does not give it a specific name (Table 8) (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). When aquatic vegetation is present, it is generally confined to nearshore areas (Edsall and Charlton 1997). Judziewicz and Koch (1993) conducted a survey of APIS’s vascular flora between 1972 and 1992. They did not list aquatic vegetation specifically, but did describe plant communities that are directly lake-influenced, including

Table 8. 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	

sandscapes, clayscapes (steep, reddish clay bluffs), and rockscapes (Precambrian sandstone ledges and bluffs).

Typically, APIS sandscapes include the following vegetation zones: a beach without vegetation, active dunes, intertidal hollows (sometimes with ephemeral pools or ponds), stabilized dunes and/or beach ridges (sometimes covered with pine savanna or forest), and finally, a filled-in lake basin covered either with bog or alder thicket vegetation (Nuhfer and Dalles 1987; Judziewicz and Koch 1993). The dominant species on dune grassland is beach grass; numerous species of herbaceous plants, willows, and non-vascular plants are also common (Judziewicz and Koch 1993).

Steep, reddish clay bluffs (clayscapes) make up over half of APIS's island coastline. The eroding slopes are vegetated mainly with speckled alder, green alder (*Alnus viridis* subsp. *crispa*), willows [beaked willow (*Salix bebbiana*), pussy willow (*S. discolor*), meadow willow (*S. gracilis*), and prairie willow (*S. humilis*)], red raspberry (*Rubus strigosus*), juneberries (*Amelanchier* spp.), red-osier dogwood (*Cornus stolonifera*), and bush-honeysuckle (*Diervilla lonicera*), although small trees and native and exotic herbs are often frequent. A third of the coastline is made up of rockscapes, where the commonest woody species are willows, including the rare satiny and flat-leaved willows (*S. pellita* and *S. planifolia*), which are Wisconsin endangered and threatened species, respectively. Many of the most common herbaceous species are weedy ones. Some ledges harbor herbaceous species with calciphilic tendencies. In all, 803 plant species and hybrids are found on the islands (Judziewicz and Koch 1993).

The vegetation of wetlands is specifically discussed in the Wetlands section below.

Phytoplankton, Zooplankton, Aquatic Invertebrates, and Benthos

Both the zooplankton and phytoplankton communities at APIS are indicative of Lake Superior's oligotrophic conditions. Samples collected in summer 1986 at three lake sites (Presque Isle Bay, Little Sand Bay, and South Twin Island) were dominated by the diatoms *Asterionella* sp., *Fragilaria* sp., and *Tabellaria* sp., and the chrysophyte *Dinobryon* sp. (Balcer and McCauley 1989). Lakewide, approximately 300 phytoplankton species are present (LSBP 2006). 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 biovolume dominated by cryptophytes (27%), diatoms (33%), and chrysophytes, and concluded that the results "suggest the lake has changed little in the past 20 years" (Barbiero and Tuchman 2001). However, unlike Munawar and Munawar, Barbiero and Tuchman did find a difference in species composition between spring and summer.

Lake Superior has the lowest zooplankton density of all the Great Lakes, as well as the lowest number of taxa (Barbiero et al. 2001). In the open waters of Lake Superior, large calanoid 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 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). In APIS, among crustacean zooplankton, copepods greatly outnumber cladocerans (Lake Superior Ecosystem Research Center 1997; Johnson et al. 2004). The ratio of calanoid copepods to cladocerans was at least 2:1 and usually 3:1 in summer 1996, indicating oligotrophic conditions (Lake Superior Ecosystem Research Center 1997), but the Apostle Islands ecoregion has approximately four times more zooplankton production than the open lake (Johnson et al. 2004). When rotifer zooplankton were considered, they dominated the zooplankton community, comprising 45% and 52% of all zooplankton in the summers of 1996 and 1997 (Johnson et al. 2004). Johnson et al. (2004) reported a structural change in the zooplankton community of western Lake Superior from the 1970s to 1996-97, with greater zooplankton densities but less zooplankton biomass, an increase in the proportion of the biomass contributed by cladocerans, a shift from larger calanoids to smaller cyclopoids, and an increase in the number of nauplii during a comparable time period in July and August.

Two large-bodied zooplankters, *Mysis relicta* and *Diporeia affinis*, are major components of the original Lake Superior food web (GLFC 2001). *Diporeia* is an indicator of lake health because it is the most abundant benthic organism in cold, offshore regions of all the Great Lakes, and is food for many forage fish species (Environment Canada and USEPA 2003). *Diporeia* are "in a state of dramatic decline" in parts of all the Great Lakes except Lake Superior, likely due to the rapid spread of zebra mussels (*Dreissenia polymorpha*) and quagga mussels (*D. bugensis*) (Environment Canada and USEPA 2003). *Diporeia* numbers did not significantly decline from 1994-2000 in western Lake Superior (Scharold et al. 2004).

Most past research on benthos in Lake Superior dealt with sub-littoral and profundal benthos (Thomas 1966; Cook 1975; Freitag et al. 1976; Dermott 1978). Barton and Hynes (1976, 1978a, b, c) described the macrobenthos in wave-swept zones of Lake Superior as typically lotic. They (1978a) also determined that the diversity and abundance of macrobenthos were directly related to the stability of substrate, with more stable substrates supporting higher diversity and abundance. Barton and Carter (1982), in their study of Georgian Bay, Ontario, found that increased exposure to wave action in shallow areas reduced diversity and abundance of epilithic invertebrates. Barton and Griffiths (1984) found that the abundance of macroinvertebrates in the nearshore zone of Lake Huron varied with depth and substrate. Dermott (1984) reported that the benthos of Batchawana Bay in Lake Superior was divided into three communities based on depth and composition of the substrates. Lakewide, the benthic community of Lake Superior is dominated by *Diporeia* and the oligochaetes (Cook 1975).

Research on the macroinvertebrates of the southern shore of Lake Superior, including the Apostle Islands, has lagged behind the work done along the Canadian shoreline (Montz 1986). Hiltunen (1969) sampled the macrobenthic fauna at 16 stations in and around the Apostle Islands, including Chequamegon Bay, in 1964. *Pontoporeia* (now *Diporeia*) *affinis* was the most abundant benthic organism collected at all stations, although its abundance was much lower than in the other Great Lakes. Turbellarian flatworms were found at depths from 53 - 114 m. Three families of Oligochaeta (Enchytraeidae, Lumbriculidae, and Tubificidae) were found, with Tubificidae being the most diverse (10 species). Two leech specimens (Hirudinea, *Piscicola* spp.) were found. Ostracoda was present in most samples and showed no depth preference. All Diptera collected were Chironomidae (midges) except for one specimen of Empididae (dance flies). *Valvata sincera* (Gastropoda) was the only species of snail found, and none occurred deeper than 28 m. Sphaeriidae was the only family of bivalves (Pelecypoda) collected, and all but one were *Pisidium* spp.. He concluded that the benthic communities of the Apostle Islands were similar to the other Great Lakes. Selgeby (1974) found that the profundal macroinvertebrate communities occurred at much greater depths than previously thought (32-100 m). Arnold (1977) studied the littoral macrobenthos of Chequamegon Bay. Munawar and Munawar (1978) reported very sparse mollusk and benthic insect populations in western Lake Superior.

Montz (1986) studied the littoral benthos of Basswood, Stockton, Cat, South Twin, and Rocky Islands from May to October 1984 to provide baseline data on community composition and density. He sampled seven transects at 0.5, 1.5, 3.0, and 4.5 m depth intervals from shore using a ponar grab sampler in soft substrates and artificial substrate samplers (barbeque baskets filled with concrete spheres) in rocky substrates. He found two major aquatic macroinvertebrate communities: a rock-rubble substrate community composed mainly of caddisflies (Trichoptera), mayflies (Ephemeroptera), midges (Chironomidae), and Mollusca species, and a soft substrate (sand) community dominated by midges and segmented worms [Annelida (Oligochaeta)]. Mean organism density was $226/m^2$ in the rock-rubble community and $3800/m^2$ in the sand community. Bare sand had lower densities than vegetated sand. The rock-rubble community had more lotic organisms, while the sand community was more typically lentic. In all, 154 genera representing 37 families were identified, with the Arthropoda predominant (Montz 1986). The number of organisms present varied significantly ($P<0.05$) with depth, and generally the shallower depths had lower densities. He determined exposure to wave action subjectively and found that it had a significant effect on macroinvertebrate densities at the 3.0 and 4.5 m depth intervals but was not significant at the shallower depths. Similarly, benthic macroinvertebrates were sampled in Stockton Island's Presque Isle Bay in August 1986 and August 1987, and off Oak Island in August 1986. They were dominated by oligochaete worms, *Diporeia,* and chironomid midge larvae (Balcer and McCauley 1989). Snails, isopods, and caddisfly larvae were also found in Presque Isle Bay.

Herptiles
Six species of salamanders, 11 species of frogs and toads, and eight species of reptiles have been reported to occur within APIS (Casper 2001b). Species of reptiles and amphibians found in the mixed hardwood forest include spotted salamander (*Ambystoma maculatum*), Eastern gray tree

frog (*Hyla versicolor*), northern red-bellied snake (*Storeria occipitomaculata occipitomaculata*), and northern ring-necked snake (*Diadophis punctatus edwardsii*). Species found in moister woods include wood frog (*Rana sylvatica*), blue-spotted salamander (*Ambystoma laterale*), and eastern red-backed salamander (*Plethodon cinereus cinereus*). Mink frogs (*Rana septentrionalis*) and northern leopard frogs (*Rana pipiens*) are found on pond and lake edges. Northern spring peepers (*Pseudacris crucifer crucifer*), eastern American toads (*Bufo americanus americanus*), painted turtles (*Chrysemys picta)*, and common garter snakes (*Thamnophis sirtalis sirtalis*) are found in a variety of habitats (NPS n.d. b). Four-toed salamanders (*Hemidactylium scutatum*), central newts (*Notophthalmus viridescens louisianensis*), and American bullfrogs (*Rana catesbeiana)* are regionally uncommon, and mudpuppies (*Necturus maculosus maculosus*) and chorus frogs (*Pseudacris* sp.) are regionally local (Casper 2001a). Green frogs (*Rana clamitans melanota*) are regionally common, while Cope's gray treefrogs (*Hyla chrysoscelis*) are regionally rare. Other species found in APIS include smooth greensnakes (*Opheodrys vernalis*) and snapping turtles (*Chelydra serpentina serpentina*) (Casper 2001a, 2001b). The eastern hog-nosed snake (*Heterodon platirhinos*) has been reported but not verified on the Bayfield Peninsula (Casper 2001b). APIS currently has matrices of herptile occurrence by island that are being maintained through ongoing research projects (Casper 2004).

Fish

A comprehensive study 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 Lake Superior and its tributaries during the 20th century (Lawrie 1978). The Great Lakes Fishery Commission (GLFC) lists 96 species (Appendix F) (GLFC 2001).

Fish species may be classified according to the trophic level they occupy as adults. The original Lake Superior food web of the offshore and nearshore open waters was simple: lake herring (*Coregonus artedi*) fed on zooplankton and were in turn eaten by lake trout (*Salvelinus namaycush*), while deepwater ciscoes (*Coregonus* spp.) and deepwater sculpin (*Myoxocephalus thompsoni*) were the primary prey of siscowet lake trout (*Salvelinus namaycush siscowet*) 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 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, 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 (Table 9) (GLFC 2001).

Table 9. Ecological roles of important Lake Superior fish species, including (*non-native species) (from GLFC 2001).

Planktivores **Diet predominantly zooplankton or phytoplankton**	**Benthivores** **Diet predominantly macroinvertebrates**	**Piscivores** **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

Fish species can also be classified according to the habitat they generally occupy. About 77% of Lake Superior's surface area 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 sculpin. 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 sculpin, trout perch (*Percopsis omiscomaycus*), longnose suckers (*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 (Ictaluridae), sea lamprey, and many species of minnows depend on spending all or part of their lives in tributaries.

The National Biological Survey (1995) summarized abundance data and trends for 14 APIS fish species from 1963 - 1994 (rainbow smelt, slimy sculpin, spoonhead sculpin (*Cottus ricei*), deepwater sculpin, burbot, ninespine stickleback, trout perch, longnose sucker, round whitefish, pygmy whitefish, lake whitefish, bloater, lake herring, and lake trout). Eight species increased in abundance, four decreased, and three were stable. Rainbow smelt, trout perch, and round whitefish were found in shallow (5-25 m) waters in all seasons; the sculpins were found in deep (>55 m) waters in all seasons; and burbot and ninespine stickleback distribution varied with season. The remainder of the 14 species were generally found in medium depth (25-55 m) waters during all seasons. Historical data for contaminants in fish tissue and eggs were also included.

An assessment of western Lake Superior fish communities in 1996 and 1997 showed that over 98% of the number and 92% of the midwater trawl biomass consisted of lake herring, rainbow smelt, and deepwater ciscoes, and catch-per-unit-effort was higher in the Apostle Islands than in the Duluth-Superior or open water ecoregions (Johnson et al. 2004). Most fish were concentrated in nearshore (<80 m) waters (Johnson et al. 2004). The annual daytime bottom trawl survey conducted in Lake Superior's nearshore waters found that in 2004, lake whitefish made up the highest percent of the total mean biomass for any species (30%), followed by lake herring (29%), bloater (18%), longnose sucker (7%), and rainbow smelt (5%) (Stockwell et al. 2005).

Fish habitat within APIS is mainly one of six types: high gradient bedrock, low gradient bedrock, low gradient boulder/cobble, low gradient sand, high gradient sand, and large gravel (Burkman and Van Stappen 2003). Preliminary results of a study of APIS nearshore (< 15 m) fisheries by habitat types (Gorman and Moore 2006) found 19 fish species, dominated by ninespine stickleback, slimy sculpin, burbot, and johnny darter (*Etheostoma nigrum*). Fish caught in trawls were more abundant and had higher species diversity in low-slope nearshore areas with vegetation (e.g., eastern shore Sand Island) than in other areas, and were most abundant in sand substrate areas (Presque Isle Bay). Species caught only in trawls included ninespine stickleback, johnny darter, rainbow smelt, logperch (*Percina caprodes*), trout-perch, round whitefish, lake whitefish, lake herring, longnose dace (*Rhinichthys cataractae*), and the exotic invasives threespine stickleback (*Gasterosteus aculeatus*) and Eurasian ruffe (*Gymnocephalus cernuus*). Windermere traps yielded the highest abundances of burbot, lake chub (*Couesius plumbeus*), and slimy sculpin. Fish caught only in traps included rock bass (*Ambloplites rupestris*), longnose sucker, brook stickleback (*Culaea inconstans*), and lake chub. Fish caught in traps were most abundant in steep bedrock habitats (e.g., east side Basswood Island) and in intermediate gradient-boulder (e.g., south tip Outer Island) nearshore habitats.

From 1999 - 2000, an investigation of the status of the shortjaw cisco (*Coregonus zenithicus*) was conducted by the Great Lakes Science Center (GLSC). In the early 1920s, shortjaw ciscoes were the most numerous deepwater ciscoes. However, the recent sampling found none in APIS, and the researchers concluded that its population has dropped by at least 99.9% (GLSC 2004). In 2004, a study was conducted of the status of coaster brook trout and their habitats in APIS Lake Superior waters and tributary streams, but results have not yet been published (WDNR and USFWS 2005). The nearshore zone of APIS is considered important spawning habitat for round whitefish, lake whitefish, lake herring, and lake trout, which are commercially important species (LSBP 2006).

Wetlands

Bogs and wetlands within APIS are associated with sandscapes, lagoons, alder thickets, and beaver flowages on the islands (NPS 2002g). They generally have unique flora and fauna adapted to these habitats and increase the overall biodiversity of the islands. Low precipitation over the last several years is causing a number of smaller wetlands, especially old beaver flowages, to convert to wet meadows (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2006). Types of wetland herbaceous communities in Wisconsin have been described by Judziewicz et al. (2001); those found in APIS are described below.

Boreal rich fens are neutral to alkaline, cold open peatlands through which carbonate-rich groundwater percolates. They occur throughout northern Wisconsin, including at Sand Bay in the mainland unit. Sphagnum (*Sphagnum* spp.) mosses are uncommon or absent; characteristic plants include woolly sedge (*Carex lasiocarpa*), twig rush (*Cladium mariscoides*), beaked bladderwort (*Utricularia cornuta*), rushes (*Juncus* spp.), and Hudson Bay cotton-grass (*Scirpus hudsonianus*). In the shrubby phase of this wetland, bog birch (*Betula pumila*), sage willow (*Salix candida*), and speckled alder are usually common (Judziewicz et al. 2001).

Shore fens are open peatland communities that occur primarily along Great Lakes shorelines, especially near the mouths of tributary streams. A sand spit usually separates this wetland from

Lake Superior. This habitat is generally covered by a floating sedge mat of woolly sedge; other dominant plants include sweet gale (*Myrica gale*) and bogbean *(Menyanthes trifoliata*). The herbs twig rush, marsh horsetail *(Equisetum fluviatile*), elliptic spike-rush (*Eleocharis elliptica*), intermediate bladderwort *(Utricularia intermedia*), marsh bellflower (*Campanula aparinoides*), narrow-leaved willow-herb (*Epilobium leptophyllum*), water-parsnip (*Sium suave*), and bog willow (*Salix pedicellaris*) are also found. This wetland type can be distinguished from open bogs and poor fens (which may adjoin them in the same wetland complex) by the lack of Sphagnum mosses, higher pH, and direct hydrologic connection to the Great Lakes (Judziewicz et al. 2001). An example of a shore fen occurs at the mouth of the Sand River in the APIS mainland unit.

Emergent aquatic wetlands are open, marsh, lake, riverine, and estuarine habitats with permanent standing water. Emergent macrophytes occur in pure stands of single species or in a variety of plant mixtures. The commonly dominant plants are cattails (*Typha* spp.), bulrushes [particularly hard-stem bulrush (*Scirpus acutus*), river bulrush (*S. fluviatilis*), and great bulrush (*S. validus*)], bur-reeds (*Sparganium* spp.), giant reed (*Phragmites australis*), pickerel-weed (*Pontederia cordata*), water-plantains (*Alisma* spp.), arrowheads (*Sagittaria* spp.), and the larger species of spike-rush such as common spike-rush (*Eleocharis smallii*) (Judziewicz et al. 2001). An example of this type of wetland occurs in the back of Quarry Bay on Stockton Island.

Rare interdunal wetlands are created in wind hollows that penetrate the water table within active dune areas along the Great Lakes. Common members of this wetland community around the Lake Superior shoreline are twig rush, species of rushes [especially arctic rush (*Juncus balticus*)], pipewort (*Eriocaulon septangulare*), green yellow sedge (*Carex viridula*), ladies-tress orchids (*Spiranthes* spp.), beaked bladderworts, and purple bladderworts (*Utricularia resupinata*) (Judziewicz et al. 2001). An example of this type of wetland occurs along the beach area of Julian Bay on Stockton Island. These wetlands require careful conservation due to the rarity and specialization of plants that characterize this fragile habitat.

Open bogs are acidic, low-nutrient non-forested peat wetlands, commonly dominated by Sphagnum mosses in Wisconsin. Moss produced hummocks and hollows are also common; trees are not present or occur at very low densities. Common species include narrow-leaved sedge species such as few-flowered hop sedge (*Carex oligosperma*) and few-flowered bog sedge (*Carex pauciflora*), cotton-grasses (*Eriophorum* spp.), and ericaceous shrubs, especially bog laurel (*Kalmia polifolia*), leatherleaf (*Chamaedaphne calyculata*), and small cranberry (*Vaccinium oxycoccos*). Generally the diversity of plants is very low; however, some characteristic and distinctive specialists may occur in this habitat. Open bogs are closely related to muskegs and may intergrade with them (Judziewicz et al. 2001). This type of wetland is one of the most common within the Apostle Islands, and examples occur on many islands. Michigan, Outer, and Stockton Islands have larger bogs that support floating and submerged aquatic macrophyte communities.

Northern poor fens are acidic, weakly minerotrophic peatlands that receive some nutrients from groundwater or overland flow. They can be distinguished from open bogs by a higher pH, nutrient availability, and the type and diversity of vegetation supported. The northern poor fen and the open bog are the two most common types of wetland found within APIS. Sphagnum mosses are typical of this habitat, but they do not produce the commonly associated hummocks. Plant diversity is higher than in the open bog, and common plants may include white beak-rush (*Rhynchospora alba*), pitcher-plant (*Sarracenia purpurea*), sundews (*Drosera* spp.), pod grass (*Scheuchzeria palustris*), and the pink-flowered orchids [grass pink (*Calopogon tuberosus*), rose pogonia (*Pogonia ophioglossoides*), and swamp-pink (*Arethusa bulbosa*)]. Common sedges are few-seeded hop sedge, muck sedge (*Carex limosa*), woolly sedge, cord-root sedge (*C. chordorrhiza*), and cotton-grasses (Judziewicz et al. 2001). APIS examples of this type of wetland include Brander Bog and the Presque Isle complex of Stockton Island.

Summit bogs (also known as perched bogs) are unique because they occur at the highest and generally most poorly-drained point on an island. They occur on wet, spongy, peat-forming ground and are entirely dependent on rainwater (ombrotrophic) for their source of water and nutrients. These bogs tend to be very acidic (pH $\leq$ 4) and low in nutrients. Sphagnum mosses, black spruce (*Picea mariana*), and ericaceous shrubs (plants in the heath family) usually dominate this type of bog (Judziewicz et al. 2001). Excellent examples of summit bogs occur on Otter, Devils, Sand, and Bear Islands, and a very small one occurs on Stockton Island. They are generally smaller and have more reduced floras than coastal bogs, but the common ericads and insectivores are usually present (Judziewicz and Koch 1993). Smaller islands can also have summit bogs, such as the northern peninsula of Cat and the western peninsula of York Islands (Judziewicz and Koch 1993).

Speckled alder-dominated wetlands are common within APIS (Judziewicz and Koch 1993). These wetlands are generally very wet and are found on the fringes of sandscape bogs, beaver flowages, and old roads. Common shrubs are skunk current and swamp red current (*Ribes triste* and *R. glandulosum*). Blue-joint (*Calamagrostis canadensis*) is common, as are the herbs spotted touch-me-not (*Impatiens capensis*), marsh cinquefoil (*Potentilla palustris*), yellow and tufted loosestrifes (*Lysimachia terrestris* and *L. thyrsiflora*), marsh-marigold (*Caltha palustris*), sedges [fringed sedge (*Carex crinita*), greater bladder sedge (*C. intumesces*), lake sedge (*C. lacustris*), common fox sedge (*C. stipata*), three-fruited sedge (*C. trisperma*), and blister sedge (*C. vesicaria*)]. Fowl meadow-grass (*Poa palustris*), tussock sedge (*Carex stricta*), great water dock (*Rumex orbiculatus*), northern and purple-leaved willow-herbs (*Epilobium cilatum* and *E. coloratum*), sticktights (*Bidens* spp.), water-parsnip, tall and early meadow-rues (*Thalictrum dasycarpum* and *T. dioicum*), rattlesnake-grass (*Glyceria canadensis*), fowl meadow-grass (*G. striata*), southern and northern three-lobed bedstraws (*Galium tinctorium* and *G. trifidum*), bulblet and common water-hemlocks (*Cicuta bulbifera* and *C. maculata*), blue flag (*Iris versicolor*), and purple-stemmed aster (*Aster puniceus*) are also usually present (Judziewicz et al. 2001). Many of these species are also found around the many old beaver flowages on Michigan, Outer, and Stockton Islands (Judziewicz and Koch 1993).

Meeker has recently mapped wetland vegetation types and communities and established long-term monitoring transects on Long Island (1998); Stockton, Outer, Michigan, Devils, and Outer Islands and Little Sand Bay (2000); and Sand River Lagoon, Sand Island Bog, and Stockton Island Bog (2002). The latter two reports were not received in time to be incorporated into this document.

APIS wetland plankton and invertebrate fauna are generally not well-documented. In particular, the unique wetland areas associated with the two larger tombolos on Stockton and Outer Islands could be habitat for rare and unique species, but have not received detailed studies.

Sandscapes

APIS has 17 designated sandscapes of five different types: beaches, sand spits, barrier spit, cuspate forelands, and tombolos, which have been monitored since 1988 (NPS 2002b). Sandscapes require three factors to occur: a source of sand, energy to carry the sand, and a calm area where sand can accumulate. Sand in the Apostle Islands comes from bluffs of soft glacial deposits that are eroded by wave action. Not all the islands have sandscapes; small islands generally do not have enough glacial deposits to provide the needed sand, and the inner islands may not have the energy to move sufficient sand.

Sand spits are usually long, narrow sand deposits that extend into the lake from a land tip or mouth of a bay, such as those on Michigan and the south ends of Outer and Cat Islands. Long Island is unique among the islands since it is actually a barrier spit.

Cuspate forelands are generally similar to sand spits, but they are wedge-shaped and about as long as wide. They are found on Raspberry, Rocky, Oak, South Twin, Ironwood, Otter, Bear, Stockton, and York Islands. The one on Oak Island has been identified as APIS's most threatened because of its long history of human use. APIS managers and the NRCS Plant Materials Center in Rose Lake, Michigan propagated 15 species of historic vegetation to Oak Island's sandscape. Most of the restoration occurred in late May of 2002 with help from a Northland College field ecology class, and 3,200 propagated plants were planted, resulting in a decrease of exotic plants from 66% to 41% (Van Stappen 2004).

Tombolos result from sand being deposited to connect two islands to each other. A well - known tombolo is Presque Isle, which is joined to Stockton Island by a tombolo formed by sediments from Anderson and Julian Bays, and has a lagoon and wetland associated with it (NPS 2002b).

Sandscape habitats are very fragile, and the plant community is highly adapted to survive harsh conditions such as shifting sand, strong winds, and nutrient-poor soils. Typical pioneer plants that survive these conditions include American beach grass and beach pea, which help to stabilize the sandscape environment. Beach pea is also capable of symbiotic nitrogen fixation, making an essential nutrient available to other plants and allowing the development of a sustained unique community of plants and animals. Shrubs that help stabilize the sandscapes include beach heather (*Hudsonia tomentosa*), dwarf juniper (*Juniperus communis*), blueberry (*Vaccinium angustifolium*), and rose (*Rosa blanda*). White pine, red pine, and white birch may also colonize and stabilize these habitats in APIS (NPS 2002b).

Groundwater

Groundwater is an important component of Lake Superior hydrology, as an estimated 75% of terrestrially originating lake water originates as groundwater (Holtschlag and Nicholas 1998). Groundwater is the predominant source of discharge in tributaries of Wisconsin's Bayfield Peninsula (LSBP 2006). The percent of flow attributable to groundwater on average for two gaged streams tributary to Lake Superior in northern Wisconsin is 62.9% for the Nemadji River near South Superior and 94.6% for the Bois Brule River at Brule (Holtschlag and Nicholas 1998).

In the mainland areas of Ashland and Bayfield Counties near APIS, small quantities of groundwater are obtained from isolated inclusions of sand and gravel generally lying on the bedrock surface below the lake plain (Young and Skinner 1974). The major areas of outwash on the Bayfield Peninsula are mostly unsaturated, but where these comprise an aquifer, yields may reach 27-270 m^3day^{-1}. Sandstones of the Bayfield Group yield 270-800 m^3day^{-1} on most of the Peninsula, with areas of higher yield south of Bayfield and near Washburn. Yields from the sandstone in Ashland County are smaller, in the 27-270 m^3day^{-1} range (Young and Skinner 1974), which may explain why the city of Ashland operates a microfiltration plant and draws its drinking water from Chequamegon Bay (City of Ashland 2006). Except for Madeline Island, Young and Skinner did not evaluate the water resources of the islands.

Glacial sand and gravel and sandstones are the two primary aquifers for the APIS islands. Sandstone is the only available aquifer in the mainland unit, since glacial lake clays overlie the sandstone there (Rose 1988). Groundwater may also be available from sand deposits in cuspate bars and forelands (Rose 1988). Of 14 wells constructed in APIS from 1979 - 1983, four were finished in glacial sand and gravel, and 10 were completed in sandstone. Specific capacities of glacial drift wells ranged from 11 - 178 m^2day^{-1}, while those in sandstone ranged from 16 - 900 m^2day^{-1} (Table 10) (Rose 1988). Depth to groundwater is from 0 - 6 m in the mainland unit and on Sand, York, and Raspberry Islands (Laumann 2003); depths on the remaining islands have not been mapped.

Groundwater is of the calcium-magnesium bicarbonate type in the sandstone, glacial sand and gravel, and cuspate-bar sand aquifers of APIS, but constituent concentrations are highest in the sandstone and lowest in the cuspate-bar aquifer (Rose 1988). In the Lake Superior basin of northern Wisconsin, high concentrations of sodium, chloride or sulfate occur locally. Hardness, iron, and manganese also occasionally pose minor problems for domestic water users (Young and Skinner 1974).

Human-induced groundwater pollution is not generally a problem in the basin (Young and Skinner 1974; Laumann 2003). The mainland unit itself is moderately to highly susceptible to groundwater contamination, while most of the land upgradient of the mainland unit has low susceptibility. Sand Island and Basswood Island have areas of low and low to moderate susceptibility; Rocky Island has low to moderate susceptibility; and Stockton Island has areas of low to moderate and moderate to high susceptibility (Figure 11) (WDNR et al. 1987). The remaining islands were not evaluated for their groundwater contamination susceptibility.

Table 10. Locations, construction information, and sampling dates for USGS groundwater sampling sites in the vicinity of Apostle Islands National Lakeshore (Rose 1988; USGS 1998).

Location	Site	Aquifer	Well Depth (m)	Specific Capacity $m^2 day^{-1}$	Dates Sampled
Samples in National Water Information System (NWIS) database (USGS 1998)					
City of Washburn	BA-49/04W/33-0134				11/11/1968-8/7/1970
South of Bayfield	BA-50/04W/28-0001				9/29/1970-9/2/1976
South of Bayfield	BA-50/04W/22-0149				6/1/1970
South of Cornucopia	BA-50/06W/21-0014				9/28/1970
Madeline Island	AS-50/03W/14-0072				9/29/1970
City of Bayfield	BA-50/04W/13-0007				6/5/1945-7/12/1966
City of Bayfield	BA-50/04W/13-0006				6/5/1945-7/12/1966
Near Cornucopia	BA-50/06W/04-0169				8/7/1973-9/2/1976
Basswood Island Dock	AS-51/03W/33-0161	Sandstone	51	15.7	7/7/1981*
Red Cliff Area	BA-51/03W/31-0144				1/19/1970-10/13/1993
Red Cliff Area	BA-51/03W/31-0146				10/13/1993
Red Cliff Area	BA-51/03W/31-0087				9/28/1970
Michigan Island	Michigan Island Well #1 (AS-180)				8/24/1984*
Stockton Island-Presque Isle Dock	AS-51/02E/01-0108	Sandstone	46	42.9	7/31/1979*
Stockton Island-Quarry Bay Dock	AS-52/02W/34-0110	Sandstone	58	500	7/24/1979*
Just south of east end of mainland unit	BA-51/04W/04-0025				10/15/1970
Oak Island Dock	AS-52/03W/33-0163	Drift	28	93.0	7/1/1981*
Immediately east of mainland park area	BA-52/04W/28-0182	Sandstone	76	805	8/9/1979*
Sand Island Dock	BA-52/05W/13-0181	Sandstone	52	894	8/2/1979*
Outer Island	AS-52/01W/02-0175 Outer Island Obs Well #1				7/28/1983-8/31/1983*
Outer Island	AS-52/01W/02-0176 Outer Island Obs Well #2				7/28/1983*
Outer Island	AS-52/01W/02-0177 Outer Island Obs Well #5				8/31/1983
Rocky Island Dock	AS-53/03W/25-0109	Sandstone	46	148	9/19/1979*
S. Twin Island Dock	AS-53/02W/30-0162	Drift	35	14.1	7/10/1981*
Other wells constructed during the investigation of Water Resources of the Apostle Islands National Lakeshore, Northern Wisconsin (Rose 1988)					
SW corner Oak Island	AS-285	Drift	19	11.3	
Cat Island	AS-286	Sandstone	46	50.0	
Mainland	BA-257	Sandstone	43	19.7	
Otter Island Dock	AS-287	Sandstone	46	25.0	
Manitou Island Dock	AS-283	Drift	19	178	
Manitou Island near campsite	AS-282	Sandstone	46	89	

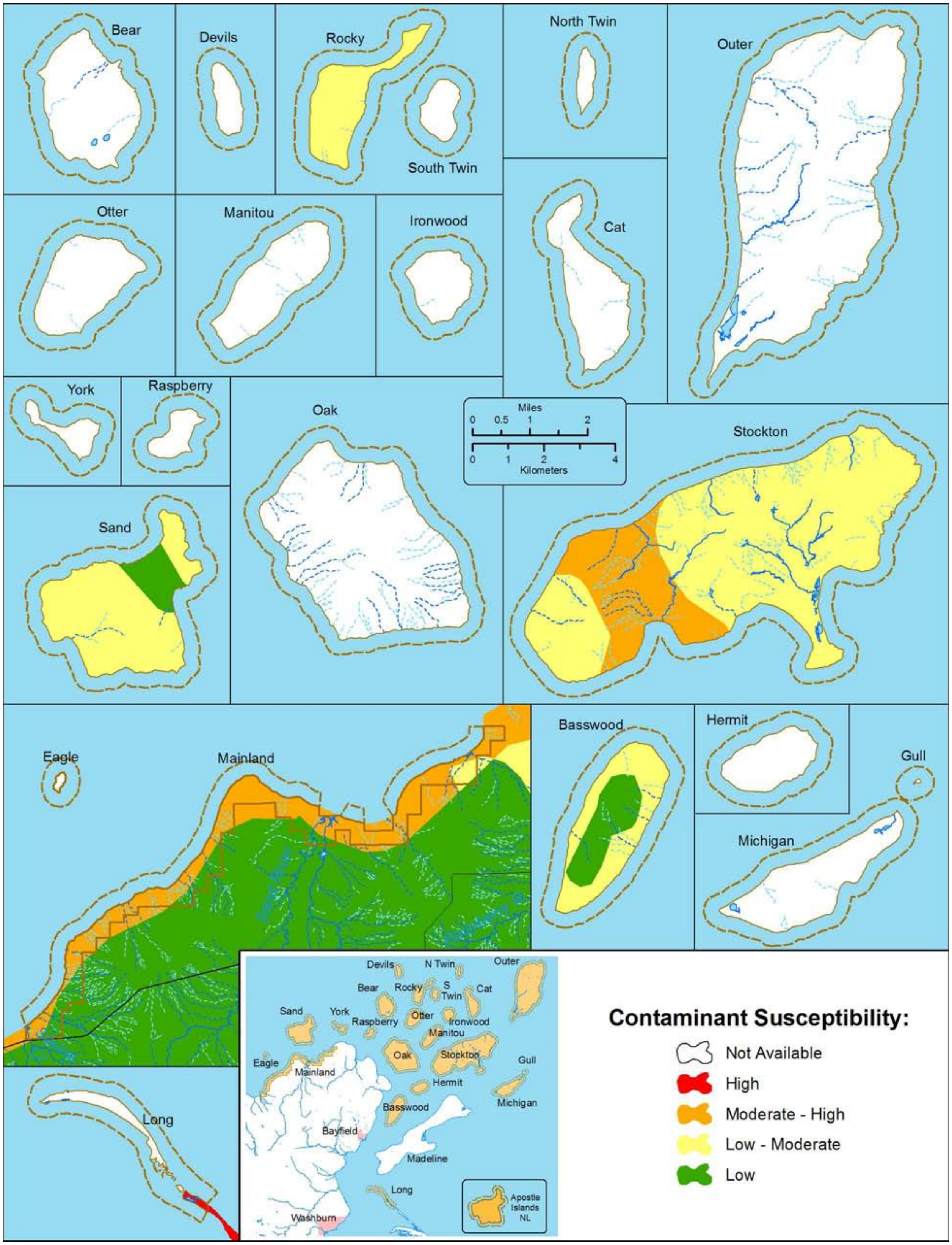


Figure 11. Groundwater contaminant susceptibility of the Apostle Islands National Lakeshore (WDNR et al. 1987).

Water Resources of the Bayfield Peninsula

Bayfield Peninsula streams that may directly affect APIS extend from Norman Point west of Siskiwit Bay on the west to Houghton Point on the east. Major drainages within this area include the Siskiwit, Sand, Raspberry, Onion, and Sioux River and Pikes Creek systems (Figure 12). The Peninsula also has many unnamed small streams that are mostly intermittent. Stream orders on the Peninsula range from 1 - 4.

Most Peninsula streams begin high on the peninsula and quickly lose gradient as they approach the lakeshore, usually resulting in large deltas deposited near the mouths. They are generally brown-stained and flashy, with discharges quickly doubling during major storm events. Since their watersheds are generally forested and well protected, the greatest potential effect on APIS is sediment transport into the waters surrounding the islands resulting in decreased light penetration and potential contamination. During large storm events, a sediment plume has been observed to extend well into the Apostle Islands from the Fish Creek river system and southern Chequamegon Bay. Most of these sediments appear to be the Chequamegon red clay found commonly within the Bayfield Peninsula.

Various methods are used to describe the quality of stream water and biological communities. One such measure is the division of trout streams into Classes I, II or III based on the ability of fish to naturally reproduce. Class I streams sustain their populations by natural reproduction. Class II streams have some natural reproduction but need stocking to maintain a desirable fishery. Class III streams do not sustain natural reproduction and require annual stocking. Bayfield County has 102 trout streams designated by the WDNR; their combined length of 681 km includes 335, 235, and 111 km of Class I, II, and III trout streams, respectively (WDNR 2002c). Most of the named streams support resident trout populations and anadromous trout and salmon runs. A second measure of stream quality is macroinvertebrate biomonitoring. Biotic Index (BI) values range from 1-10, with lower numbers indicating better water quality. BI data (Szczytko unpublished) for three Peninsula streams indicate that the water quality from the Onion River was "excellent" in 2001 (BI=2.18), Saxine Creek "excellent" in 2003 (BI=2.67), and Sioux River "very good" in 2003 (BI=3.78). However, specific water quality data encompassing current chemical and biological components are meager.

Specific segments of the Bayfield Peninsula in the APIS vicinity are discussed from west to east below. Stream lengths were calculated by selecting individual stream segments from the Wisconsin DNR 24K Hydrography Database, version 5 (WDNR 2005j).

Siskiwit Bay to Mawikwe Point

The area from Siskiwit Bay to Mawikwe (formerly Squaw) Point includes six streams: Lost Creeks Nos. 1, 2, and 3, the Siskiwit River, and two unnamed streams that drain north to Lake Superior. Lost Creek No. 2 (3.98 km), with two southern tributaries (0.79 km and 1.15 km), joins Lost Creek No. 3 ca. 2.36 km above its entrance to Lake Superior. Lost Creek No. 1 (5.94 km), with five southern tributaries varying in length from 1.07 - 2.11 km, joins Lost Creek No. 3 ca. 0.91 km above Lake Superior. In addition to these tributaries, Lost Creek No. 3 (7.20 km) has one unnamed 1.73 km western tributary and three unnamed southern tributaries varying in length from 1.14 - 2.94 km. The mouth of the Lost Creek system forms a broad marshy wetland along the Lake Superior shore. All of Lost Creeks 2 and 3 are Class II brook trout and anadromous

Figure 12. Water resources of the Bayfield Peninsula, including the mainland unit of Apostle Islands National Lakeshore (WDNR 2001; NPS 2005d; NRCS 2005).

species waters (WDNR 2002c). An unnamed, unclassified 4.15 km Lake Superior tributary stream is located between Lost Creek No. 1 and the Siskiwit River.

The 20.31 km Siskiwit River, which originates at the outfall of Little Siskiwit Lake, is the longest tributary to Siskiwit Bay. It has 11 unnamed tributaries ranging from 0.99 – 2.96 km in length. The Siskiwit River from the spring source downstream to Siskiwit Falls is Class I trout water supporting brook, brown, and rainbow trout; the remainder downstream to Lake Superior is Class II and anadromous water. The unnamed 2.1 km southernmost tributary to the Siskiwit River is Class II brook trout water (WDNR 2002c). There is a harbor and marina at the mouth of the Siskiwit River in Cornucopia. The unnamed 1.03 km stream that enters Lake Superior east of Cornucopia has no WDNR fisheries classification.

Mawikwe Point to the East End of Mawikwe Bay

From Mawikwe Point, southwest of Eagle Island, to the east end of Mawikwe Bay, Mawikwe and Saxine Creeks and six unnamed streams enter Lake Superior. All except Mawikwe Creek are included in the mainland unit of APIS. The unnamed tributaries vary in length from 1.02 - 3.31 km.

Mawikwe Creek is a 4.76 km exceptional resource water with three tributaries varying in length from 1.68 – 2.83 km. The creek supports a Class I cold water fishery and anadromous fish (WDNR 2002c). The 1.68 km tributary enters Mawikwe Creek in Section 25, T51N R6W and is a Class III trout stream (WDNR 2005i).

Saxine Creek (4.51 km) is the westernmost of the small creeks and larger rivers that discharge to Lake Superior in the mainland unit, and its mouth marks APIS's western boundary. Saxine Creek is an exceptional resource water, with a Class I brook trout and rainbow trout fishery (WDNR 2005i). It also supports migratory runs of fish from Lake Superior and is a nursery area for rainbow trout. The stream bottom is mostly sand, with occasional gravel areas. Watershed vegetation is primarily upland hardwoods. Macroinvertebrate taxa richness is moderate, and four rare species considered rare in Wisconsin were present in 1997 (*Hydroporus pseudovilis, Onocosmoecus quadrinotatus, Psychoglypha subborealis, and Rhyacophilia acropedes*) (Epstein et al. 1997). Potential problems include low flows (Epstein et al. 1997) and erosion of the red clay soils (WDNR 2005i). Saxine Creek has five tributaries varying in length from 0.63 – 4.41 km. One tributary, a Class III brook and rainbow trout stream 3.2 km in length, flows through upland hardwoods and enters Saxine Creek in Section 19, T51N R5W. This stream is a high-gradient spring creek, but has poor trout habitat because of a shifting sand bottom and limited food supply (WDNR 2005i).

Saxine Creek, Mawikwe Creek, and another tributary at Section 19, T51N R5W all form small areas of coastal wetlands where they enter Mawikwe Bay (WDNR 2005i). These small wetlands are important to the integrity of the Lake Superior ecosystem for fish and wildlife spawning and nursery grounds (WDNR 2005i).

Most of the rest of Mawikwe Bay has a sand beach shoreline. Meyers Beach is a popular spot with visitors, and there are some issues with human waste at this site, accessible by land from a newly paved road off State Highway 13 (APIS, Julie Van Stappen, Branch Chief, Natural

Resources, pers. comm. 2007). Between Mawikwe Bay and Sand Bay, the Lake Superior shoreline contains some unique features, including undercut cliffs that form sea caves (Figure 13) (WDNR 2005i). Seven unnamed, unclassified streams varying in length from 0.98 – 2.00 km also enter Lake Superior in this area.

Figure 13. Mainland shoreline between Meyers Beach and Little Sand Bay, summer, 2006 (Photo by D. Mechenich).

Sand Point to Point Detour, including Sand and Little Sand Bays

From Sand Point to Point Detour, the Sand River and three unnamed tributaries varying in length from 1.42 – 3.59 km drain north to Lake Superior. The Sand River watershed is one of the largest in the northern Bayfield Peninsula, and the river is the longest in the mainland unit; it is 30.81 km long (WDNR 2005j) with a maximum width of 4 m (Epstein et al. 1997). It has 27 tributaries varying in length from 0.86 – 10.72 km, including Racket Creek. The upper 70% of the river is intermittent. It is nearly contained within the Lake Superior Lake Plain regional landscape ecosystem, although its headwaters are near the Bayfield Sand Barrens regional landscape ecosystem. The Bayfield Barrens encompasses the central part of the Bayfield Peninsula (Albert 1995), and may influence the Sand River (Epstein et al. 1997).

Most of the watershed is forested and undeveloped. In its uppermost reaches, which are primarily bordered by upland hardwoods, the river flows through an extensive wetland area where beavers are common (WDNR 2005i). Its upper 22.5 km are classified as a warm water forage fishery. Its lower reaches are bordered by dense willow stands (WDNR 2005i), northern sedge meadow, and alder thicket (Epstein et al. 2002). Many small bottom springs and spring streamlets flow into the Sand River for about 6.4 km upstream of its mouth, allowing it to support a Class II trout fishery and anadromous waters for brown and rainbow trout (WDNR 2002c, 2005i). The aquatic macroinvertebrate diversity in the Sand River is regionally significant (Epstein et al. 2002). Five of the twenty aquatic insect taxa found were considered rare in Wisconsin in 1997 (*Hydroporus pseudovilis, Cordulegaster obliqua, Onocosmoecus quadrinotatus, Oreodytes scitulus, and Timpanoga simplex)* (Epstein et al. 1997). The WDNR has identified turbidity, low flow, exotic species, and bank erosion as significant management concerns for the Sand River (Epstein et al. 1997). The old Town of Russell landfill is very near the watershed divide for the Sand River and Sand Bay; a determination of potential effects on these water resources has not been made.

During the five years when it was continuously monitored, the Sand River's flow at State Highway 13 varied from 0.1 - 46 m^3sec^{-1} (Rose 1988). The minimum 7-day mean flow below which the flow will fall on an average of once in 10 years ($Q_{7,10}$) is estimated to be 0.1 m^3sec^{-1} (Rose 1988). At the other extreme, the river periodically experiences flash floods, as high as 3-4 m above normal water levels, which scour most in-stream cover for aquatic organisms (WDNR 2005i).

Water quality samples collected from 1982 - 1984 at the Highway 13 crossing showed high quality water with little indication of human-made contamination. Concentrations of most constituents (pH, specific conductance, dissolved oxygen (DO), hardness, major ions, and nutrients) were higher at low flow or baseflow, indicating the relatively dilute nature of surface runoff compared to groundwater (Rose 1988). From 1980 - 1984, the river yielded an average of 11,884 metric tons of sediment and 2,917 kg of total phosphorus per year (Rose 1988). Some of the sediment has been deposited as a bar that reaches out toward Sand Island (WDNR 2005i).

Racket Creek, 10.72 km in length, is a spring-fed tributary of Sand River that runs through county forest land (WDNR 2005i). It has a sand and gravel bottom and is believed to be capable of supporting a Class III brown trout fishery, but little information is available. Epstein et al. (1997) found moderate macroinvertebrate taxa richness and two species of macroinvertebrates considered rare in Wisconsin at that time (*Onocosmoecus quadrinotatus* and *Cordulegaster obliqua*). Bank erosion was significant, and low flows significantly affected habitat quality (Epstein et al. 1997). Sand and gravel mining operations are located in the watershed (WDNR 2006c). An unnamed tributary to Sand Bay, 2.66 km in length, is located in T51N R4W S6. It is an exceptional resource water that supports a Class I coldwater fishery for brook and rainbow trout throughout its length (WDNR 2005i).

Figure 14. Mouth of Sand Bay (Photo by Bayfield County Land Records Department http://www.bayfieldcounty.org/landrecords/shore_2002/info_oblique2002.htm).

The drowned mouth of the Sand River forms a small estuary where it enters Lake Superior at Sand Bay. A forested sand spit separates the river and its wetlands from the lake (Figure 14) (Epstein et al. 2002). Several spring streamlets occur west of the lagoon at the stream's outlet, while to the east there is a peatland with coastal fen, coastal bog, and tamarack swamp. Rocky headlands with significant outcroppings of sandstone cliffs occur on either side of Sand Bay (Epstein et al. 2002). The WDNR Natural Heritage Inventory program reports that most of the coastal bog is composed of Sphagnum mosses, ericaceous shrubs, sedges, and insectivorous plants. Common vascular species include leatherleaf, bog rosemary (*Andromeda glaucophylla*), woolly sedge, pitcher plant, muck sedge, white beak-rush, small cranberry, and scattered sapling-size tamarack. Between the sand spit and tamarack swamp, a very wet mat is composed mostly of woolly sedge, with very low moss cover. Associates of this coastal fen include livid sedge (*Carex livida* var *radicaulis*), sooty beak-rush (*Rhynchospora fusca*), intermediate sundew (*Drosera intermedia*), marsh horsetail, bog arrow-grass (*Triglochin maritima*), and intermediate bladderwort. Bogbean and sweet gale are common throughout both open peatland communities. The tamarack swamp is composed of small trees over a dense layer of speckled alder. Leatherleaf, lake sedge, marsh horsetail, dwarf red raspberry (*Rubus pubescens*), and marsh cinquefoil are common understory species (Epstein et al. 1997).

Rare plants identified at Sand Bay include swamp-pink, autumnal water-starwort (*Callitriche hermaphroditica*), livid sedge, sparse-flowered sedge (*Carex tenuiflora*), crinkled hairgrass

(*Deschampsia flexuosa*), Robbins spike-rush (*Eleocharis robbinsii*), marsh willow-herb (*Epilobium palustre*), downy willow-herb (*E. strictum*), broad-leaved twayblade (*Listera convallarioides*), large roundleaf orchid (*Platanthera orbiculata*), and sooty beak-rush. Other rare species include the bog fritillary (*Boloria eunomia*), bog copper (*Lycaena epixanthe*), evening grosbeak (*Coccothraustes vespertinus*), Connecticut warbler (*Oporornis agilis*), gray jay (*Perisoreus canadensis*), and Tennessee warbler (*Vermivora peregrine*) (Epstein et al. 1997). Mollusks in Sand Bay were surveyed by Doolittle (1991), but only one *Anodonta grandis grandis* was found in four hours of sampling effort.

Little Sand Bay is a small inlet between Sand Bay and Point Detour that includes a small area of coastal wetlands, a sand beach, and hemlock and cedar vegetation (Figure 15) (WDNR 2005i). One of APIS's visitor centers is located there, as well as a commercial fishing historic site, and a boat ramp and campground operated by the town of Russell. Little Sand Bay is afforded some protection from northwesterly fall and winter storms by the presence of Sand Island (Center for Lake Superior Environmental Studies 1975).

A detailed study of the physical parameters, coastal processes, and biota was conducted on Little Sand Bay in 1974 to evaluate design parameters for the installation of a dock (Center for Lake Superior Environmental Studies 1975). The zooplankton community was dominated by rotifers, especially *Conochilus* spp. and *Kellicottia longispina*. *Cyclops* spp. and *Diaptomus* sp. were the most abundant copepods, while *Bosmina longirostris* and *Daphnia* spp. were the most common cladocerans. The predominant benthic organisms were species of Annelida, Chironomidae, and Sphaerium, with previously unreported species of *Hydra*, *Leptodora*, *Eurycercus*, Odonata, Ephemeroptera, *Cheumatopsyche*, Plecoptera, and Libertia also found. Fish caught by seine, trawl, and gill net included brown trout, round whitefish, rainbow smelt, white sucker, longnose sucker, burbot, Johnny darter, slimy sculpin, spottail shiner (*Notropis hudsonius*), lake chub, and unidentified minnows.

Bacteria sampling was conducted twice weekly from mid-May to mid- September of 1986 and 1987 north of the breakwall at Little Sand Bay (Balcer and McCauley 1989). On only two occasions (June 13, 1986 and July 20, 1987) did fecal coliform counts exceed 10 colonies/100 mL, and all samples were well below the guideline of less than 200 colonies/100 mL. Fecal streptococcus numbers were considerably higher (with a range of 2 to too numerous to count), but the fecal coliform/fecal streptococcus ratio suggested input from birds or from surface water runoff (Balcer and McCauley 1989). Net phytoplankton were also sampled, and Little Sand Bay had the highest density and lowest diversity of the seven APIS sites sampled. Seventy percent of the community was composed of *Asterionella* sp., a common inhabitant of oligotrophic waters (Balcer and McCauley 1989).

Figure 15. Little Sand Bay (Photo by Bayfield County Land Records Department http://www.bayfieldcounty.org/landrecords/shore_2002/info_oblique2002.htm).

Point Detour to Raspberry Bay

From Point Detour to the east end of Raspberry Bay, the Raspberry River and two unnamed tributary streams enter Lake Superior, all within the Red Cliff Indian Reservation. The Raspberry River watershed is one of the largest in the northern Peninsula. The river is 23.24 km long and includes nine western, two eastern, and nine southern unnamed, unclassified tributaries that vary in length from 0.84 - 5.45 km. The Raspberry River upstream from Lake Superior to the town road crossing is Class II waters with resident and anadromous brook and brown trout, while its northernmost tributary is classified as Class III waters supporting resident brook trout. The northernmost unnamed tributary to Lake Superior is 5.45 km long, with three western tributaries 2.12 - 3.00 km in length. The other unnamed tributary is only 0.67 km, has no tributaries, and is likely ephemeral.

Raspberry Point to Red Cliff Point, including Frog Bay

From Raspberry Point to Red Cliff Point, five unnamed streams and Frog Creek enter Lake Superior, all within the Red Cliff Indian Reservation. The unnamed and unclassified streams vary in length from 0.82 - 1.61 km. Frog Creek is 6.76 km long, with one southern and three western tributaries that vary in length from 0.99 - 1.34 km.

Red Cliff Bay Area

The Red Cliff Bay area is included in the Red Cliff Indian Reservation and has two unnamed tributary streams and Red Cliff Creek that drain into Lake Superior. Red Cliff Creek is 10.41 km long and has 5 western, 2 eastern, and 2 southern unnamed tributaries that vary in length from 0.92 - 4.26 km. The two unnamed tributaries of Lake Superior are each 1.20 km long. These streams have no WDNR fisheries classifications.

Buffalo Bay Area

The Buffalo Bay area includes 5.54 km Chicago Creek, its 0.75 km western unnamed tributary, and a 1.64 km tributary to Lake Superior south of Chicago Creek. Chicago Creek is classified as Class II waters supporting resident brook trout and anadromous species from Lake Superior up to Hwy 13. The Lake Superior tributary has no WDNR fisheries classification.

Roys Point to Bayfield

The mainland area from Roys Point to Bayfield includes Brickyard Creek and six unnamed Lake Superior tributaries. Brickyard Creek is 4.73 km long and has no tributaries, and is a Class II stream supporting resident brook trout. The other tributary streams vary in length from 0.74 - 1.23 km and are unclassified.

Bayfield Area

Two unnamed Lake Superior tributaries flow through the city of Bayfield; the northernmost is 3.18 km and the other is 1.60 km long. A 4.68 km unnamed stream enters Lake Superior just south of Bayfield. These streams do not have a WDNR fisheries classification.

Pikes Bay Area

The Pikes Bay area includes 15.20 km Pikes Creek and its tributaries, which include North Pikes Creek (13.4 km), Birch Run Creek (2.82 km), and four southern, four western, and two northern unnamed tributaries that vary in length from 0.84 – 6.01 km. Birch Run Creek itself has three northern unnamed tributaries that vary from 0.74 - 1.13 km in length. North Pikes Creek has five western and three eastern unnamed tributaries that vary in length from 0.75 - 5.33 km. Pikes Creek and North Pikes Creek are Class I waters supporting brook, brown, and rainbow trout as well as anadromous coho and Chinook salmon seasonally. Birch Run Creek is also classified as Class I waters supporting native and anadromous brook trout. A WDNR fish hatchery near the mouth of Pikes Creek is an important rearing facility for anadromous trout and salmon stocked into Lake Superior.

Van Tassells Point to Houghton Point

The shoreline area from Van Tassells Point to Houghton Point just north of the city of Washburn includes the Onion and Sioux Rivers and three unnamed Lake Superior tributary streams. The Onion River (7.53 km) is the northernmost tributary stream to Lake Superior in this stretch and has two northern, two northwestern, one western, and two southern unnamed tributary streams that vary in length from 0.83 - 3.20 km. The entire length of the Onion River is Class I water supporting resident brook, rainbow, and brown trout as well as anadromous coho and Chinook salmon. Its northeasternmost tributary is Class I water supporting resident brook, rainbow, and brown trout.

The Sioux River watershed, one of the largest in the lower Bayfield Peninsula, includes the 28.58 km Sioux River, three unnamed perennial Lake Superior tributary streams, and one intermittent stream. The Sioux River, one of the more important anadromous fish streams in the Peninsula, has 9 unnamed northwestern and 11 unnamed southern tributaries, as well as the northwestern Little Sioux River and Fourmile Creek tributaries. These 22 tributaries vary in length from 0.87 - 11.38 km. The Little Sioux is 11.33 km long and has three northern, five western, and one southern unnamed tributaries ranging in length from 1.2 - 3.99 km. Fourmile Creek, 11.38 km long, has 12 unnamed tributaries, six northern and six southern, varying in length from 1.03 - 2.54 km.

The Sioux River upstream to County Highway C (6.4 km) is Class I water supporting brook, brown and anadromous rainbow trout and coho and Chinook salmon. From County Highway C to the lake (12.9 km) it is Class II water supporting brook and brown trout. A 2.6 km northeastern Sioux River tributary is Class II water supporting brook and brown trout and anadromous coho and Chinook salmon, while a 4.3 km northwestern tributary is Class II water supporting brook and brown trout.

The three unnamed western tributaries to Lake Superior south of the Sioux River system to Houghton Point north of Washburn vary in length from 1.30 - 6.69 km and have no WDNR fisheries classifications.

Chequamegon Bay

Chequamegon Bay is bounded by the Bayfield Peninsula to the northwest and Chequamegon Point to the northeast, and connected to Lake Superior by a 3.2 km stretch of open water between the tip of Chequamegon Point and Houghton Point on the Bayfield Peninsula (WDNR 2003d). It is relatively shallow, with an average depth of 8.5 m and a maximum depth of 20 m.

Its watershed area as delineated by the WDNR encompasses nearly 375,000 ha and includes parts of Ashland, Bayfield, and Iron counties (Figure 16) (WDNR 2005j). Circulation in the bay is normally counterclockwise, but is easily disrupted by easterly winds (WDNR 2003d). Streams that discharge into Chequamegon Bay include Bono Creek, Boyd Creek, Whittlesey Creek, the North and South Branches of Fish Creek, Bay City Creek, Wood Creek, Beartrap Creek, the Kakagon River, and a few unnamed tributaries to Lake Superior east of the city of Ashland (WDNR 2003d). The WDNR includes the watershed of the Bad River in the Bay's watershed. The River does not actually discharge into the Bay, but during high water periods, it mingles with waters of the Kakagon in a large wetland area north of Highway 2. If the Bad River and its tributaries are not included, the Bay's watershed area drops to just over 110,000 ha.

In a source water assessment for the city of Ashland, the WDNR (2003d) reported that the northern and western portions of the bay generally experience cleaner water than the southern and eastern portions. Water clarity at the city of Ashland's water intake drops during spring runoff and during windstorms and heavy fall and summer rainstorms. Coliform bacteria are frequently detected at the intake, and one of thirteen tests for the protozoan *Giardia* returned positive.

Reported threats to the bay's water quality include erosion and runoff from the watershed's clay soils, agriculture and pastureland draining into Bono, Boyd and Fish Creeks, urban development in the city of Ashland, and sites of historical contamination, including the two largest, the Superfund site at the Ashland waterfront and the DuPont plant in the town of Barksdale.

An open water (Lake Superior) site 3.2 km south of Long Island within Chequamegon Bay was sampled monthly during the summer of 1996. The site had low nutrient concentrations, a large cladoceran population before August, and a ratio of calanoid copeopods to cladocerans less than 1:1. Benthic organisms included (in order of decreasing density) oligochaete worms, clams, caddisfly larvae, snails, chironomids, and *Diporeia* (Lake Superior Ecosystem Research Center 1997).

Chequamegon Bay contains three Wisconsin Natural Heritage Inventory sites, which are designated to document occurrences of rare species and natural communities, including state and federal endangered and threatened species: Bad River-Kakagon Sloughs, Fish Creek Sloughs, and the Bayview Beach – Sioux River Slough (Epstein et al. 2002). Of these, the Bad River – Kakagon Sloughs is the largest, encompassing 22,735 ha, of which 7,000 ha are wetlands, including emergent marsh, coastal fen, coastal bog, tamarack swamp, shrub swamp, and a series of coastal lagoons. This site may be the largest freshwater estuarine system of this size, type, and quality in the world, supporting a great diversity of high quality natural communities and rare plant and animal species (Epstein et al. 2002). The Fish Creek Sloughs, located at the head of Chequamegon Bay, are considerably smaller, around 200 ha, and are located on the outskirts of Ashland and crossed by Highway 2 (Epstein et al. 2002). The 125 ha Bayview Beach – Sioux River Slough has been partially developed to accommodate a state highway and a public beach, but still contains significant marsh and fen communities (Epstein et al. 2002). Additional Lake Superior Heritage sites near APIS include the Red Cliff Reservation site, Big Bay on Madeline Island, and Lost Creek, Port Wing, and Bark Bay to the west of the mainland unit.

Figure 16. Location of the Chequamegon Bay watershed in the vicinity of Apostle Islands National Lakeshore (WDNR 2003e).

Water Resources of the Islands

All streams on the APIS islands are unnamed and with one exception have no WDNR fisheries classifications. Many are ephemeral; some flow during wet seasons, while others flow for longer periods of time but dry up during mid to late summer. Only three are potentially perennial; the main tributary of the Stockton Island lagoon and two streams close together near the northwest end of Oak Island in a steep ravine (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2006). No streams or wetlands are found on Cat, Eagle, Gull, North Twin or South Twin Islands (Table 11) (NPS 1999c; NRCS 2005), although undocumented temporary streams or wetlands may occur. APIS island streams are essentially unstudied, and future studies are needed to characterize them.

Maps in this section (Figures 17, 19, 20, 22) as well as the Key Features map (Figure 5) show streams and wetlands included on the NRCS 1:12K hydrography (NRCS 2005) and the NPS hydrography (1999c) coverages, respectively; not all wetlands listed in Judziewicz and Koch (1993) are shown, as their report did not include maps.

Table 11. Sizes of the islands of Apostle Islands National Lakeshore and their streams and wetlands on the NPS hydrography and NRCS 1:12K hydrography coverages (NPS 1999c; NRCS 2005).

Island	Size (ha)	Stream numbers and lengths	Wetlands
Basswood	774.71	7 eastern, 2 western, 0.62 - 1.91 km	None
Bear	734.14	3 eastern, 1 western, 0.74 - 1.37 km	2, 1.96 and 2.17 ha
Cat	541.92	None	None
Devils	125.57	None	1, 3 ha
Eagle	11.22	None	None
Gull	1.42	None	None
Hermit	316.72	None	1, 1.03 ha
Ironwood	269.55	1 southwestern, 0.51 km	None
Long	124.94	None	See Table 12
Manitou	536.31	4 southwestern, 5 northwestern, 0.27 - 0.70 km.	None
Michigan	622.73	See Table 14	See Table 13
North Twin	67.04	None	None
Oak	2,033.25	See Table 15	None
Otter	535.29	1 southwestern, 1 western, 1 northwestern, 0.35 – 0.68 km	2, 4.69 and 6.56 ha
Outer	3,181.30	See Table 16	See Table 17
Raspberry	116.39	None	3, 0.51 - 0.64 ha
Rocky	424.66	2 eastern, 2 southern 0.22 – 0.37 km	3, 1.27 - 2.44 ha
Sand	1,157.17	2 eastern, 1 western 0.48 - 2.59 km	3, 9.73 – 44.35 ha
South Twin	136.13	None	None
Stockton	4,003.48	See Table 18	See Table 19
York	110.82	None	1, 1.66 ha

Splash pools occur on many of the islands where rocky ledges face Lake Superior, including on Sand Island at Lighthouse and Justice Bays and below the Lighthouse; on Stockton Island at the south end of Julian Bay and at Anderson Point; at the north end of Outer Island; and on the north and east sides of Devils Island. These temporary pools may teem with macro- and micro-life during short periods of time but have not been studied (Szczytko, personal observation).

The psammon community (organisms that live in or move through sand) of the Apostle Islands is unknown and unstudied. This fragile community exists in the sand-beach area known as the eulittoral and supralittoral zones, which receive water from waves and splash generated by Lake Superior. This habitat, which harbors a unique fauna, exists along islands that have sandy beach areas such as Julian and Presque Isle Bays and other smaller beaches on Stockton Island, the East and West bays of Sand Island, the entire north shore of Long Island, and many smaller beaches or sand spits on other islands.

Vernal pools are small, temporary pools that form 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 and invertebrates at a critical time in their life cycle. 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 developed unique survival strategies designed to ensure success in these highly variable habitats (Batzer et al. 2004). In APIS, vernal pools are reported to be present on Basswood, Bear, Cat, Hermit, Long, Manitou, and Outer Islands (Casper 2001a). The geographic distribution, hydroperiods, and biotic and abiotic dynamics of APIS's vernal pools should be documented so that these unique habitats can be protected and managed.

Basswood Island
No wetlands are found on Basswood Island (Figure 5) (NPS 1999c). Most of the streams are located on the eastern shoreline, where seven streams vary in length from 0.62 - 1.91 km. The 1.91 km stream has four tributaries that range from 0.37 - 0.88 km. The western shoreline has only two streams. The one in the southwestern 1/3 of the island is 1.12 km, and the other, near the northwestern end, is 0.94 km. A basic ecological and recreational resources inventory of the island was done by Anderson and Milfred (1983).

Bear Island
One of the most spectacular summit bogs within APIS occurs on Bear Island. It is 2 ha in size and is located in a summit depression at 800 m AMSL surrounded by a 5,600 – 9,500 year old beach ridge (Kowalski 1976). This wetland is a Sphagnum bog with scattered white pine, black spruce, and tamarack trees along with the usual bog floral community (Judziewicz and Koch 1993).

A 2 ha cuspate foreland at the southern tip of the island has been impacted by human use, and several private cabins still remain there. A small spring-swamp on the west side of the foreland supports many alder thicket species (Judziewicz and Koch 1993). This swamp is probably the 2.17 ha wetland shown on the NPS hydrography coverage (NPS 1999c). A second wetland nearby is 1.96 ha. Bear Island has three eastern streams from 0.74 - 1.37 km long and one western stream that is 0.94 km long.

Cat Island

Cat Island has no true bogs or wetlands, but a "boggy woods" (Cats Head Bog) is located in the poorly drained center of the northern peninsula (Judziewicz and Koch 1993). This wet area supports black spruce, a few bog ericads, winterberry holly (*Ilex verticillata*), and three-leaved false Solomon's–seal (*Smilacina trifolia*) (Judziewicz and Koch 1993).

The cat's tail is formed by a 0.5 ha sand spit at the southern end of the island. The west side dune plant community is dominated by beach grass; beach pea, beach wormwood (*Artemisia stelleriana*), crinkled hairgrass, and dwarf juniper are also found (Judziewicz and Koch 1993).

Two wetlands appear on the NPS hydrography coverage (NPS 1999c) at the northeast end of the island (Figure 5). A 2.52 ha wetland close to the northwest shore is likely the one discussed by Judziewicz and Koch (1993); the other is located near the constriction of the peninsula along the northeast shore and is 0.22 ha. A 10.31 ha wetland is located near the southern 1/3 of the island and is drained by an eastern 0.86 km stream. A southern stream is 0.36 km long, and two western streams are 0.45 and 0.88 km long, with the one nearest the narrowest part of the island being the shorter.

Devils Island

On the trail from the light house to the south end of the island, there is a 3 ha ericad-Sphagnum bog with a few scattered white pines, tamaracks, black spruce, and the common bog ericads and sedges (Judziewicz and Koch 1993). It is interesting to note that this bog is not on the NPS (1999c) hydrography coverage, and no streams appear on the NRCS (2005) hydrography coverage.

Hermit Island

Hermit Island has no streams (NRCS 2005) and one 1.03 ha wetland near its southwestern end (NPS 1999c). A ravine at the northwestern end has a marshy alder thicket near its mouth (Judziewicz and Koch 1993). A basic ecological and recreational resources inventory of the island was done by Anderson and Milfred (1983).

Long Island

Long Island, which separates the waters of Chequamegon Bay from Lake Superior, is western Lake Superior's most extensive and least disturbed coastal barrier spit. The island has no streams (NRCS 2005), but is about 25% wetland, which includes interdunal wetland, open bog, shrub swamp, and wet sand flats (Epstein et al. 2002). The interdunal ponds are a rare community statewide that provide habitat for several rare plants. Long Island is heavily used by migratory birds. Rare species found on Long Island include lenticular sedge (*Carex lenticularis*), tufted hairgrass (*Deschampsia cespitosa*), variegated horsetail (*Equisetum variegatum*), beach-dune tiger beetle (*Cicindela hirticollis rhodensis*), and blue-legged grasshopper (*Melanoplus flavidus*) (Epstein et al. 1997). The invasive purple loosestrife (*Lythrum salicaria*) has become well established on the sand flats (Epstein et al. 1997).

Meeker (1998) used photo interpretation and field reconnaissance to locate and designate nine specific wetland types on Long Island based on dominant vegetation and the presence or absence of a peaty organic layer in the upper soil horizon (Table 12). These included sphagnum lawn, leatherleaf/sphagnum wetland, alder/leatherleaf/sphagnum wetland, sedge peat wetland, panne, sedge/grass meadow, alder/willow wetland, shallow marsh, and deep marsh. Older wetland types tended to be Sphagnum-dominated and occurred in deeper swales northwest of the washover zone. These varied in size from small pockets <100 m^2 to elongate wetlands over 1,000 m^2.

Table 12. Wetland types of Long Island, Apostle Islands National Lakeshore (Meeker 1998).

Substrate	Type	Subtype	Description
Peat			> 15 cm peaty organic layer
	Sphagnum peat	Sphagnum lawn Leatherleaf/sphagnum Alder/leatherleaf/sphagnum	
	Sedge peat		
Inorganic			< 15 cm peaty organic layer
	Saturated	Pannes	Less than 100% vegetative cover, damp sand, rushes, sedges, forbs
		Sedge/grass meadow	Beginning peat accumulation, monotypic grasses and sedges, including blue-joint and woolly sedge
		Alder/willow	Alder and willow overstory, blue-joint grass and sedge understory
	Standing water	Shallow marsh	Edges of pools that support emergent vegetation
		Deep marsh	Pools with submerged and floating vegetation

Judziewicz and Koch (1993) found many narrow beach ridges and swales throughout the APIS portion of the island. The oldest ridges occurred on the bay side (south and southwest side) of the island. They reported that the north and northeast facing shoreline is accreting at an alarming rate. Linear Sphagnum bogs on the bay side of the island support fairly complete bog floras, including many sedges, ericads, sweet gale, insectivores, sweet flag (*Acorus calamus*), and bog birch. Many ephemeral sand ponds occur among the dunes near the western end of the island with extensive growths of watermilfoil (*Myriophyllum heterophyllum*). A bog pool just south of the extreme western tip supports a diverse flora including white water-lily (*Nymphaea odorata*), greater duckweed (*Spirodela polyrhiza*), and arrowheads (*Sagittaria latifolia* and *S. rigida*). They also found a wet sedge-rush meadow on the bay side near the filled-in breach called the "Sand Cut" (Judziewicz and Koch 1993).

Of the islands it studied, Long Island was considered by the Lake Superior Ecosystem Research Center (1997) to be the island most likely to be affected by industrial activities because of its proximity to Ashland. It is also one of the most susceptible to invasive and exotic species because of its periodic connection to the mainland. The quality of the waters surrounding its northwest tip may also be affected by streams from the southern end of the Bayfield Peninsula and tributary streams along the southwestern end of Madeline Island.

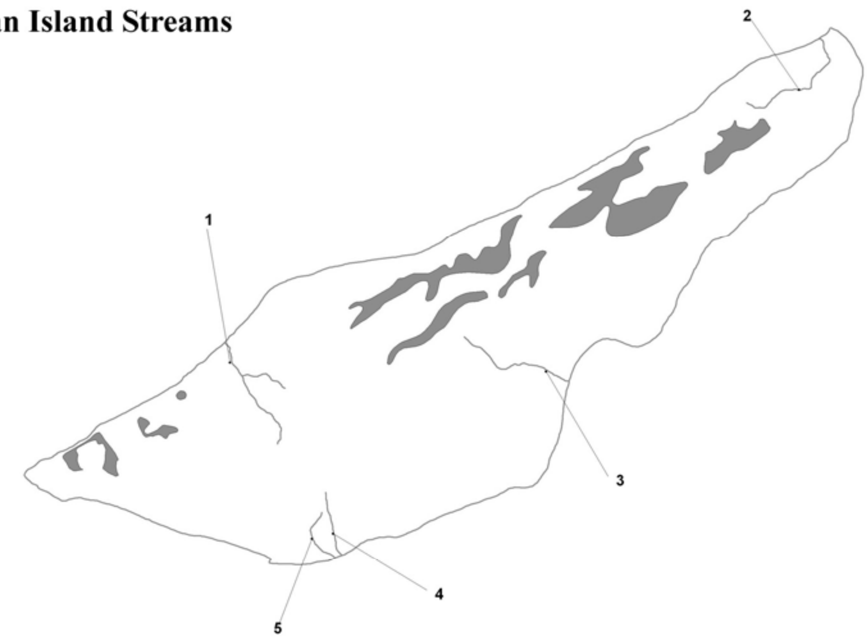
Madeline Island
Although Madeline Island is not part of APIS, the water quality of its streams may affect APIS water quality. The island has four tributary streams near its southwestern end; the two western streams (1.46 and 1.24 km) do not drain into Lake Superior and are likely ephemeral, while the two southern streams (0.83 and 1.15 km) drain into Chebomnicon Bay within 7.5 – 8 km of the western tip of Long Island. A 52.71 ha tombolo located at the southeast end of the island, within Big Bay State Park, has a 2.32 km stream that flows through it into Lake Superior at the park's northeast end. There are eight southeastern (0.84-2.36 km) and two eastern (0.95 and 2.23 km) unnamed Lake Superior tributary streams. A 14.52 ha bog lake has a 2.23 km stream that flows through it into Lake Superior northeast of Big Bay State Park near Amnicon Bay. Interestingly, there are no Lake Superior tributary streams on the northern side of Madeline Island.

Manitou Island
There are no large wetlands on the NPS (1999c) hydrography coverage for Manitou Island, but a tiny, linear, upland "boglet" about 100 m long and 20 m wide occurs near the summit of the island (Judziewicz and Koch 1993). The island has four southwestern streams varying from 0.34 - 0.58 km long and five northwestern streams varying from 0.27 - 0.70 km. A basic ecological and recreational resources inventory of the island was done by Anderson and Milfred (1983).

Michigan Island
Michigan Island is rich in surface water, with eight defined wetlands (Table 13, Figure 17) and five unnamed streams (Table 14, Figure 17). A broad "U" shaped 2.66 ha wetland (A) is located very close to the southwestern tip of the island. Just to the northeast (0.21 km) of this wetland is a reversed "J" shaped wetland (B) that is 1.22 ha, and 0.53 km north of the "J" shaped wetland, there is also a round 0.25 ha wetland (C).

A series of five elongate wetlands are located near the narrowed northern 1/3 of the island and are aligned along a northeast to southwest axis. These wetlands are positioned closer to the northwest shoreline. The southern cluster of wetlands are 11.17 ha (D), 4.47 ha (E), and 2.14 ha (F). North of this cluster, a 17.21 ha elongate wetland (G), the largest on the island, is split and joined by a narrow connection. Approximately 0.15 km northeast of this wetland, a 5.33 ha wetland (H) is positioned equidistant from the northwest and southeast shores.

Michigan Island Streams



Michigan Island Wetlands

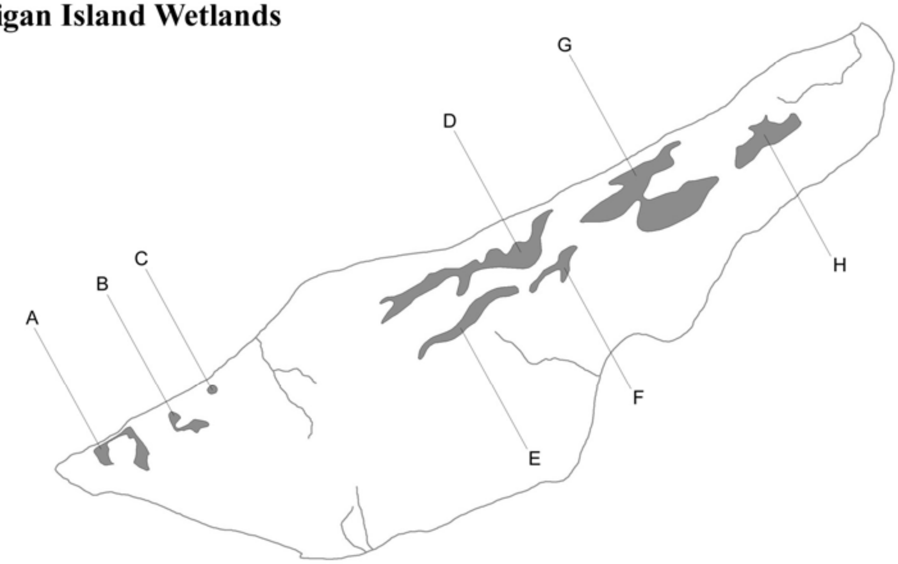


Figure 17. Streams and wetlands of Michigan Island, Apostle Islands National Lakeshore.

Table 13. Wetlands of Michigan Island, Apostle Islands National Lakeshore (NPS 1999c).

Wetland	Size (ha)
A	2.66
B	1.22
C	0.25
D	11.17
E	4.47
F	2.14
G	17.21
H	5.33

Table 14. Streams of Michigan Island, Apostle Islands National Lakeshore (NRCS 2005).

Stream	Length (km)
1	0.77
2	0.85
3	0.87
4	0.42
5	0.38

One of the island's five streams (#1) is 0.77 km, with a 0.31 km eastern tributary, and is located near the northwest end of the island. At the northeast tip, 0.85 km stream #2 drains from the southwest. An eastern stream (#3) near the midpoint of the island is 0.87 km long. Two southern streams (# 4, 5) are close together approximately ¾ the length of the southern shoreline from the northern tip; they are 0.42 and 0.38 km long.

Wetland A, located at the southwest end of the island, is associated with the Michigan Island Lagoon. The wetland's habitats and plant community are very diverse, exceeded in the islands only by the larger wetland complexes on Outer, Stockton, and Madeline Islands. The internal bog mat is diverse, with many of the common bog species as well as many species of sedges, rushes, and grasses.

The lagoon is located along the north bar of the sand spit and is separated from Lake Superior by a bar 1.1 m above the lake surface (Figure 18). Its maximum depth has been reported as 2 m (Rose 1988) and 1.4 m (Lake Superior Ecosystem Research Center 1997), and its open water surface area as 1.6 ha (Rose 1988). Its water level is 1.8 - 9.1 cm above the water level of Lake Superior (average 5.9 cm). Its water budget consists of inflows of precipitation, wave washover, surface inflow from wetlands, and intermittent groundwater inflow, with precipitation and wave washover most significant (Rose 1988). Outflows include evaporation, surface flow to adjoining wetlands, and groundwater outflow.

Figure 18. Southwestern end of Michigan Island, showing sand spit and lagoon (NPS photo).

The lagoon's water is of a calcium-magnesium bicarbonate type (Rose 1988) with a pH range of 5.6-6.9 (Lake Superior Ecosystem Research Center 1997). Soluble nutrients are generally low, but silica concentrations are relatively high (1.2 – 4.4 mg/L) (Lake Superior Ecosystem Research Center 1997), perhaps because diatoms wash in from Lake Superior and then decompose in the more acidic lagoon environment (Rose 1988).

Zooplankton found included the cladocerans *Diaphanosoma* sp., *Chydorus* sp., *Daphnia* sp., and *Polyphemus* sp.; the calanoid copepods *Senecella* sp. and *Diaptomus* sp.; and the cyclopoid copepod *Cyclops* sp. (Lake Superior Ecosystem Research Center 1997). The open water supports a large population of water-shield (*Brasenia schreberi*), yellow pond-lily (*Nuphar lutea*), common bladderwort (*Utricularia vulgaris*), and pondweeds (*Potamogeton berchtoldii* and *P. illinoiensis*) (Judziewicz and Koch 1993). Sediments consist of mud and fine sand. Balcer and McCauley (1989) reported benthos abundance of 165-534/ m^2, with chironomids accounting for 64-92%; the only benthic organisms reported by the Lake Superior Ecosystem Research Center (1997) were clams, with a very low density (43.1/m^2).

An acid swampy blue-joint meadow lies between wetland A and the south shore, and boggy meadows are found on both sides of the trail that crosses the island east of the bog. The eastern end of the island is poorly drained, and a series of old beaver ponds in this area are changing to wet meadows dominated by blue-joint, yellow loosestrife (*Lysimachia punctata*), calla-lily (*Calla palustris*), and three-way sedge (*Dulichium arundinaceum*). In many places the meadows are being invaded by speckled alders (Judziewicz and Koch 1993).

North Twin Island

No streams or wetlands are found on the NPS (1999c) or the NRCS (2005) coverages for North Twin Island. Judziewicz and Koch (1993) reported the occurrence of a swamp woods near the summit of the island along the west shore. They found soft-leaf sedge (*Carex disperma*), three-fruited sedge, dwarf raspberry, northern bugleweed (*Lycopus uniflorus*), mad-dog skullcap (*Scutellaria lateriflora*), and southern three-lobed bedstraw present in this semi-wetland.

Oak Island

Oak Island is pentagonal and has a rugged shoreline with deep ravines, each supporting one or more streams, radiating out on all sides (Figure 19). It has nearly twice the elevation (65 m) of any other island in the archipelago, and the steep landscape supports only one 0.42 ha wetland near the island's center. The shoreline is mostly high clay bluffs, and these are the highest on the Wisconsin Lake Superior coast. Sandstone cliffs and ledges occur intermittently but are most common along the eastern shoreline.

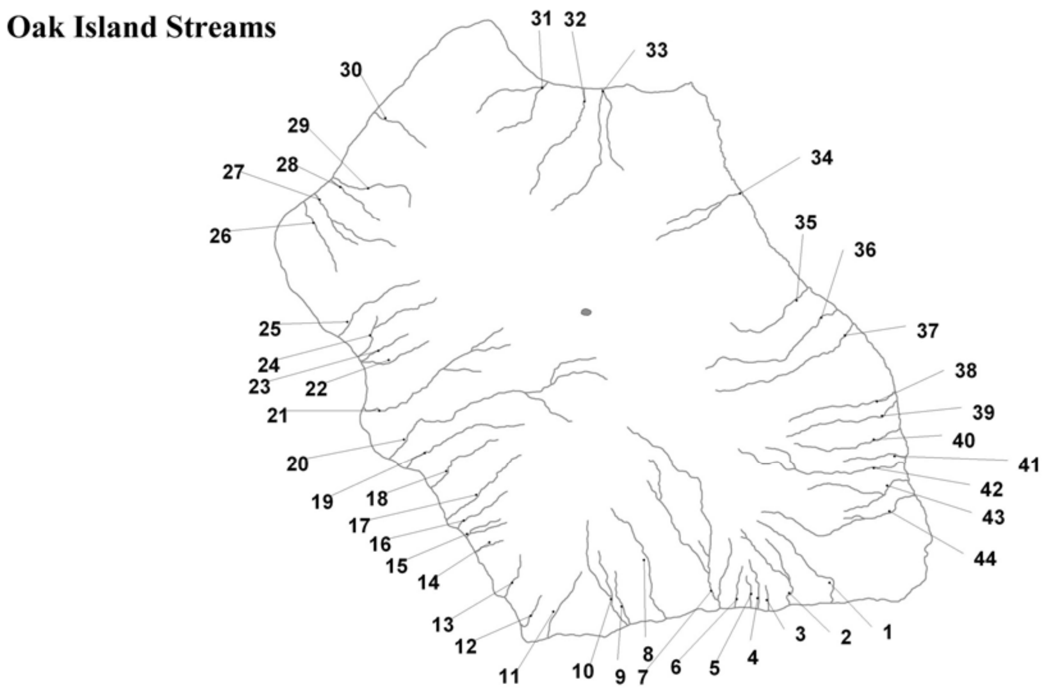


Figure 19. Streams of Oak Island, Apostle Islands National Lakeshore (NRCS 2005).

A cuspate foreland occurs at the southern tip of the island. Sand beaches occur on the northwestern and northern coasts, and very small isolated beaches, or pocket beaches, are also found on the southern coast (Judziewicz and Koch 1993). Seeps are common throughout the island's steep ravines, and nearly all support small populations of the state-threatened species broad-leaved twayblade and drooping sedge (*Carex prasina*) and the uncommon eastern rough sedge (*Carex scabrata*) (Judziewicz and Koch 1993). The deepest ravines are located along the north and southwest coasts. The ravine topography allows Oak Island to support many southern plant forms that are unique or rare elsewhere within the archipelago. Most of these ravines have been severely altered by fire and logging; most of the island burned in 1943, and logging operations continued until the 1930's (Judziewicz and Koch 1993).

Oak Island has 44 streams that vary from 0.23 - 2.36 km in length (Figure 19, Table 15) and one minor wetland. Except for two streams (#25, 26) on the northwest end of the island, all are

Table 15. Streams of Oak Island, Apostle Islands National Lakeshore (NRCS 2005).

Stream	Length (km)	Number of tributaries	Lengths (km)
1	1.16		
2	0.72	1	0.72
3	0.23		
4	0.49		
5	0.31		
6	0.39		
7	2.13	3	0.59, 0.17, 1.27
8	1.22		
9	0.52		
10	0.77	1	0.78
11	0.69		
12	0.38		
13	0.43		
14	0.28		
15	0.35	1	0.32
16	0.59		
17	0.95		
18	0.83		
19	1.23		
20	2.36	2	0.53, 0.55
21	1.61	2	0.35, 0.37
22	0.68		
23	0.29		
24	1.00	1	0.12
25	0.95		
26	0.74		
27	0.65	1	0.66
28	0.60		
29	0.91		
30	0.60		
31	0.72	1	0.71
32	1.19		
33	1.33	1	0.80
34	0.94	1	(0.54
35	0.92		
36	1.47		
37	1.50		
38	1.05		
39	1.14		
40	1.04		
41	0.59		
42	1.65	1	0.38
43	0.71	1	1.65
44	1.60	1	0.20

ephemeral, flowing only during the wet times of the year. The two potentially perennial streams are located near the high northwest cliffs and occur in steep ravines (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2006). During high precipitation events, they discharge a large sediment load into the lake. One of these northwest streams (nearest the high cliffs) is probably permanent and flows throughout the year. There are a few stream-mouth meadows such as the one at the NPS dock near the island midpoint along the west shoreline.

There are 10 streams (#1 – 10) along the western shoreline from the southern tip to the high banks of the north coast, varying in length from 0.23 - 2.13 km. The 14 streams (#11 – 24) along the western shoreline vary in length from 0.35 - 2.36 km. There are five streams along the northwestern shoreline (#26 – 30) that vary in length from 0.60 - 0.95 km and three streams (#31 – 33) along the northeastern shore that vary in length from 0.94 - 1.33 km. The 11 streams along the eastern shoreline (#34 – 44) vary in length from 0.59 – 1.65 km.

Rose (1988) identified six major watersheds (three northern, one southern, and two southeastern), and he sampled and gauged streams in the northern and southern watersheds. The average channel slope was 7.4%, and the average basin storage was 0% (Rose 1988). For streams with baseflow, discharge was groundwater-dominated, based on specific conductivity, pH, and alkalinity values. The median pH was 6.8; the dominant ions were calcium, magnesium, and bicarbonate, with sulfate and silica also significant. Balcer and McCauley (1989) sampled the largest stream on the northern end of the island during the summer of 1986 and reported a pH range of 7-7.5, conductivities of 45-95 umhos/cm^2, and alkalinities of 41-68 mg/L $CaCO_3$.

Data on the island's aquatic fauna are sparse. Lafrancois and Glase (2005) reported that Dean (1980) found brook trout and sculpin in a permanent stream and classified it as a class II trout stream, making it the only classified stream in the islands. Slade (1994) found juvenile brook trout (possibly coaster brook trout) in two streams and slimy sculpin in one stream. One unidentified species of fish was also observed in October 2003 in one of the western streams. The habitat appeared suitable for smaller species and for rearing juvenile salmonids such as brook trout (NPS, Jay Glase, Fishery Biologist, pers. comm. 2007).

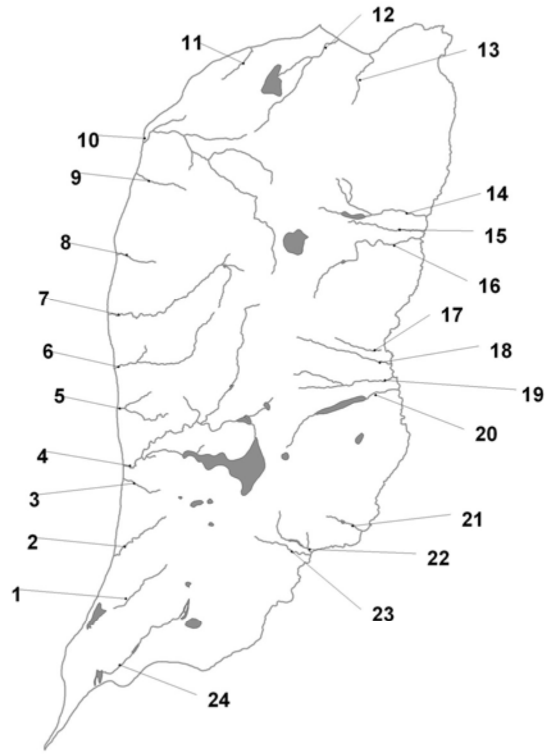
Otter Island

Otter Island has three small streams: one southwestern (0.68 km), one western (0.63 km), and one northwestern (0.35 km). Two undescribed wetlands (4.69 and 6.56 ha) occur on the island (NPS 1999c), as well as a 5 ha open shrub bog near the island summit known locally as "Blueberry Bog" (Judziewicz and Koch 1993). The bog supported scattered white pine, black spruce, and tamarack in 1993. A tiny cuspate foreland at the southeast tip of the island contains wild madder (*Galium obtusum*), honewort (*Cyptotaenia canadensis*), arrow-leaved aster (*Aster urophyllus*), pale touch-me-not (*Impatiens pallida*), and clearweed (*Pilea pumila*), which are all rarely collected in the rest of the archipelago. The rare satiny willow found in this area had been found in only one other Wisconsin site (Judziewicz and Koch 1993).

Outer Island

Outer Island's diverse water resources include 24 ephemeral streams and 24 wetlands (Figure 20, Table 16, Table 17) including one associated with the lagoon and sand spit that are part of the Apostle Islands Sandscapes State Natural Area designated by the WDNR (Epstein et al. 2002).

Outer Island Streams



Outer Island Wetlands

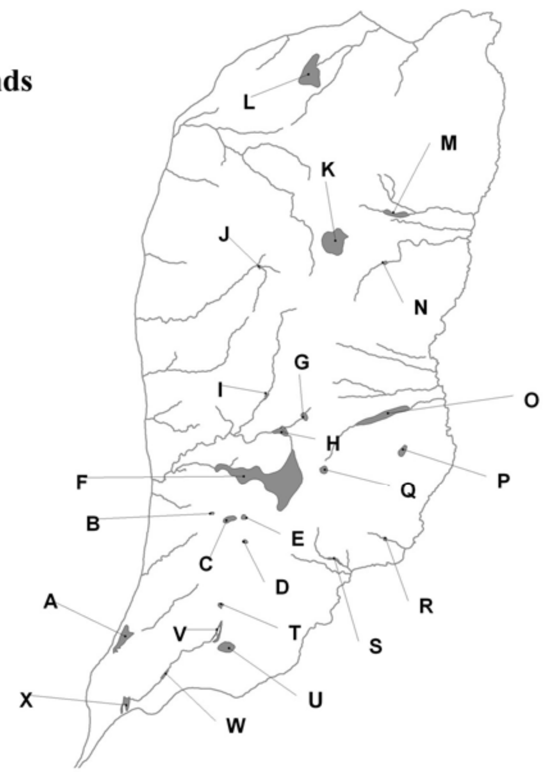


Figure 20. Streams and wetlands of Outer Island, Apostle Islands National Lakeshore.

Table 16. Streams of Outer Island, Apostle Islands National Lakeshore (NRCS 2005).

Stream	Length (km)
1	1.03
2	1.08
3	0.59
4	3.01
5	0.91
6	1.94
7	2.32
8	0.60
9	0.78
10	0.78
11	0.66
12	1.12
13	0.89
14	1.62
15	1.16
16	2.22
17	0.71
18	1.43
19	1.43
20	1.95
21	0.58
22	0.91
23	0.92
24	1.45

Table 17. Wetlands of Outer Island, Apostle Islands National Lakeshore (NPS 1999c).

Wetland	Size (ha)
A	3.07
B	0.13
C	1.05
D	0.28
E	0.38
F	28.07
G	0.62
H	1.44
I	0.24
J	0.12
K	7.90
L	7.39
M	1.79
N	0.21
O	4.99
P	1.01
Q	0.77
R	0.16
S	0.51
T	0.34
U	2.26
V	0.99
W	0.43
X	1.27

Outer Island's water resources have been through a recent period of transition related to its initial logging. The southern half was logged in the 1930s, and the northern half in the 1950s-1960s. Forest regrowth was dominated by trembling aspen, a favorite food of beavers, leading to a great increase in beaver populations and beaver flowages. During the 1970s the maturing forest was dominated by white and yellow birch, sugar maple, white cedar, and aspen. By the 1990s, aspen and beaver populations declined sharply, and only a few active lodges remained on the northern half of the island. Outer Island currently has only three active beaver colonies. Most of the old beaver flowages have shifted into wet meadow habitats; open water bodies decreased 39% on the island from 1992 to 2003 (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2007). Several of these have evolved into black ash (*Fraxinus nigra*) swamps that transition into cedar swamps and alder thickets (Judziewicz and Koch 1993).

Anderson et al. (1979) reported that in general, Outer Island surface waters were warm, acidic, low in conductivity, alkalinity, and hardness, high in chemical oxygen demand (COD), and variable in nutrients and DO. COD is generally higher on the northern half of the island, perhaps because fires have more recently destroyed organic materials in the southern half (Anderson et al. 1979), or perhaps because the northern half is generally lower-lying and more poorly drained.

Anderson et al (1979) reported finding 23 genera of plankton and nannoplankton in interior island waters, as well as 13 orders of aquatic invertebrates. Fish found included northern pike (*Esox lucius*), which were introduced, and central mudminnow (*Umbra limi*) in the lagoon, and brook stickleback in beaver flowages. Amphibians included blue-spotted salamander, American toad, spring peeper, green frog, and wood frog; reptiles included painted turtle, eastern garter snake, and red bellied snake.

Outer Island Sand Spit and Lagoon

Figure 21. Outer Island sand spit and lagoon (NPS photo).

At the island's southern tip is the Outer Island Sand Spit and Lagoon (Figure 21), part of the Apostle Islands Sandscapes State Natural Area. The sand spit includes extensive unvegetated beach, lake dunes, and a xeric pine forest. The open peatlands surrounding the lagoon are sedge-dominated to the south, including species such as woolly sedge, twig rush, beak-rushes, bogbean, and sweet gale. To the north, the mat is boggier, becoming Sphagnum dominated, with ericaceous shrubs such as leatherleaf, bog rosemary, and small cranberry, as well as few seeded sedge, pod grass, and pitcher plant. The dunes are vegetated with beach grass, beach-pea, and sand cherry (*Prunus pumila*). The second-growth, maturing xeric forest has a canopy of red pine, white pine, and white birch. Jack pine occurs in a few locations but is uncommon. Balsam fir is present in gaps and scattered throughout the forest understory (Epstein et al. 1997).

Rare species at this site include the plants swamp-pink, lenticular sedge, Robbins spikerush, brown beak-rush, and northeastern bladderwort, and the birds Swainson's thrush (*Catharus ustulatus*), merlin (*Falco columbarius*), and red-breasted merganser (*Mergus serrator*). It hosts notable concentrations of migratory birds in the fall, especially passerines and raptors. Loons, grebes, and cormorants congregate in the waters off of the spit, and southbound shorebirds are frequent visitors (Epstein et al. 1997).

The 21 ha Outer Island lagoon's maximum depth is 2.1 m, and its average depth is 0.8 m. It is separated from Lake Superior by a 1.5 m sand bar, which has had some human modification as recently as the 1940s (Rose 1988). The lagoon's water level is 1.2 – 11.6 cm (average 6 cm) above the Lake level. Lagoon inflows include precipitation, surface discharge from a bog, groundwater, and wave washover. Because the bar is higher than the bar on the Michigan Island lagoon, wave washover is less important here; precipitation and bog discharge are the two major sources of water. Outflows include evaporation, surface discharge to the same bog, and groundwater outflow (Rose 1988).

Rose (1988) and Balcer and McCauley (1989) sampled the Outer Island lagoon and described it as acidic, with low specific conductance and low concentrations of chemical constituents. Neither found much difference between the northern and southern basins. Rose (1988) reported no vertical stratification. The Lake Superior Ecosystem Research Center (1997) reported dissolved oxygen (DO) concentrations close to saturation levels and extremely low levels of dissolved nutrients. The zooplankton population consisted mainly of adult calenoid copepods (*Limnocalanus*, *Epischura*, and *Diaptomus*) and cladocerans (*Daphnia*, *Holopedium*, *Bosmina,* and *Polyphemus*), with relative population sizes varying by month in the summer. The presence of *Limnocalanus* indicates that the lagoon is periodically subject to wave washover (Lake Superior Ecosystem Research Center 1997).

Benthos in the Outer Island lagoon consisted of chironomids, oligochaetes, and snails (Balcer and McCauley 1989); the Lake Superior Ecosystem Research Center (1997) additionally found mayfly and caddisfly larvae and leeches. Reported densities ranged from 127 – 617/ m^2.

Outer Island Streams and Wetlands

Outer Island has 24 ephemeral streams varying in length from 0.58 – 3.01 km (Table 16, Figure 20). Generally, most are dewatered by mid-July. Most are located along the western and eastern shorelines, with the majority along the west. Many streams have variously shaped wetlands associated with them. Some are near headwaters or mouths; some elongate wetlands along stream reaches probably represent old beaver flowages. Island streams drain to Lake Superior with the exception of a 1.02 km stream (#1) near the southeast end of the island.

The western and northern shores of this island are steep bluffs that reach 30 m in height (Judziewicz and Koch 1993). A 3.07 ha wetland (A) is just northwest of the sand spit close to the lakeshore (Table 17, Figure 20) and is part of the previously discussed Apostle Islands Sandscapes State Natural Area. A cluster of four interior wetlands (B - D) (0.13 - 1.05 ha) is located northeast of wetland A. Eleven streams along the western shoreline (#1-10, 24) vary in length from 0.59 - 3.01 km. The largest wetland on the island (F) is 28.07 ha and is located to the northwest of wetlands B-D. It forms the headwaters of a tributary branch of stream #4. Three additional wetlands (G – I) (0.24 – 1.44 ha) are also located on other branches of this stream. A 0.12 ha wetland (J) is associated with stream #7 near the midpoint of the island along the south shore. Three streams (#11 – 13) on the northern end of the island vary in length from 0.66 - 1.39 km. A 7.39 ha wetland (L) forms the headwaters of stream #12.

The eastern shoreline is mostly rocky and transitions into sandstone ledges toward the north end of the island (Judziewicz and Koch 1993). The northeast end above the sand spit area is devoid of streams. Ten streams (#14 – 23) along the eastern shoreline vary in length from 0.58 - 2.22 km. An elongate 1.79 ha wetland (M) is located along stream #14, and a 7.90 ha round interior wetland (K) is positioned ca. 0.64 km to the southwest of wetland M. Near the midpoint of the island along the east shore, a 4.99 ha elongate wetland (O) is associated with stream #20, and a round 0.77 ha wetland (Q) is located near its headwaters. A round 1.01 ha wetland (P) is located nearer the eastern shoreline. Elongate 0.21 ha and 0.51 ha wetlands (R, S) are located on streams #21 and #22 respectively near the bottom 1/3 of the island. Also in the southern 1/3 of the island above the sand spit, three wetlands are associated with the main southern stream (#24); an elongate 0.99 ha wetland (V) that forms its headwaters, a 0.43 ha elongate wetland (W) mid-length, and a broader 1.27 ha wetland (X) near its mouth. Two round 0.34 and 2.26 ha wetlands (T, U) are located nearby.

Raspberry Island

Raspberry Island has no streams, but there are two round wetlands located at the southwest (0.51 ha) and northwest (0.64 ha) ends of the island, and one triangular shaped wetland (0.54 ha) is located near the sand spit at the southeast tip of the island.

Middleton (1983) reported a small 1-2 ha cuspate foreland and enclosed bog at the southeast tip of the island. The bog in back of the foreland is small (0.54 ha) but supports a high diversity of bog plants, including Sphagnum and sedges. A small open pond supports duckweed (*Lemna minor*), narrow-leaved bur-reed (*Sparganium chlorocarpum*), and intermediate bladderwort (Judziewicz and Koch 1993). Part of Raspberry Island is in the Apostle Islands Sandscapes State Natural Area (WDNR 2006f).

Rocky Island

Rocky Island has two eastern streams (the northern is 0.22 km and the more southern is 0.37 km) and two southern streams (the western is 0.36 km and the eastern stream is 0.36 with a 1.27 ha wetland at its mouth). Two other wetlands, a 2.44 ha wetland near the extreme southeastern tip and a 2.43 ha wetland south of the narrowed northern peninsula, appear in the NPS (1999c) hydrography coverage. Part of Rocky Island is in the Apostle Islands Sandscapes State Natural Area (WDNR 2006f).

Sand Island

Sand Island is generally low and swampy. The coastline is one of the more diverse of the islands, with five narrow beaches: two larger ones at East Bay and Lighthouse Bay, and smaller ones at West Bay, Justice Bay, and the northwest bay. The shoreline has rocky cliffs and ledges at Swallow Point, from Lighthouse Point to Justice Bay, and from the west end of Lighthouse Bay to the northwest bay, with the remainder generally low clay banks. A basic ecological and recreational resources inventory of the island was done by Anderson et al. (1982).

Sand Island has three wetlands and three streams on the NPS (1999c) and the NRCS (2005) hydrography coverages. The largest wetland (44.35 ha) is located between East Bay and Lighthouse Bay, approximately 1 km southwest of East Bay Dock. It extends nearly from the eastern to the western shoreline near the narrow part of the northeast peninsula, approximately 1.34 km. The island's northernmost eastern stream, 0.73 km, originates only 0.21 km from this wetland. The second large wetland (21.89 ha) is located near the southern 1/3 of the island approximately 0.74 km from the eastern shoreline. A 2.59 km western stream, the island's longest, connects the wetland to a 9.73 ha wetland approximately 0.54 km to the northwest. This stream has one 0.47 km tributary. Another eastern stream (0.48 km) originates near the southeast end of the island. A tiny, seeping sedge marsh is found a few meters southwest of East Dock (Judziewicz and Koch 1993). The island also has two large boggy, sphagnous conifer swamps, dominated by black spruce with some tamarack and white birch, which are partially open (Judziewicz and Koch 1993).

South Twin Island

No streams or wetlands appear on the NPS (1999c) or the NRCS (2005) hydrography coverages for South Twin Island. Except for a prominent cuspate foreland on the western end of the island, most of the island is lined by clay bluffs that are relatively low except at the southern tip and east bay. A low sandstone outcrop occurs at the northern end. The central and northern ends of the island are poorly drained, and puddles supporting calla-lily and three-fruited sedge are common. A sandscape on the western end of the island has been modified by human activity and supports a number of exotic plants. The abandoned air strip on the western end has many associated sandy ditches that support many common bog species (Judziewicz and Koch 1993).

Stockton Island

At 3,971 ha, Stockton Island is the largest of the islands included in APIS, larger even than the mainland unit itself. It was the first to be developed by the NPS for recreation (Stadnyk et al. 1974), the most extensively developed, and the one that is most used for camping (NPS 2005a). Significant water-related features of the island include three bays (Presque Isle, Quarry, and Julian), a large wetland and lagoon between two sand spits on the Stockton Island tombolo, and numerous small streams that drain the island's interior (Epstein et al. 1997).

Presque Isle Bay

Presque Isle Bay is the most heavily used of Stockton Island's bays. It has been developed with two concrete docks. The western dock is 123 m long and the eastern one is 85 m (Dahl 2001). The bay also has a visitor center, 19 individual campsites, a well, and vault toilets (NPS n.d.a).

Bottom samples taken by Rose (1988) show that the bay is up to 24 m deep in at least one location. A thermocline was found at 8-10 m in July 1996, but was not present in June or August (Lake Superior Ecosystem Research Center 1997). Complex patterns of water movement are found in the shallow waters; the current velocity is relatively low, but the frequent occurrence of longshore drift may result in the deposition of silt and sand along the docks (Balcer and McCauley 1989).

Water quality studies for Presque Isle Bay have focused on adverse impacts of visitor use. Rose (1988) reported that "no adverse impacts from visitor use were detected" after examining water quality samples for fecal coliform bacteria, total phosphorus, total organic carbon, and mercury. Balcer and McCauley (1989) reported elevated fecal coliform and fecal streptococcus counts in the summers of 1986 and 1987, but suggested they were caused by animals and were carried to the bay in rainwater runoff. They reported the chemical composition of the water to be similar to that reported by Anderson et al. (1980) and Rose (1988); circumneutral in pH, and moderate in alkalinity, conductivity, and total organic carbon, comparable to levels observed in the open lake (Balcer and McCauley 1989).

Of three sites sampled for net phytoplankton in July 1986 (Little Sand Bay, South Twin Island, and Presque Isle Bay), the bay had the lowest density (165/L) but the highest diversity index (0.739). Species found included the diatoms *Asterionella* sp. (40%), *Fragilaria* sp. (17%), and *Tabellaria* sp. (15%), and the chrysophyte *Dinobryon* sp. (15%) (Balcer and McCauley 1989). In 1996, zooplankton densities increased from June to July and dropped in August. Copepodite forms of cyclopoid and calanoid copepods (*Diaptomus* sp. and *Cyclops* sp.) dominated in June and July, but cladocerans increased to 32% of the total zooplankton population by August (mostly *Holopedium* sp. with some *Daphnia* sp.). One native giant waterflea (*Leptodora* sp.) and very low numbers of the invasive spiny waterflea (*Bythotrephes longimanus*) were also found (Lake Superior Ecosystem Research Center 1997).

Bottom sediment samples from Presque Isle Bay were coarser, and contained less organic carbon and nutrients, than those at a site between Rocky and South Twin Islands (Rose 1988) but were finer, and higher in organic carbon and phosphorus, than those taken on the northwest side of Oak Island (Balcer and McCauley 1989). Presque Isle samples were similar in physical characteristics to sediments from nondepositional zones of Lake Superior. Sediments within the harbor were coarser than those at the other locations within the bay (Balcer and McCauley 1989). Organic carbon and total phosphorus levels were within the range reported for other sites within APIS and well below the lakewide averages (Balcer and McCauley 1989).

In July 1982, Rose (1988) sampled nine sites in Presque Isle Bay and found a benthic macroinvertebrate fauna dominated by the amphipod *Diporeia*, chironomids, clams, snails, and Ceratopogonidae (no-see-um fly larvae). Balcer and McCauley (1989) found the highest number of oligochaetes, followed by *Diporeia* and chironomids, at two sites in August 1986 and 1987. In

1996, the Lake Superior Ecosystem Research Center (1997) observed snails, clams, oligochaete worms, *Diporeia*, caddisfly larvae, and chironomids, but did not indicate their relative abundance. Doolittle (1991) reported finding no unionid taxa in Presque Isle Bay.

Julian Bay

A USGS topographic map (Stockton Island quadrangle) shows water depth in Julian Bay to be at least 11 m deep. Water quality data for Julian Bay, on the east side of the Stockton Island tombolo, is limited to two sets of samples collected in 1979 by Anderson et al. (1980), and a set collected by the NPS in 1981 (NPS 1999a). The 1979 results were nearly identical to those for Presque Isle Bay, described above, except that total phosphorus levels were slightly higher. In 1981, a slightly lower pH and total phosphorus concentration were found, and a low level of fecal coliform bacteria was also present. Doolittle (1991) sampled for unionid taxa in Julian Bay and reported that the Gaspe floater (*Anodonta cataracta marginata*) was the only species found in 2.3 hours of effort.

The diversity of the bog flora of the Julian Bay Lagoon is the greatest in the Apostle Islands, and only the Big Bay complex on Madeline Island has similar diversity. Coast sedge (*Carex exilis*) and Michaux's sedge (*Carex michauxiana*), listed by the WDNR as threatened plants, are common, and the rare species sooty beak-rush, swamp-pink, and yellow-eyed grass (*Xyris montana*) also occur there. Unconfirmed sightings of the rare English sundew (*Drosera anglica*) and/or the linear leaved sundew (*Drosera linearis)*, listed as threatened by the WDNR, have been reported. Interdunal wetlands (pools) exist between the lagoon and the lakeshore, and twig rush, rushes, lenticular sedge, and beaked and purple bladderworts occur along the margins (Judziewicz and Koch 1993).

Quarry Bay

A USGS topographic map (Stockton Island quadrangle) shows water depth in Quarry Bay to be at least 26 m deep. Stadnyk et al. (1974) collected a single water chemistry sample from the dock at Quarry Bay in 1973. Anderson et al. (1979) also collected two sets of samples for basic water chemistry, fecal coliform, and nutrients on Quarry Bay in 1979. Results were similar to each other and again were very similar to those for Presque Isle Bay.

Stadnyk et al. (1974) sampled zooplankton in the Quarry Bay marsh and identified five species of copepods (*Diaptomus sicilis, D. oregonensis, Cyclops varicans rubellus, Eucyclops agilis, Mesocyclops edax*), six to eight species of cladocerans [*Chydorus gibbus, C. sphaericus, Acroperus harpae, Pleuroxus denticulatus, Alona affinis*(?), *Simocephalus vetulus, Diaphanosoma brachyurum*(?), *Bosmina longirostris* (question marks in original text)], and three genera of rotifers (*Asplanchna* spp, *Keratella* spp, *Brachionus* spp). They indicated that the species composition was that of littoral habitats and differed greatly from open Lake Superior samples, with the exception of the diaptomids. Immature copepods and rotifers dominated the samples, while cladocerans were relatively scarce. Doolittle (1991) reported finding no unionid taxa in Quarry Bay. A small bog mat just inside the beach at Quarry Bay transitions into a large alder thicket and blue-joint meadow that supports many species of wetland plants (Judziewicz and Koch 1993).

Stockton Island Streams and Wetlands

Stockton Island has some of the most numerous and diverse surface waters of the Apostle Islands, including 49 streams and 27 wetlands (Figure 22, Table 18, Table 19). Rose (1988) identified nine watersheds on the island, with four major drainages. The largest drainage is composed of five major tributary streams and drains through the large wetland complex east into Julian Bay. There is a smaller watershed that drains to the north-northwest near Trout Point, one smaller watershed that drains to the northwest nearly at the midpoint along the west shore, another larger one south of the previous that also drains to the northwest, and a narrow elongate watershed that drains into Quarry Bay. Improved hydrologic map coverages (NPS 1999c; NRCS 2005) have allowed us to measure and describe these watersheds, and others, in greater detail below.

A large watershed with three main northern and western tributaries (#1, 2, 3) and an isolated small stream (#49) drains into Quarry Bay near the southwest end of the island. Five wetlands are located in this watershed. A 0.19 ha wetland (F) is found along tributary 2, a larger (4.63 ha) bifurcated wetland (G) is ca. 2/3 up the length of tributary 3, and two separated wetlands, 0.53 and 2.59 ha (H, I) are located 0.35 - 0.64 km west of the headwaters of tributary 3. The three main tributaries join in a broad 2.73 ha wetland (E), 0.1 km from the shoreline of Quarry Bay.

A 0.33 km stream (#4) is found along the south shoreline just west of Presque Isle Bay. Two streams (#5, 6) drain into Presque Isle Bay. The westernmost (#5) is 2.02 km, with a 15.24 ha elongate wetland (X) and two short western tributaries. Four other separated wetlands (V, Y, Z, AA) varying in size from 0.36 - 3.89 ha, are associated with this stream. The 0.75 km eastern stream (#6) has no tributaries. A disconnected 3.07 ha elongate wetland (W), ca. 0.81 km long, occurs along the northwest end of Presque Isle Bay very near the shoreline.

The wetland network that feeds the 1.93 km elongate tombolo along the southeastern end of the island near Julian Bay is complex and the largest within APIS. It has seven distinct wetlands (L, P, Q, R, S, T, U) and eight main streams (#7-14), varying in length from 0.71 – 2.76 km, associated with it. The largest wetland (R), 97.93 ha, is associated with the Stockton Island lagoon, and is discussed in more detail below. It is close to the Lake Superior shoreline along the sand dune area. It is split and connected by a small neck through the main unnamed tributary stream that drains into Julian Bay. Four of the streams (#11-14) have additional wetlands in their upper reaches. Wetland S, 7.44 ha, is located along 1.49 km tributary #14. The northeast wetland (P), also known locally as Brander Bog, is 38.85 ha, and the small wetland (Q) just south of this bog is 0.61 ha. These wetlands are located on 2.31 km stream #13. The two interior wetlands (T, U) that feed this system are located near the headwaters of streams and are 0.31 and 8.05 ha. Wetland L, also associated with a northwest drainage, feeds this system as well.

The southeastern and eastern shoreline of the island includes five short streams (#15 – 19) varying in length from 0.37 – 0. 67 km. An elongate 16.06 ha wetland (O) is oriented in a north-south direction near the northeastern end of the island.

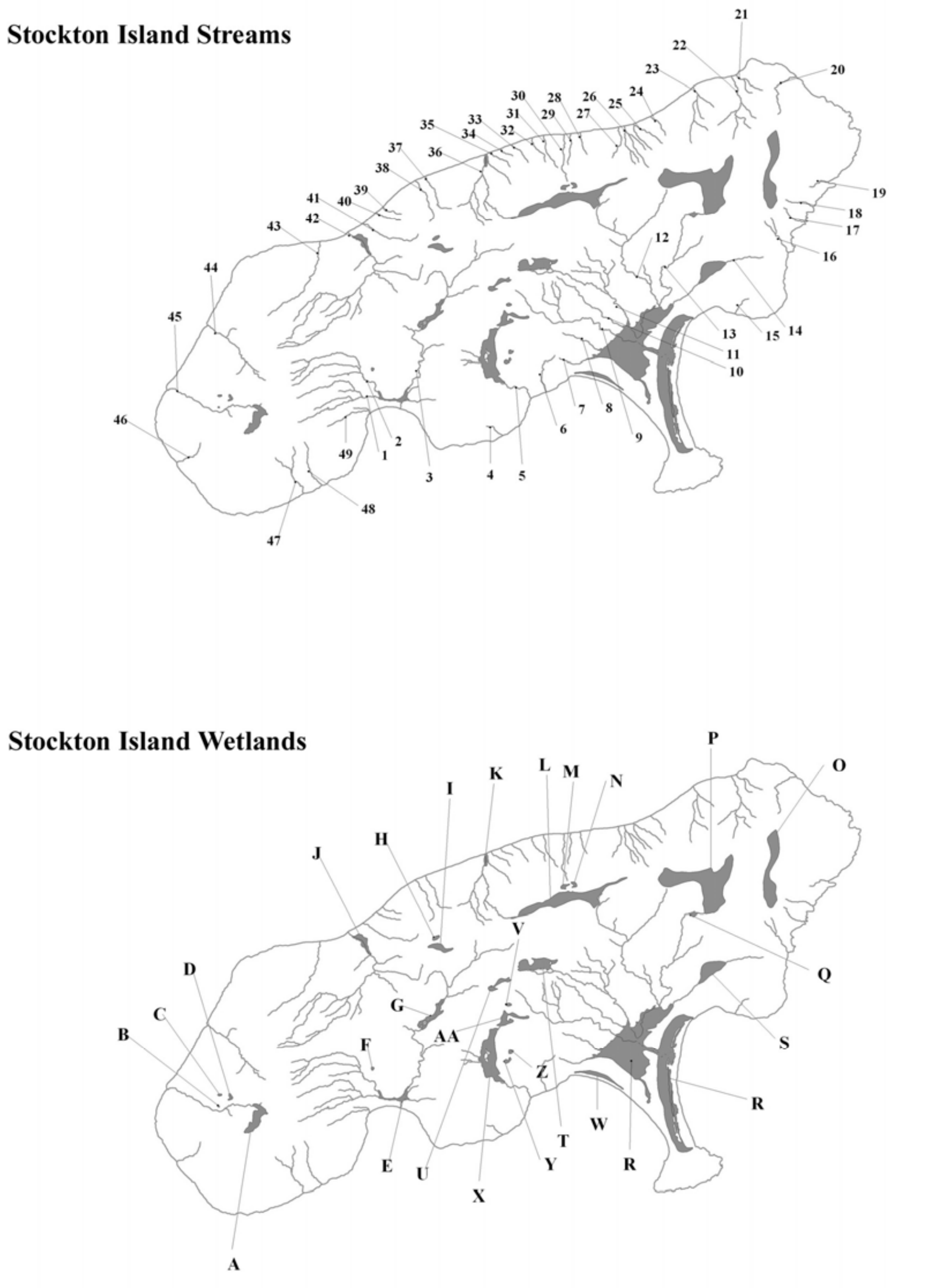


Figure 22. Streams and wetlands of Stockton Island, Apostle Islands National Lakeshore (NPS 1999c; NRCS 2005).

Table 18. Streams of Stockton Island, Apostle Islands National Lakeshore (NRCS 2005).

Stream Number	Length (km)	Number of tributaries and lengths (km)
1	1.93	2 northwestern (0.70 and 1.34)
2	2.14	2 western (0.56 and 1.27)
3	4.06	5 eastern (0.23 – 0.57), 3 northeastern (0.22-0.64)
4	0.33	
5	2.02	2 western (0.38 and 0.41)
6	0.75	
7	0.71	
8	0.74	
9	2.16	1 northern (0.76)
10	1.52	
11	2.51	1 northern (0.68)
12	2.67	1 northern (0.39), 2 northwestern (0.24 and 1.08)
13	2.31	1 northeastern (0.66)
14	1.49	
15	0.36	
16	0.67	1 northeastern (0.28)
17	0.47	
18	0.47	
19	0.37	
20	0.94	
21	0.53	1 eastern (0.30)
22	1.16	3 eastern (0.36 – 0.36), 1 southwestern (0.40)
23	0.48	1 southern (0.74)
24	0.41	
25	0.56	1 southeastern (0.52)
26	0.79	2 southeastern (0.38 and 0.61)
27	0.58	
28	0.38	
29	0.53	
30	0.83	
31	0.60	
32	0.49	
33	0.41	
34	0.24	
35	0.42	
36	1.83	1 southeastern (0.51), 2 southwestern (0.18 and 1.06)
37	0.80	
38	0.82	
39	0.34	
40	0.42	
41	1.04	
42	2.07	3 eastern (0.48, 0.56, 1.00), 4 southwestern (0.37, 0.57, 1.60, 1.36)
43	1.68	
44	1.14	1 northern (0.25), 1 southeastern (0.30), 1 southwestern (0.25)
45	1.82	1 southeastern (0.19)
46	0.58	
47	0.89	1 northwestern (0.40)
48	0.82	
49	0.31	1 western (0.74)

Table 19. Wetlands of Stockton Island, Apostle Islands National Lakeshore (NPS 1999c).

Wetland	Size (ha)	Wetland	Size (ha)
A	6.45	O	16.06
B	0.06	P (Brander Bog)	38.85
C	0.19	Q	0.61
D	0.46	R	97.93
E	2.73	S	7.44
F	0.19	T	8.05
G	4.63	U	2.10
H	0.35	V	0.31
I	0.64	W	3.07
J	3.10	X	15.24
K	0.95	Y	0.53
L	20.5	Z	0.36
M	0.64	AA	3.89
N	0.52		

Three streams (#20 – 22) near Trout Point on the northern tip of the island vary in length from 0.48 – 1.16 km. On the northwestern shoreline, 21 streams (#23 – 43) vary in length from 0.24 – 1.83 km. Five wetlands are associated with them. Stream #36 has a 20.5 ha elongate wetland (L) located at its headwaters as well as a 0.95 ha wetland (K) positioned near its mouth. Wetland L is unusual because it serves as the headwaters for both a northwestern and a southeastern stream. A pair (M, N) of detached wetlands, 0.52 and 0.64 ha, are located just north of wetland L. Wetland J (3.10 ha) is located on stream #42 ca. 0.1 km from the Lake Superior shoreline.

Salzer (1979) reported an archeological site of a pre-historic Amerindian hunting camp containing numerous moose bones along the coast near one of the northwestern streams. Judziewicz and Koch (1993) noted this as being of historical zoogeographic interest, since there were no other records of moose being found within the Apostle Islands. However, moose remains were found in APIS in 1995, and a moose was observed on Long Island in 2002 (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2007).

Three streams (# 44 – 46) near the southwestern tip of the island vary in length from 0.58 – 1.82 km and drain to the northwest and west. The longest (#45) has a 6.45 ha wetland (A) associated with it. Three additional wetlands (B, C, D) near stream #45 and north and west of wetland A vary in size from 0.06 – 0.46 ha. Two streams (# 47, 48) drain to the south near the island's southwestern end and are 0.82 and 0.89 km.

Of nine stream sites investigated by Rose in July and August of 1980, four had no flow, four had measurable flow, and one had flow too slow to measure. The average channel slope is 1.7%, and the average basin storage is 7% (Rose 1988). Stadnyk et al. (1974) noted the "bog-like nature" of these waters, with low pH and DO at critically low levels. Anderson et al. (1979) noted that the streams were generally "mildly acidic, low in alkalinity and available nitrogen, and high in chemical oxygen demand." Both Anderson and Rose (1988) noted that most of the stream flow originates in wetlands and beaver ponds, and little of it appears to have had long-term contact with the subsurface.

The interior of the northeastern end of Stockton Island has a number of perched bogs that support the common bog ericads and insectivores along with the few-flowered bog sedge. On the northwest coast, a cuspate foreland supports many dune species. Historic beaver flowages support many wetland plant species including blue-joint, Torrey's manna-grass and true manna-grasses (*Glyceria* spp.), boneset (*Eupatorium perfoliatum*), field-mint (*Mentha arvensis*), water-parsnip, water-hemlocks (*Cicuta* spp.), and rough hedge-nettle (*Stachys tenuifolia*) (Judziewicz and Koch 1993). However, beaver activity has been greatly reduced by predation by black bears; there have been no active beaver lodges on Stockton Island since 1996 (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2007). Anderson et al. (1980) provided data on soil types and some vegetation analysis associated with wetlands on Stockton Island.

Stockton Island Lagoon

The lagoon (associated with wetland R in Figure 22) is found on the southeast end of the island, where it is enclosed between the two sand spits that connect Presque Isle Point to the main body of the island. Lagoon water quality was monitored on four dates (June 30 and September 1, 1986 and June 24 and October 8, 1987) by Balcer and McCauley (1989). They noted surface DO levels of 8.3-12.8 mg/L, pH values of 6.0 to 7.1, and alkalinity values of 11.0 to 16.5 mg/L as $CaCO_3$, and attributed the "fairly neutral" pH to surface runoff from the lagoon's large drainage basin. They also reported a low diversity of benthic invertebrates (12 - 151/ m^2), with 46% oligochaetes and 39% chironomids.

A more detailed investigation by the Lake Superior Ecosystem Research Center (1997) indicated that the lagoon was a large, sand-bottomed open hole, only 2 m in depth, in a large, shallow wetland, which occasionally opened out onto Lake Superior. The water was dark-red and had a high light extinction coefficient. A well-defined thermocline developed at 1 m. The water column became anoxic at and below the 1 m depth by August. The pH ranged from 5.9 - 6.4 in June and August, and dropped to 4.8-5.7 in July. Silica and nitrate/nitrite nitrogen concentrations were very low, orthophosphate levels varied, and ammonia was detected at 0.17 mg/L NH_3 in August. Overall zooplankton densities were low, and the community in June was dominated by early instar copepodites, cyclopoid copepods, the rotifer *Asplanchna* sp., and the cladoceran *Bosmina* sp.. In July, cladocerans dominated (mostly *Bosmina* sp. and *Holopedium* sp., with a small population of *Ceriodaphnia* sp.). By August, 75% of the population consisted of adult *Cyclops* sp. and calanoid and cyclopoid copepodites. The benthic substrate was a mixture of "fine sand and sulfurous-smelling mud" which supported a dense growth of macrophytes, dominated by *Chara* sp.. Benthic organism density was extremely low; benthos was dominated by oligochaete worms in June and caddisfly larvae in August; clams were also present, and chironomids were present only in June.

Data collected by Axler et al. (2006) in 2004 again showed higher pH values (7.18-7.73). Reasons for the variability in pH might include fluctuations in water levels, precipitation, or primary productivity, but the exact reason is not known at this time.

Stockton Island Tombolo

Figure 23. Interdunal pool, Stockton Island Tombolo (Photo by E. Judziewicz).

The lagoon is part of the Stockton Island Tombolo portion of the Apostle Islands Sandscapes State Natural Area (WDNR 2005h). This portion includes a total of 275 ha, of which 117 ha is wetland (Epstein et al. 2002). A variety of wetland types are found in the swales between parallel sand ridges, including submergent aquatic, emergent aquatic, coastal fen, coastal bog, alder thicket, and tamarack swamp communities. Communities associated with the sand spits surrounding the lagoon and wetlands include Great Lakes beach, Great Lakes dune, Great Lakes barrens, boreal forest, northern dry-mesic forest, and interdunal wetlands and pools (Figure 23) (Epstein et al. 2002). Three state-threatened plant species are found there: Michaux's sedge, lenticular sedge, and narrow false oats (*Trisetum spicatum*) (WDNR 2004e, 2005h). Other rare species found there include the plants swamp-pink, coast sedge, tufted hairgrass, crinkled hairgrass, Robbins spike-rush, large roundleaf orchid, bird's eye primrose (*Primula mistassinica*), brown beak-rush, and purple bladderwort; the four-toed salamander; and the birds common goldeneye (*Bucephala clangula*), Swainson's thrush, northern harrier (*Circus cyaneus*), Blackburnian warbler (*Dendroica fusca*), merlin, red-breasted merganser, and common merganser (*Mergus merganser*) (Epstein et al. 1997).

Stockton Island Biota

Fish noted by Stadnyk et al. (1974) in the interior bogs, marshes and streams included northern redbelly dace (*Chrosomus eos*), golden shiner (*Notemigonus crysoleucas*), brook stickleback, central mudminnow, and black bullhead [*Ictaluris melas* (now *Ameiurus melas*)].

Stadnyk et al. (1974) observed the following amphibians on the island: American toad, eastern wood frog (*Rana sylvatica cantobrigensis*), spring peeper (*Hyla crucifer*), mink frog, northern cricket frog (*Acrisgryllus crepitans*), and red-backed salamander. Anderson et al. (1980) observed all these except the northern cricket frog, and also observed the green frog, blue-spotted salamander, and four-toed salamander. Stadnyk et al. (1974) also observed the following reptiles:

common garter snake, red-bellied snake, and unspecified turtles. Anderson et al. (1980) also observed these two snakes and the painted turtle.

York Island

No streams appear on the NPS (1999c) hydrography coverage for York Island, but one 1.66 ha wetland, a shrubby willow-alder-sedge marsh, occurs along the beach area in the narrow constriction between the northwestern and southeastern ends of the island (NRCS 2005). A very small eroding sand spit occurs on the southeastern end of the island (Judziewicz and Koch 1993).

Assessment of Park Water Resources

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 on the critical pollutants list in the U.S. (aldrin/dieldrin, chlordane, DDT/DDE, and toxaphene) (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 - 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, pesticides currently in use, 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 composed 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 northern Wisconsin, but nitrate and ammonia emissions, 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). The average pH of rain at the National Atmospheric Deposition Program (NADP) monitoring station at Trout Lake, 105 km southeast, has shown a generally increasing trend from 4.6 in 1980 to 5.1 in 2005, while the NADP site at Wolf Lake, 56 km northwest, has shown a fairly flat trend at 4.9 from 1997 - 2004 (NADP 2006).

Local Air Emissions: Three facilities in Ashland are listed on the USEPA's Toxic Release Inventory (Table 20, Figure 24) (USEPA 2005a). Of these, only Northern States Power releases substances from the critical pollutants list. In 2003, the last year for which reports are available, it released 6.8 kg of mercury and 2.64 grams (g) of dioxins in its air stack emissions. Other toxic releases to the air in the Ashland area included hydrochloric acid, metals (barium, lead, manganese, and zinc), polycyclic aromatic hydrocarbons (PAHs) (including benzo(ghi)perylene), and volatile organic compounds (methyl isobutyl ketone, xylene isomers, and toluene) (USEPA 2005a).

Air pollutants from industrial areas in Duluth and Superior, about 113 km west of Sand Island, may reach the Lakeshore during certain wind conditions (NPS 2005a). Toxic air releases in the Duluth-Superior area include mercury, hydrogen fluoride, metals, PAHs, and various other organic compounds (Table 21) (USEPA 2005a). However, in Ashland County, nonroad mobile sources (which include 2 or 4 stroke and diesel engines, nonroad vehicles, aircraft, commercial marine vehicles, recreational boats, and locomotives) contributed 79% of the hazardous air pollutants, or 848,700 kg in 1999. Major point sources contributed 2%, area sources (such as dry cleaners and gasoline stations) contributed 7%, and onroad vehicles contributed 12% (USEPA 2006c).

Table 20. Facilities on the USEPA Toxic Release Inventory in the vicinity of Apostle Islands National Lakeshore with releases in 2000 or later (USEPA 2005a).

Facility and City	SIC Code and Industry Type	Most recent reporting date	Substance	Air stack emissions/ year (kg)	Air fugitive emissions/ year (kg)
Northern States Power, Ashland	4931 Electric and Other Services Combined	2003	barium compounds	531	-
			benzo(ghi)perylene	0.1	-
			dioxin and dioxin-like compounds	0.00264	-
			hydrochloric acid	4,277	-
			lead compounds	99	-
			manganese compounds	90	18
			mercury compounds	6.8	-
			polycyclic aromatic compounds	3.32	-
			zinc compounds	113	-
Larson Juhl US LLC, Ashland	2499 Wood Products, not elsewhere classified	2003	methyl isobutyl ketone	3,517	-
			toluene	6,723	-
			xylene (mixed isomers)	4,340	-
Larson Juhl Inc, Ashland	2499 Wood Products, not elsewhere classified	2000	methyl isobutyl ketone	1,122	2,084
			toluene	2,829	5,253

SIC = Standard Industrial Classification.
Air fugitive emissions = those emissions which could not reasonably pass through a stack, chimney, vent, or other functionally-equivalent opening.

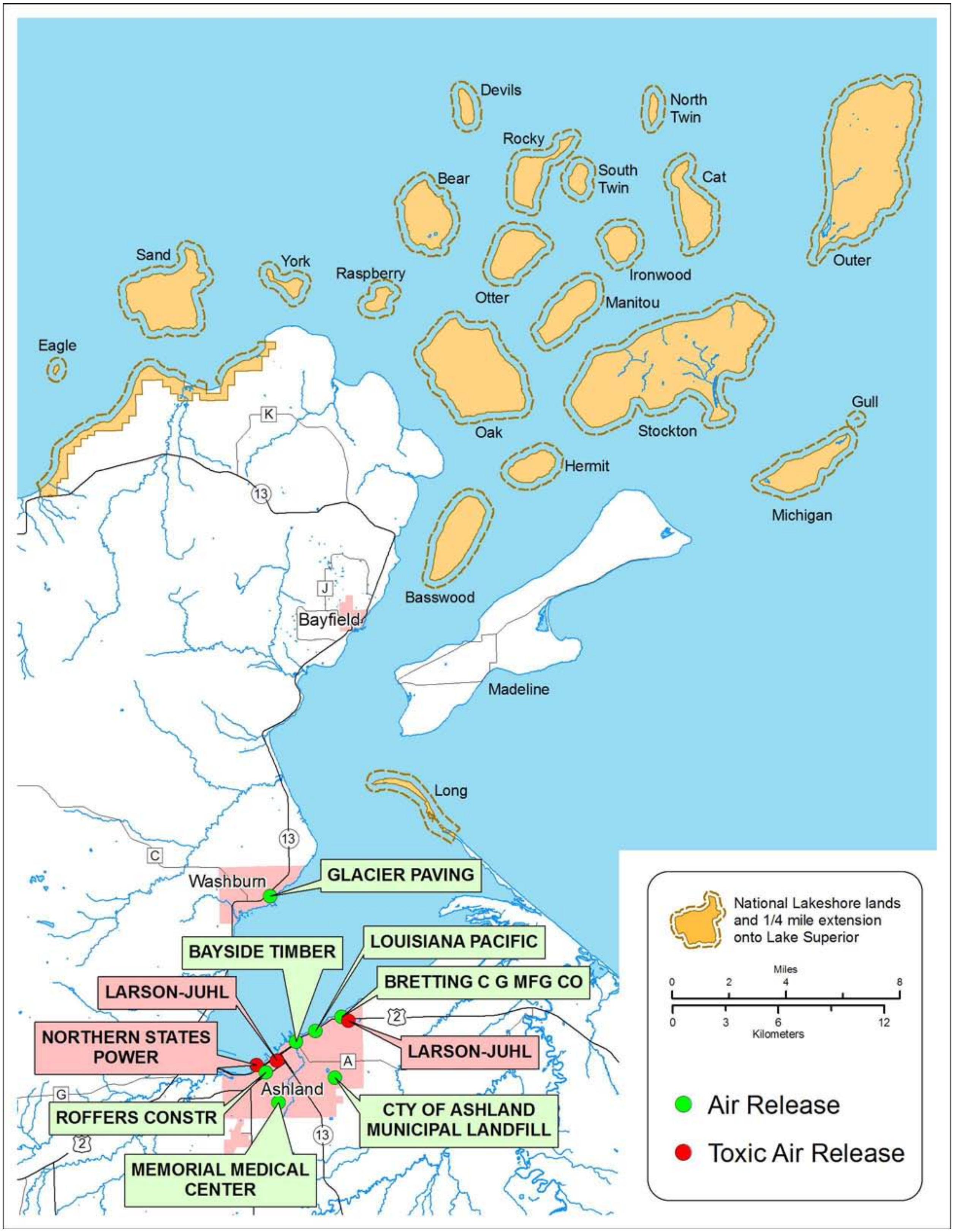


Figure 24. Toxic air releases and other air pollutant releases in the vicinity of Apostle Islands National Lakeshore (USEPA 2005a).

Table 21. Facilities on the USEPA Toxic Release Inventory with releases in 2000 or later, Duluth, MN and Superior, WI, approximately 113 km from Apostle Islands National Lakeshore (USEPA 2005a).

Facility	**SIC Code and Industry Type**	**Most recent reporting date**	**Substance**	**Air stack emissions/year in kg**	**Air fugitive emissions/year in kg**
ABC-NACO	3743 Railroad equipment	2000	manganese	113	113
CLM Corp.	3274 Lime	2003	barium compounds	8.4	2
			lead compounds	0.6	0.1
Genesis Attachments LLC	3511 Steam, gas, and hydraulic turbines, and turbine generator set units	2003	manganese	--	5
Georgia Pacific Corp.	2493 Reconstituted wood products	2001	ethylbenzene	11,958	--
			methanol	28,336	--
			xylene (mixed isomers)	51,887	--
Koppers Inc.	2491 Wood preserving	2003	creosote	340	771
			polycyclic aromatic hydrocarbons	0.2	0.5
Murphy Oil USA Inc.	2911 Petroleum refining	2003	1,2,4-trimethylbenzene	19.6	490.1
			benzene	262.7	353
			cyclohexane	231.2	354.8
			diethanolamine	--	34.5
			ethylbenzene	24.6	193.6
			ethylene	--	77.9
			hydrogen fluoride	--	3.7
			lead	2.5	--
			mercury	0.1	--
			n-hexane	831.2	1,150.9
			propylene	333.9	3,148.8
			toluene	295.5	729.6
			xylene (mixed isomers)	69.9	827.3
AE Staley Manufacturing Co.	2869 Industrial organic chemicals, not elsewhere classified	2003	maleic anhydride	23.4	6.0
Georgia-Pacific Corp.	2493 Reconstituted wood products	2003	benzo(g,h,i)perylene	0.01	--
			lead	21.80	0.005
			methanol	49,954	194.5
			polycyclic aromatic hydrocarbons	1.73	--

Table 21. Facilities on the USEPA Toxic Release Inventory with releases in 2000 or later, Duluth, MN and Superior, WI, approximately 113 km from Apostle Islands National Lakeshore (USEPA 2005a) (continued).

Facility	SIC Code and Industry Type	Most recent reporting date	Substance	Air stack emissions/year in kg	Air fugitive emissions/year in kg
M E International	3325 Steel foundries, not elsewhere classified	2003	barium compounds	2	2
			chromium compounds	2	2
			lead compounds	0.05	0.05
			manganese compounds	27	14
			molybdenum trioxide	2	2
			nickel compounds	5	2
Stora Enso North America Duluth Paper Mill	2621 Paper mills	2003	methanol	30,390	317
			ethylene glycol	--	5
U.S. Air Force	9711 National security	2003	napthalene	56	3,503

SIC = Standard Industrial Classification.
Air fugitive emissions = those emissions which could not reasonably pass through a stack, chimney, vent, or other functionally-equivalent opening.

Other air pollutants that are not classified as toxic, but are regulated under the Clean Air Act (CAA), are listed in the USEPA's Aerometric Information Retrieval System (AIRS) and the AIRS Facility Subsystem (AFS). Eleven such facilities are located near APIS, most in and around the city of Ashland. They include asphalt paving facilities, sawmills and planing mills, a landfill, and a hospital (Table 22, Figure 24) (USEPA 2005a).

APIS is a Class II air quality area. Under the CAA, Class I areas, which receive the highest degree of protection, are those national parks over 2,400 ha and national wilderness areas over 2,000 ha that were in existence on August 7, 1977 (NPS 2006c). Tribes, including the Red Cliff and Bad River Bands of Lake Superior Chippewas, also have the authority under section 164 of the CAA to request designation as Class I areas with stricter air quality standards. In 2005, the Bad River Band obtained Treatment as a State (TAS) Designation, allowing the Tribe to comment on air pollution permits issued within 80 km of the Reservation (LSBP 2006). The Bad River Band is also seeking Class I status from the USEPA (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2007).

Air monitoring stations in the vicinity of APIS include four wet deposition monitoring sites operated by the NADP National Trends Network: MN99 at Wolf Ridge ELC, 56 km northwest; MN05 at the Fond du Lac Reservation, 121 km southwest; WI36 at Trout Lake, 105 km southeast; and MI199 at Chassell, 97 km northeast. Two dry deposition sites operated by the Clean Air Status and Trends Network (CASTNet) are located at Perkinstown, 177 km south (PRK134) and at Voyageurs National Park, 210 km northwest (VOY413). Two particulate matter monitoring sites in the Interagency Monitoring of Protected Visual Environments (IMPROVE) network are located at Boundary Waters Canoe Area, 121 km northwest (BOWA1) and at Isle Royale National Park, 113 km northeast (ISLE1). Two ozone monitoring stations are located at Boulder Junction, 113 km southeast (55-125-0001) and in Carlton County, 130 km southwest (27-017-7416) (Maniero and Pohlman 2003).

Table 22. Facilities on the USEPA Air Releases (AIRS/AFS) Inventory in the vicinity of Apostle Islands National Lakeshore (USEPA 2005a).

Facility	County	SIC Code and Industry Type
Glacier Paving Inc.	Bayfield	2951 Asphalt Paving Mixtures and Blocks
City of Ashland Municipal Landfill	Ashland	9999 Nonclassifiable Establishments
Bayside Timber Corp.	Ashland	2421 Sawmills and Planing Mills, General
Bretting C G Manufacturing Co.	Ashland	3554 Paper Industries Machinery
Larson Juhl Inc. (2 locations)	Ashland	2499 Wood Products Not Elsewhere Classified
Louisiana Pacific Corp.	Ashland	2421 Sawmills and Planing Mills, General
Memorial Medical Center	Ashland	8062 General Medical and Surgical Hospitals
Northern States Power Company - Wisconsin Bay Front	Ashland	4931 Electric and Other Services Combined
Roffers Construction (2 locations)	Ashland	2951 Asphalt Paving Mixtures and Blocks

Facilities with NPDES Permits to Discharge Treated Wastewater

Untreated or poorly treated wastewater can be a hazard to human health and contribute to the eutrophication of water bodies. A number of relatively small municipal wastewater treatment plants discharge wastewater that has received secondary treatment to Lake Superior in the APIS vicinity (Table 23, Figure 25). The Madeline Sanitary District discharges 114 m^3day^{-1} from Madeline Island, one of the Apostle Islands not included in APIS. The communities of Ashland, Greater Bayfield, Washburn, and the Red Cliff Indian Reservation wastewater treatment plant and fish hatchery discharge approximately 6,500 m^3day^{-1} into the relatively confined waters of Chequamegon Bay. Other small communities, such as Port Wing, Herbster (Clover Sanitary District), and Cornucopia (Bell Sanitary District), discharge northward into Lake Superior west of the APIS mainland unit. Approximately 113 km to the west, the very large municipalities of Superior, WI and Duluth, MN discharge over 158,000 m^3day^{-1} of effluent into Lake Superior (USEPA 2006a).

Many of the nation's 16,000 wastewater treatment systems are in poor condition and plagued by overflows during wet weather (ASCE 2005). In the vicinity of APIS, the city of Ashland has experienced difficulty in treating all of its wastewater during wet weather periods. It diverts untreated wastewater into Lake Superior 2-3 times per year, and received a notice of violation from the WDNR for doing so in April 2004 (Broman 2005). The WDNR has asked the city to identify sources of stormwater infiltration and to develop a plan to eliminate them. In 2004, the city of Bayfield and the Pikes Bay Sanitary District signed an agreement to build a new combined Greater Bayfield Wastewater Treatment Plant (O'Brien 2004). The plant, opened in 2006, is the first U.S. plant on Lake Superior to adopt the Great Lakes zero discharge policy, meaning that all discharges will be equal to or better in quality than the lake water (WDNR, Sheri Snowbank, Wastewater Specialist, pers. comm. 2007)

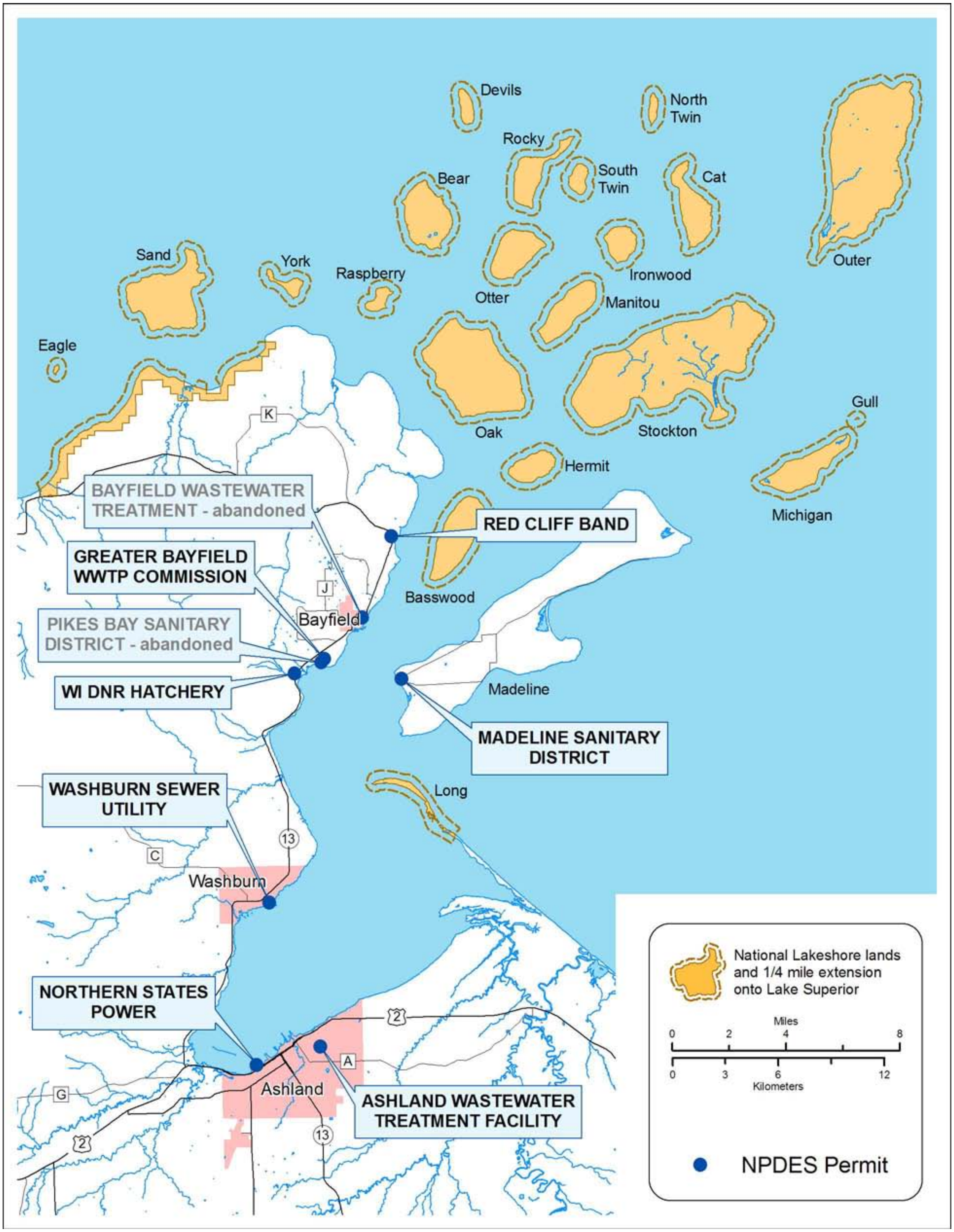


Figure 25. Facilities with NPDES permits in the vicinity of Apostle Islands National Lakeshore (USEPA 2005a).

Table 23. Wastewater treatment facilities in the Lake Superior basin in the vicinity of Apostle Islands National Lakeshore in 2000 (*Red Cliff plant added 2004, Greater Bayfield plant added 2006) (Broman 2005; Olivo 2004; USEPA 2000a, 2005b, 2006a; WDNR 2005o; Greg Fischer, UWSP Aquaculture Facility, pers. comm. 2007; Matt Symbal, Red Cliff Fish Hatchery, pers. comm 2007).

Facility name and USEPA ID number	County	Population Served	Wastewater Treatment Process	Existing discharge, $m^3 day^{-1}$	Sludge Treatment Process	Permit Violations 2003-2005
Ashland WWTP (55000220001)	Ashland	8,672	Influent pumping, bar screen, grit removal, secondary alum addition, oxidation ditch, secondary clarification, ultraviolet disinfection, custom built plant, semi-automated	3,975	Gravity thickening, lime stabilization, anaerobic digestion, digestor gas utilization facilities, landfill/ trenching, land spreading	Reporting violation 2005, pH 2004, 2005; overflow of untreated sewage, 2004
Madeline Sanitary District (55009502001)	Ashland	1,803	Influent pumping, bar screen, aerated lagoon, chlorination, control/lab/maintenance building, custom built plant, semi-automated	114	Not stated	None listed
Northern States Power Company Wisconsin Bay Front	Ashland	Not applicable	No treatment for condenser cooling water Settling ponds for process water	128,700 1,110	Not applicable	None listed
Greater Bayfield WWTP *opened 2006	Bayfield	1,083	Bar screen, biological phosphorus removal, oxidation ditch, clarifiers, disk filters, ultraviolet light,	473	Aerobic digestion, reed beds for drying and storage	Not applicable
Bayfield WWTP (55000360001) (now abandoned)	Bayfield	683	Influent pumping, bar screen, grit removal, activated sludge-contact stabilization, chlorination, dechlorination, outfall diffuser, control/lab/maintenance building, custom built plant, semi-automated	568	Aerobic digestion – air, land spreading	None listed

Table 23. Wastewater treatment facilities in the Lake Superior basin in the vicinity of Apostle Islands National Lakeshore in 2000 (*Red Cliff plant added 2004, Greater Bayfield plant added 2006) (Broman 2005; Olivo 2004; USEPA 2000a, 2005b, 2006a; WDNR 2005o; Greg Fischer, UWSP Aquaculture Facility, pers. comm. 2007; Matt Symbal, Red Cliff Fish Hatchery, pers. comm 2007) (continued).

Facility name and USEPA ID number	**County**	**Population Served**	**Wastewater Treatment Process**	**Existing discharge, m^3day^{-1}**	**Sludge Treatment Process**	**Permit Violations 2003-2005**
Washburn Sewer Utility (55005020001)	Bayfield	2,345	Influent pumping, bar screen, comminution, aerated lagoon, chlorination, dechlorination, control/lab/maintenance building, custom built plant, semi-automated	1,060	Not stated	None listed
Wisconsin DNR Bayfield Fish Hatchery	Bayfield	--	Three pollution control ponds in series Activated sludge for domestic wastes	13,250 15	Not stated	None listed
Town of Port Wing (55003855001)	Bayfield	300	Influent pumping, bar screen, stabilization pond, custom built plant, manually controlled	75	Not stated	None listed
Pikes Bay Sanitary District (55000007001) *now abandoned	Bayfield	400	Comminution, aerated lagoon, chlorination, dechlorination	38	Not stated	None listed
Town of Bell (Cornucopia) (55001165001)	Bayfield	262	Influent pumping, stabilization pond	75	Not stated	None listed
Town of Clover (Herbster) (55002137001)	Bayfield	173	Influent pumping, stabilization pond, chlorination	38	Not stated	None listed
Red Cliff Band of Lake Superior Chippewas *opened 2003	Bayfield	1,830	Pretreatment, secondary treatment, effluent clarification, disinfection	75	Aerobic digestion	Total P (2003-2005), mercury (2003, 2005), fecal coliform (2004)

Table 23. Wastewater treatment facilities in the Lake Superior basin in the vicinity of Apostle Islands National Lakeshore in 2000 (*Red Cliff plant added 2004, Greater Bayfield plant added 2006) (Broman 2005; Olivo 2004; USEPA 2000a, 2005b, 2006a; WDNR 2005o; Greg Fischer, UWSP Aquaculture Facility, pers. comm. 2007; Matt Symbal, Red Cliff Fish Hatchery, pers. comm 2007) (continued).

Facility name and USEPA ID number	County	Population Served	Wastewater Treatment Process	Existing discharge, $m^3 day^{-1}$	Sludge Treatment Process	Permit Violations 2003-2005
Red Cliff Band of Lake Superior Chippewas Fish Hatchery	Bayfield	--	Settling area and wetland ponds	2,560	None	
UW – Stevens Point Aquaculture facility	Bayfield	-	Settling ponds, and in the future, a constructed wetland	818	None	No permit
Superior WWTP (55004730001)	Douglas	27,368	Influent pumping, bar screen, grit removal, ferric chloride addition, preaeration, primary sedimentation, activated sludge – conventional, chlorination, dechlorination (not in use), control/lab/maintenance building, custom built plant, semi-automated	14,000	Biosolids lagoons, anaerobic digestion, polymer addition, digestor gas utilization facility, land spreading	Violations for BOD-5 day, total suspended solids, total phosphorus (2003-04), pH, fecal coliform, total residual chlorine (2004)
Western Lake Superior Sanitary District #1 WWTF (Duluth area) (27000002001)	Saint Louis	107,088	Influent pumping, grit removal, microstrainer-primary, mixed media filter, activated sludge – pure oxygen, other physical/chemical, secondary clarification, chlorination, control/lab/maintenance building, custom built plant, semi-automated	146,500	Dissolved air floatation thickening, incineration-fluidized bed, lime stabilization, landfill/trenching, mechanical dewatering-vacuum	None listed

The Northern States Power Company – Wisconsin Bay Front facility at Ashland is a 73 megawatt steam electric generating plant that burns coal, wood chips, railroad ties, tire-derived fuel, and natural gas. It discharges, on an annual average, 128,700 $m^3 day^{-1}$ of condenser cooling water and 1,110 $m^3 day^{-1}$ of process water into Chequamegon Bay. The cooling water does not require treatment, but the process water from the boilers is run through two settling ponds before discharge (WDNR 2002a). The facility is required to monitor its condenser cooling water discharge flow, temperature, pH, and copper levels, and its process cooling water discharge flow, pH, temperature, copper levels, total suspended solids levels, mercury levels, oil and grease levels, and acute and chronic whole effluent toxicity levels. The facility also has several other outfalls with monitored smaller flows. As of September 2002, it was in compliance with all requirements of its discharge permit (WDNR 2002a).

The Bayfield Fish Hatchery uses three pollution control ponds in series to treat water from the fish raceways and tanks, and an activated sludge secondary treatment plant similar to a municipal treatment plant to treat domestic wastewater from its operation. It discharges 13,250 $m^3 day^{-1}$ to Lake Superior via Pikes Creek. As of January 2002, it was in compliance with all requirements of its discharge permit (WDNR 2002b).

Local Sources of Soil and Groundwater Contamination

Since the beginning of the USEPA's underground storage tank program in 1984, nearly 70% of the 400,000 known leaking tanks have been cleaned up, but nearly 12,000 more leaking tanks are discovered nationwide each year (USEPA 2004). In Wisconsin, the WDNR tracks cleanup of underground storage tanks as well as other sources of soil and groundwater contamination through its Bureau of Remediation and Redevelopment. In APIS, four contaminated sites are currently listed in the Bureau's database; two, at Little Sand Bay and on Raspberry Island, have been resolved, but contamination problems persist on Outer Island at the Lighthouse and old Lullaby Logging Camp site (Table 24) (WDNR 2006b). On lands near the APIS mainland unit, the Russell Town Landfill is still considered a potential groundwater contamination source (WDNR 2006b). Madeline Island has four previously contaminated sites. Communities in the larger watershed that drains to Lake Superior in the APIS vicinity, including Ashland, Bayfield, Cornucopia, and Washburn, have a total of 31 active or conditionally closed remediation sites, as well as 162 sites where remediation has been completed (WDNR 2006b).

National Priorities List Site - Chequamegon Bay

A waterfront site in the city of Ashland has been listed on the National Priorities ("Superfund") list because of contamination with volatile organic compounds and semivolatile organic compounds (USEPA 2006b). Possible sources of contaminants in the area include a closed manufactured gas plant, a wood treatment facility, a railroad yard, and a former city landfill (Xcel Energy n.d.). Approximately 4 ha of bay sediments are contaminated, and access to this section of the bay is blocked off with navigational buoys to avoid further disturbance. Groundwater remediation is underway, and some soil has been removed. Fish in Chequamegon Bay have been sampled and do not contain site-related contaminants at levels of health concern (USEPA 2006b).

Table 24. Locations of spills and leaks that have contaminated soil and groundwater in the vicinity of Apostle Islands National Lakeshore, and the status of their cleanup (WDNR 2006b).

Locations within APIS	Contaminant	Status of Remediation
Little Sand Bay	petroleum/diesel fuel	Closed
Lullaby Logging Camp - Outer Island	diesel fuel/gasoline	Open
Outer Island Lighthouse	lead scrap metal, chromium, metals	Open
Raspberry Island	petroleum/diesel fuel	Recommended for closure

Locations near the APIS mainland unit	Contaminant	Status of Remediation
Bayfield Town Shop Site B	diesel fuel	Closed
Russell Town Garage	gasoline- leaded and unleaded/diesel fuel	Closed
Schellenberg Residence - Little Sand Bay Rd	gasoline- leaded and unleaded	Closed
Russell Town Landfill	not stated	Open

Locations on Madeline Island	Contaminant	Status of Remediation
Brummer Oil - Madeline Island	gasoline- leaded and unleaded/petroleum	Closed
LaPointe Town Garage	gasoline- leaded and unleaded/diesel fuel/petroleum	Closed
Madeline Island Yacht Club	petroleum	Closed
St. John's United Church of Christ- Madeline	petroleum	Closed

Locations in and around Ashland	Contaminant	Status of Remediation
C&NW Railroad Roundhouse	not stated	Conditional closure
Harbor Bait Bulk Plant	petroleum	Conditional closure
UW Ag Research Station	gasoline-leaded and unleaded/petroleum	Conditional closure
Ashland City Landfill	not stated	Open
Ashland County Right of Way	gasoline-leaded and unleaded	Open
Ashland Historical Museum/Wilmarth Mansion	petroleum	Open
Ashland Precision Products	not stated	Open
Ashland Travel Center ICO (Spur)	gasoline-leaded and unleaded/diesel fuel	Open
Eder Bros	gasoline-leaded and unleaded	Open
Holiday Station#66	gasoline-leaded and unleaded	Open
Lake Shore Mobil	gasoline-leaded and unleaded/diesel fuel	Open
Land O Lakes	ammonia, other substance, petroleum	Open
Midland Services Inc	diesel fuel	Open
Mr. Movies	petroleum	Open
Neps Bar	gasoline-leaded and unleaded	Open
NSP Aboveground Tank Farm	not stated	Open

Table 24. Locations of spills and leaks that have contaminated soil and groundwater in the vicinity of Apostle Islands National Lakeshore, and the status of their cleanup (WDNR 2006b) (continued).

Locations in and around Ashland	**Contaminant**	**Status of Remediation**
NSP Coal Gas Waste	(superfund site)	Open
Ashland City/Kreher Park	(associated with superfund site)	Open
Wisconsin Central LTD/ Kreher Park	(associated with superfund site)	Open
Three Eagles Gift and Smoke Shop	gasoline-leaded and unleaded	Open
Tower Bar	gasoline-leaded and unleaded	Open
Wisconsin Central LTD	not stated	Open
147 other sites		Closed

Locations in and around Bayfield	**Contaminant**	**Status of Remediation**
Superior Petrol Bulk Plant	gasoline - leaded and unleaded/diesel fuel	Open
10 other sites		Closed

Locations in and around Cornucopia	**Contaminant**	**Status of Remediation**
Siskiwit Bay Marina	gasoline- leaded and unleaded	Open
3 other sites		Closed

Locations in and around Washburn	**Contaminant**	**Status of Remediation**
Alice Kurschner	petroleum	Open
Baillie Bulk Oil	petroleum	Open
Leinos Gas and Goods	gasoline-leaded and unleaded/diesel fuel	Open
Teschner	not stated/old junkyard	Open
Washburn Chlorinated Hydrocarbons	chlorinated solvents/percholoroethylene	Open
Washburn County Garage	gasoline-leaded and unleaded/diesel fuel	Open
Washburn Marina	gasoline-leaded and unleaded/diesel fuel	Open
12 other sites		Closed

DuPont Barksdale Works Project

The DuPont Barksdale plant, which manufactured trinitrotoluene (TNT) from 1904 - 1971, is located on Boyd Creek, which discharges into Lake Superior between Ashland and Bayfield (WDNR 2003a). Chemical wastes generated in the production of explosives, and their breakdown products, include sulfuric acid, sulfites, nitric acid, ammonium nitrates, nitrates and nitrites, soda ash, toluene, nitroazoxytoluenes, nitroanilines, nitrobenzenes, nitrotoluene and dinitrotoluene (DNT), and TNT (WDHFS 2002). DuPont company files indicate that all waste streams from the nitric and sulfuric acid areas, which included cooling water and spilled sulfur, wash from the production of nitroglycerine, and red water from washing crude TNT were channeled into Boyd Creek (WDNR 2005a). At the time the plant closed, no aquatic life was detected in Boyd Creek (WDNR 2005a).

In 2005, DuPont reported detecting perchlorate in groundwater around the nitric acid production facility, and lead and arsenic in soils along old roadways in a part of the site currently being used for recreational activities (DuPont 2005). The company removed over 180 kg of TNT in 2005 as part of its ongoing site investigation and cleanup activities (DuPont 2005). DuPont is also working with researchers from the University of Georgia to develop a soil bioremediation pilot plant for the site (DuPont 2005).

Boyd Creek sampling in 2002 detected nitroaromatic compounds in the water and sediments at concentrations below potential toxic levels to aquatic life (WDNR 2003a). The Barksdale site is listed as a potential contaminated sediment site in Wisconsin's draft Great Lakes Strategy (WDNR 2005b).

St. Louis River Area of Concern

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 or AOCs. The 63 km of the St. Louis River below Cloquet, Minnesota are an AOC because of impairments in nine beneficial uses (restrictions on fish and wildlife consumption, degradation of fish and wildlife populations, fish tumors or other deformities, degradation of benthos, restrictions on dredging activities, eutrophication or undesirable algae, beach closings, loss of fish and wildlife habitat, and degradation of aesthetics) (USEPA 2003a). Sources of pollution include contaminated sediments, abandoned hazardous waste sites, poorly designed or leaky landfills, airborne deposition, industrial discharges, chemical spills, improperly sewered wastes, and surface runoff (USEPA 2003a). This AOC is approximately 113 km away and is the nearest AOC to APIS.

Great Lakes Shipping

Lake Superior is an important water highway 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 18^{th} in the nation in terms of total cargo volume (Duluth Seaway Port Authority 2004). About 1,100 vessels visit the port of Duluth each year.

Ships may affect the quality of the waters on which they travel in numerous ways. These may include accidents that spill cargo, accidents that spill fuel, normal losses of fuel during engine operation, and discharges of garbage, human sewage, dunnage, bilge water, and ballast water. Dunnage is the material placed between cargo during shipping. 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 hold it down when it is not carrying cargo.

The risk of a shipwreck or accident on Lake Superior that results in a spill of fuel or cargo is not insignificant. Lake Superior's cliffs and reefs and unpredictable weather have contributed to many shipwrecks in the past, including 47 recorded shipwrecks in the Lake Superior waters of

Wisconsin, the majority of them in the APIS vicinity (Wisconsin Historical Society 2006). Ships traveling to the port of Duluth (upbound) in the designated shipping lanes are approximately 7.1 km from Devils Island and 7.6 km from Sand Island as they pass APIS. Those traveling downbound are approximately 19 km from Devils Island at their closest point to APIS. Ships using the port at Ashland come within approximately 6 km of Michigan Island and 1 km of Long Island (Figure 26) (NOAA 2003) However, ships may leave the designated shipping lanes and travel closer to APIS, and even among the islands, in bad weather conditions when accidents become most likely. The location of the shipping lanes, therefore, does not fully describe the degree of risk.

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. It specifically 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 Wisconsin (USEPA 2006e).

Cargo: Shipping data for Lake Superior indicate that for the port of Duluth, the major commodities shipped include iron ore (40%), coal (40%), and grain (10%) (Duluth Seaway Port Authority 2004). Superior also ships iron ore, coal, and grain, and it receives limestone and cement. The other smaller ports whose shipping lanes join the Duluth shipping lane before it passes APIS are Two Harbors and Silver Bay, which ship iron ore and coal. The port at Ashland receives shipments of coal (Lake Carriers Association 2004). These cargoes, if spilled, would not likely create a major threat to APIS.

Fuel: The 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).

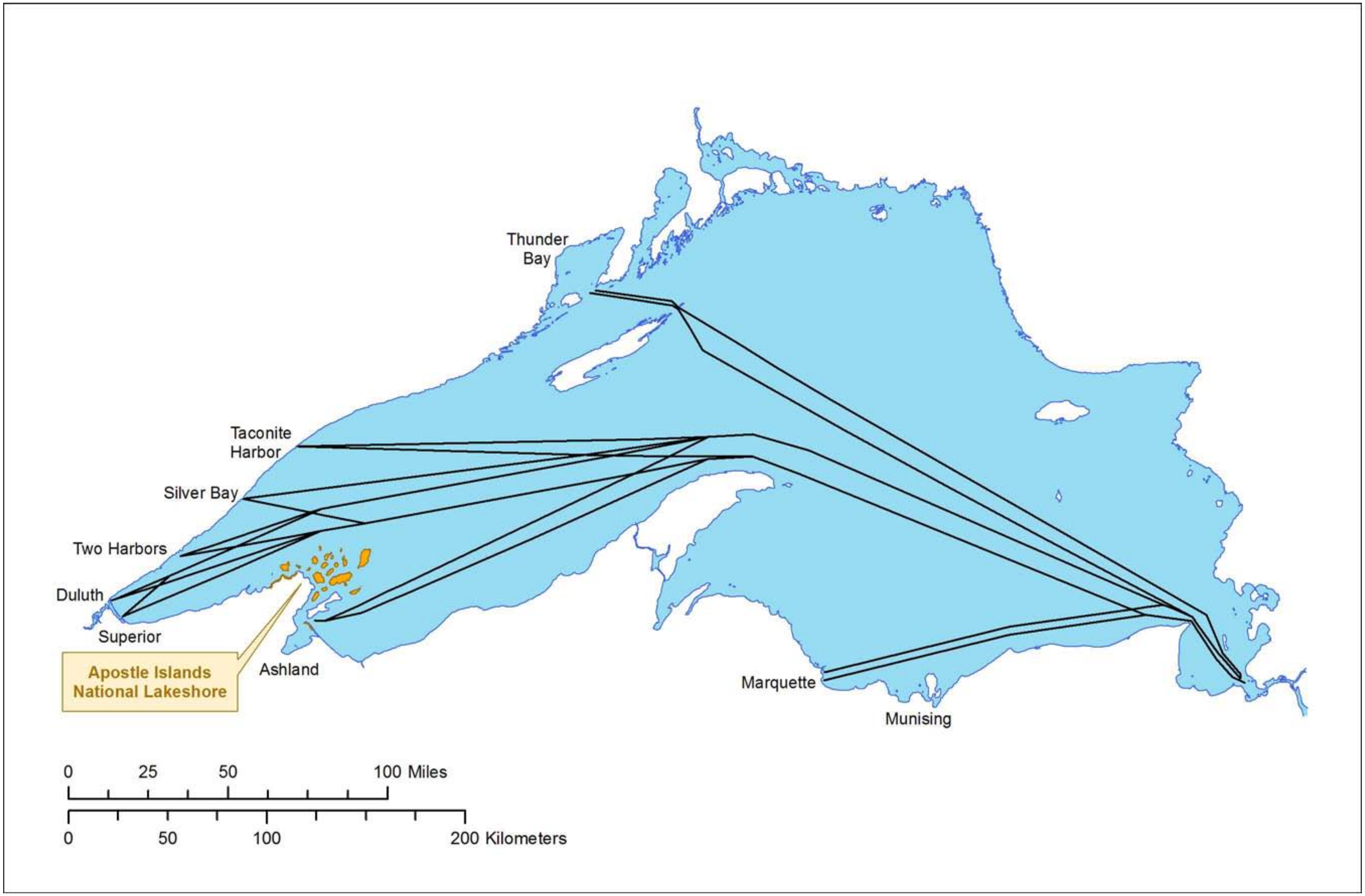


Figure 26. Lake Superior shipping lanes (NOAA 2005d).

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 APIS 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 sensitivity of water resources in its Region 5 to oil spills. The report for Western Lake Superior shows that APIS has 85.89 km of rocky cliffs and bedrock shores with low sensitivity; 167.07 km of sand and gravel beaches with low-medium sensitivity; 0.26 km of sheltered vegetated low banks with medium sensitivity; and 7.56 km of fringing and extensive wetlands, which have the highest sensitivity ratings (Table 7, Figure 27) (USEPA Region 5 2000). APIS is covered by an Area Contingency Spill Plan for Western Lake Superior, and specific park guidance also has been developed to deal with spills (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2007).

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 nutrient state, limited primary productivity, and

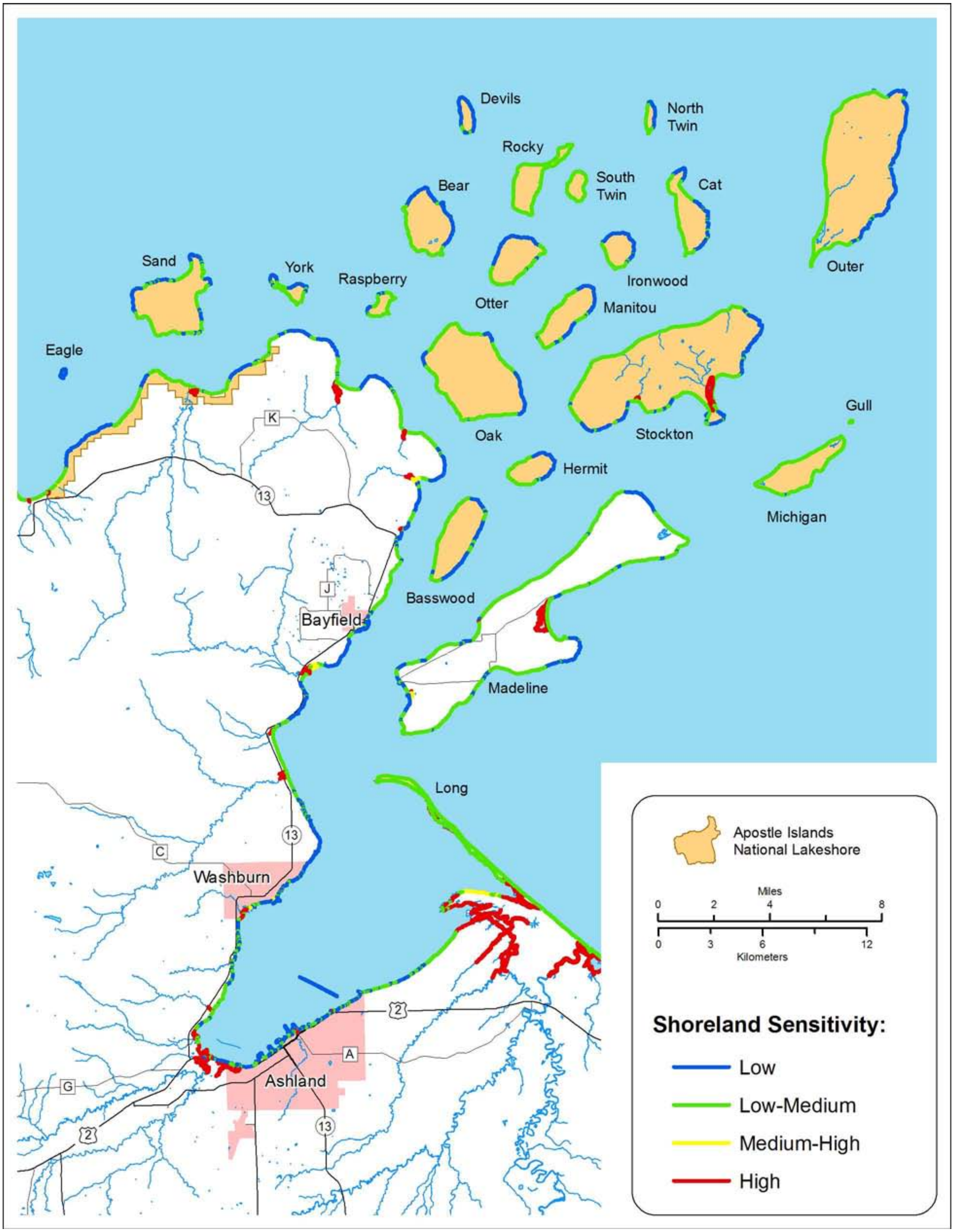


Figure 27. Shoreline sensitivity classifications for the Apostle Islands National Lakeshore (USEPA Region 5 2000).

high ratio of profundal-limnetic to littoral zones may be mitigating factors that limit aquatic invasive species (Grigorovich et al. 2003a).

The state of Michigan has established 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 Michigan Department of Environmental Quality (MIDEQ 2002). 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). Although Wisconsin does not have such programs in place, it may benefit from this program, since all ships coming to Lake Superior ports must pass through Sault St. Marie, Michigan.

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, Ferries, and Windsleds

Apostle Islands Cruise Service, APIS's official concessionaire, conducts five trips to the islands each day from its docks at Bayfield, using two vessels, the Island Princess and the Ashland Bay Express. The Island Princess is a 22 m double deck vessel with two diesel engines that can carry 149 passengers. The Ashland Bay Express is a 12 m vessel with two diesel engines that carries 80 passengers. They also offer a water taxi service on an 8.5 m Sportcraft, which goes out about twice a week on average during the summer months (Apostle Islands Cruise Service 2006; Apostle Islands Cruise Service, Dave Strzok, pers. comm. 2006). In 2006, about 26,000 APIS visitors toured the islands on the concessionaire's tour boat (APIS, Jim Nepstad, Chief of Planning and Resource Management, pers. comm. 2007).

Madeline Island, the only one of the Apostle Islands that is not part of APIS, has a year-round population of approximately 220 people and a summer population of around 3,000 (Madeline Island Chamber of Commerce n.d.). For most of the year, transportation to the island is provided by ferries from the Madeline Island Ferry Line. The largest of these and the main workhorse of the four-ferry fleet is the *Bayfield*, which is 36.5 m long and can carry 26 vehicles and 149 passengers. It is powered by two 325 horsepower diesel engines (Madeline Island Ferry Line n.d.). Two of the ferries are able to operate in ice up to 20 cm thick. When ice on the bay is suitably thick, the town of LaPointe maintains a plowed road on the ice from Bayfield to LaPointe on the island. Windsleds are necessary for several weeks a year to bridge the gap between ferry operations and safe travel on the ice road. The larger of the two windsleds, the *Ice Angel*, is 8 m long and can carry 27 passengers. It is powered by two 520 horsepower engines (Apostle Islands Windsled and Aviation Museum Inc. n.d.).

Recreational Boating

The waters of Lake Superior are also a much-used resource for private recreational boating. In 2001, approximately 48,000 APIS visitors used private motorboats, kayaks or sailboats to tour the islands (NPS 2004a). The APIS web site lists five boat tour and water taxi services, eight sailboat charters, two charter fishing services, and seven businesses in the category of kayak outfitters/guides/adventure travel in the APIS vicinity (NPS 2004c). The inland waters of APIS are not suitable for recreational boating. Personal watercraft (jet skis) are not allowed in APIS (NPS 2003), but they are occasionally found in Lake Superior within APIS boundaries (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2007) and their presence just outside the boundaries may still contribute to water or air quality issues within the park.

In general, the major impacts of motorized watercraft on aquatic ecosystems may include sediment resuspension, water pollution, disturbance of fish and wildlife, destruction of aquatic plants, and shoreline erosion (Asplund 2000). The mechanisms by which these impacts occur include propeller contact with plants and animals, turbulence caused by the propulsion system, wakes, noises, and movement that disturbs wildlife (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). The primary pollutants of concern from marine engines in Lake Superior include MTBE (methyl tertiary butyl ether), PAHs, BTEX (benzene, toluene, ethylbenzene, and xylene) and heavy metals such as copper (NPS 2002e). A study done for Pictured Rocks National Lakeshore (PIRO) found that recreational boating was a larger potential source of these pollutants than were tour boats, commercial fishing, or commercial boating. However, the large size of the lake, lack of well-defined bays, and moderate water depths near shore were considered to be mitigating factors at PIRO (NPS 2002e). No study of boating impacts, whether caused by emissions or physical contact, was found for APIS, but the large number of recreational boats makes such study advisable.

Marinas, Docks, and Anchorages

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 (Ocean Conservancy 2001). Recent research in Isle Royale National Park found clear evidence of PAH contamination at significant levels near marinas (Clements and Cox 2006).

In Wisconsin, marinas operate under permit from the WDNR (WDNR 2005e). Twelve marine facilities exist to provide services and amenities for boaters in the vicinity of APIS. Eleven are located on the Bayfield Peninsula, and one is on Madeline Island (Table 25) (Dahl 2001). Most of them provide gasoline and diesel fuel, pump out sewage tanks, and provide restrooms. The NPS maintains fuel supply facilities for its own fleet on South Twin Island (NPS 1989) and at Little Sand Bay (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2007).

Table 25. Marine facilities providing services and amenities to boaters in the vicinity of Apostle Islands National Lakeshore (Dahl 2001).

	Transient Docking	Gasoline	Diesel	Pumpouts	Restrooms
Bayfield City Dock	X				
Apostle Islands Marina	X	X	X	X	X
Apostle Islands Yacht Club	X				X
Erickson's Marina	X			X	X
Port Superior Marina	X	X	X	X	X
Pike's Bay Marina		X	X	X	X
Madeline Island Yacht Club	X	X	X	X	X
Roy's Point Marina		X	X	X	X
Red Cliff Marina	X	X		X	X
Schooner Bay Marina				X	X
Siskiwit Bay Marina	X	X	X	X	X
Cornucopia City Dock	X				

Although fuel and repair services are not provided for visitors within APIS, many of the islands and the mainland unit have NPS docks where boats may stop for some period of time (Table 26, Figure 28) (Dahl 2001; NPS 2003). The town of Russell also maintains a dock at Little Sand Bay. In addition, most of the islands have anchorage areas that provide shelter from storm winds and opportunities for recreational activities in good weather (Dahl 2001).

Table 26. NPS docks in Apostle Islands National Lakeshore (Dahl 2001).

Island	Location	Dock length (m)	Dock type
Basswood	West	32	Wood
Devils	South Landing	55	Wood
Devils	Breakwater	25	Wood
Little Sand Bay	Visitor	107	Wood
Little Sand Bay	Hokenson	61	Wood
Long	Light station	18	Concrete and steel
Manitou	Fish Camp	50	Wood
Michigan	Lighthouse	47	Concrete
Oak	West	38	Wood
Otter	Southeast	26, 18, 42	Wood
Outer	Lighthouse	91	Wood
Raspberry	Lighthouse West and East	35, 20	Wood
Rocky	East	71	Wood
Sand	East Bay Campground	39	Wood
Sand	East Bay Ranger	21	Wood
South Twin	South	42	Wood
Stockton	Presque Isle West and East	123, 85	Concrete
Stockton	Quarry Bay	90	Wood

Stormwater

Current DNR rules require communities with at least 10,000 residents to obtain stormwater discharge permits, but none of the communities in the APIS vicinity meet that criterion (WDNR 2006a). However, communities around APIS have addressed stormwater issues in various ways.

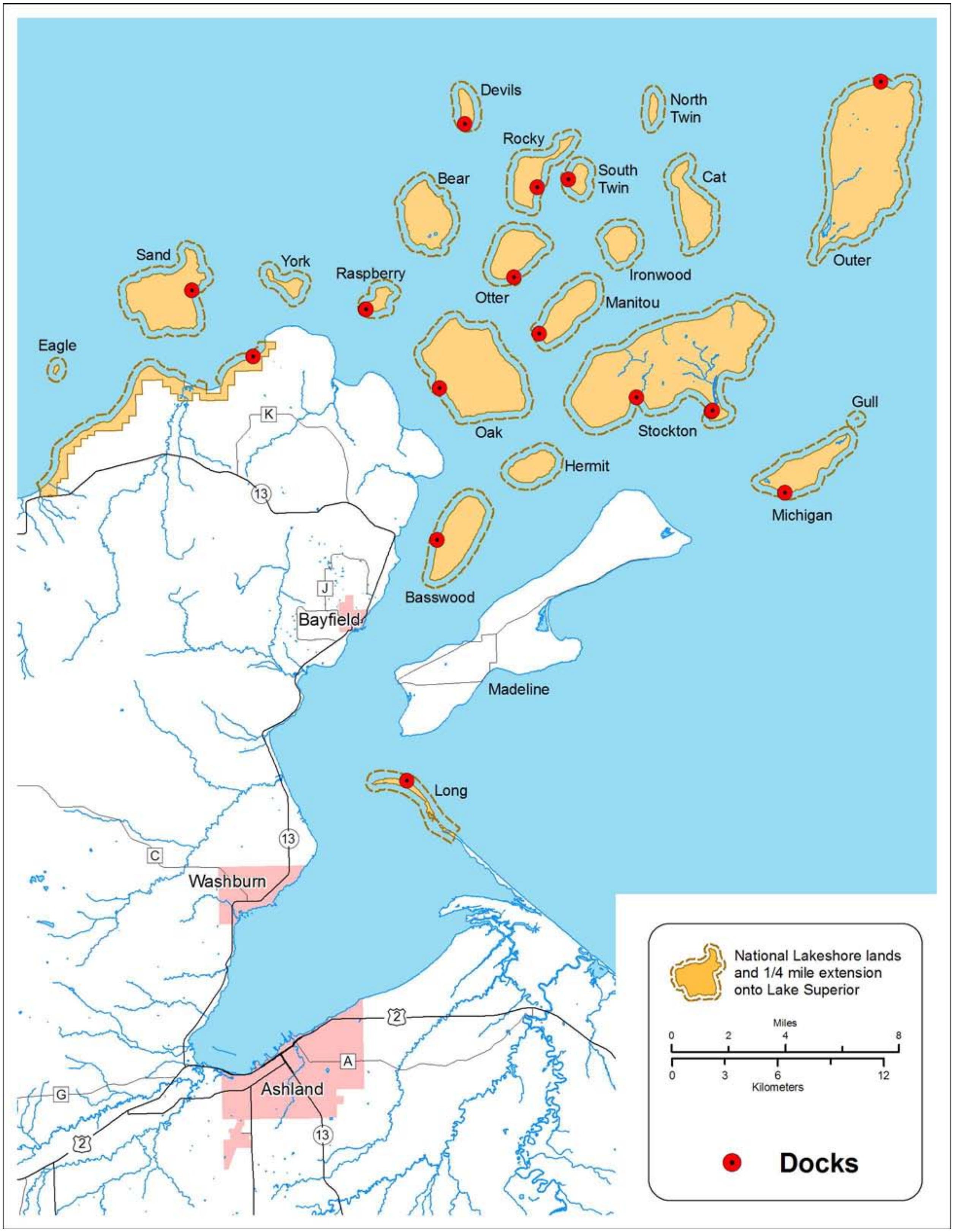


Figure 28. Docks in the Apostle Islands National Lakeshore (NPS 2003)

In the area's largest community, Ashland, a stormwater sewer system services most of the city's developed area. In older parts of the city, storm water is untreated, but some new developments are required to have storm water retention/detention and treatment systems. Stormwater is being diverted away from the contaminated area on the city's waterfront and into a meadow and retention area. The city's comprehensive plan commits it "to handle storm water runoff in an environmentally responsible manner" (City of Ashland Planning Commission 2004). The city of Bayfield has included its desire to work cooperatively with the towns of Russell and Bayfield to "control and reduce stormwater runoff" (City of Bayfield 2002). In 2005, the city of Washburn created a stormwater utility that is intended to "eliminate(s) flooding, minimize(s) environmental degradation and thereby improve(s) living conditions within the City of Washburn" (City of Washburn 2006). The town of Clover has no underground stormwater management system, but it recognizes problems with road damage as well as the larger problem of runoff into Lake Superior (Town of Clover Plan Commission 2003). The Red Cliff reservation has indicated a need to reduce runoff and erosion (Red Cliff Band of Lake Superior Chippewa 2005). Since 2003, all construction sites in Wisconsin with 0.4 ha or more of land disturbance need a construction site stormwater permit, and since August 1, 2004, the permit program has been administered by the WDNR (WDNR 2005c).

Landfills

Only one licensed landfill is currently operating in the APIS vicinity – the Northern States Power ash landfill in the town of Eileen in Bayfield County (WDNR 2005d). In addition, the South Shore Waste Systems LLC landfill (a small size construction and demolition waste landfill which does not require a license) is active and is being monitored (WDNR, Terry Koehn, Hydrogeologist, pers. comm. 2006). Within the Lake Superior Basin, 10 closed landfills are located in Ashland County (including one on Madeline Island), and 19 closed landfills are located in Bayfield County (Bradof et al. 2000). One of these, the town of Russell landfill, is located very near a watershed divide and may be in the watershed of Sand Bay. In Ashland County, two Ashland city landfills, two demolition landfills, and a paper company landfill are still being actively monitored for soil and groundwater contamination. In Bayfield County, the old municipal landfills for Bayfield and Washburn, a town demolition landfill, and two Northern States Power landfills are also still being actively monitored (WDNR 2006b).

Sites that may be accepting municipal solid waste from communities in the APIS vicinity include Timberline Trail in Rusk County, Lake Area Landfill in Washburn County, Moccasin Mike in Douglas County, Highway G Landfill in Vilas County, and additional landfills in Michigan (WDNR, Terry Koehn, Hydrogeologist, pers. comm. 2006).

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 in many cases to remove bacteria and minimize human health risks, 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 and Metropolitan Council 2002). The NPS manages six on-site wastewater treatment mound systems, located at Little Sand Bay and on Devils, Oak, Raspberry, Rocky, and Stockton Islands, and four greywater treatment systems for employee housing on Manitou, Michigan, Outer, and Sand Islands (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2006). In addition, APIS operates vault toilets, which do not discharge to the environment, on Basswood, Cat, Devils, Manitou, Oak, Otter, Outer, Raspberry, Rocky, Sand, South Twin, Stockton, and York Islands (NPS n.d. a.). On the mainland, the density of on-site wastewater treatment systems in the watershed is very low. Only 35 seasonal homes and 62 permanent homes occupied by 154 people are within the 32,141 acres of the mainland unit's watershed (Figure 29) (U.S. Census Bureau 2006). The exact number of on-site wastewater treatment systems is not known but can be reasonably assumed to be no more than 97. Wastewater flow into on-site systems in the entire Town of Bayfield is estimated to be 68-136 m^3day^{-1}, with a peak summer loading of 167 m^3day^{-1} (NWRPC 2005). Despite the low density, individual failing systems can still produce localized surface water or groundwater problems.

In Wisconsin, uniform private on-site wastewater treatment system requirements have been developed by the Wisconsin Department of Commerce (2004). In Bayfield County, the regulations are enforced by the Zoning Department (Bayfield County Board of Supervisors 2002). Much of the watershed does not have suitable soils for the development of conventional on-site wastewater treatment systems, which may present some limitations for future housing development on individual systems (NWRPC 2005).

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). Three golf courses are located in the vicinity of APIS: the Chequamegon Bay Golf Club in Ashland, the Apostle Highlands Golf Course in Bayfield, and the Madeline Island Golf Club. The types of best management practices used at these courses, and their impacts on water resources, have not been studied.

Agriculture

Bayfield County had 468 farms on 45,264 ha of land in the 2002 agricultural census (USDA 2002). In 2003, the town of Bayfield, which includes the watershed for the Sand River, had 149 agricultural parcels, and agricultural activities mainly consisted of small independent produce operations, orchards, and hobby farms (NWRPC 2005). At present, there are no dairy farms, commercial livestock, poultry, fish, or concentrated animal feeding operations in the town. The town of Russell, on the tip of the Peninsula, has 240 ha of agricultural land, which includes animal husbandry, orchards, pasture, and forage production (Town of Russell Land Use Planning Committee 2001). The town of Bayview, directly west of Long Island, has 553 ha, or 5.1% of its land base, in agricultural land (Town of Bayview Planning Commission 2001).

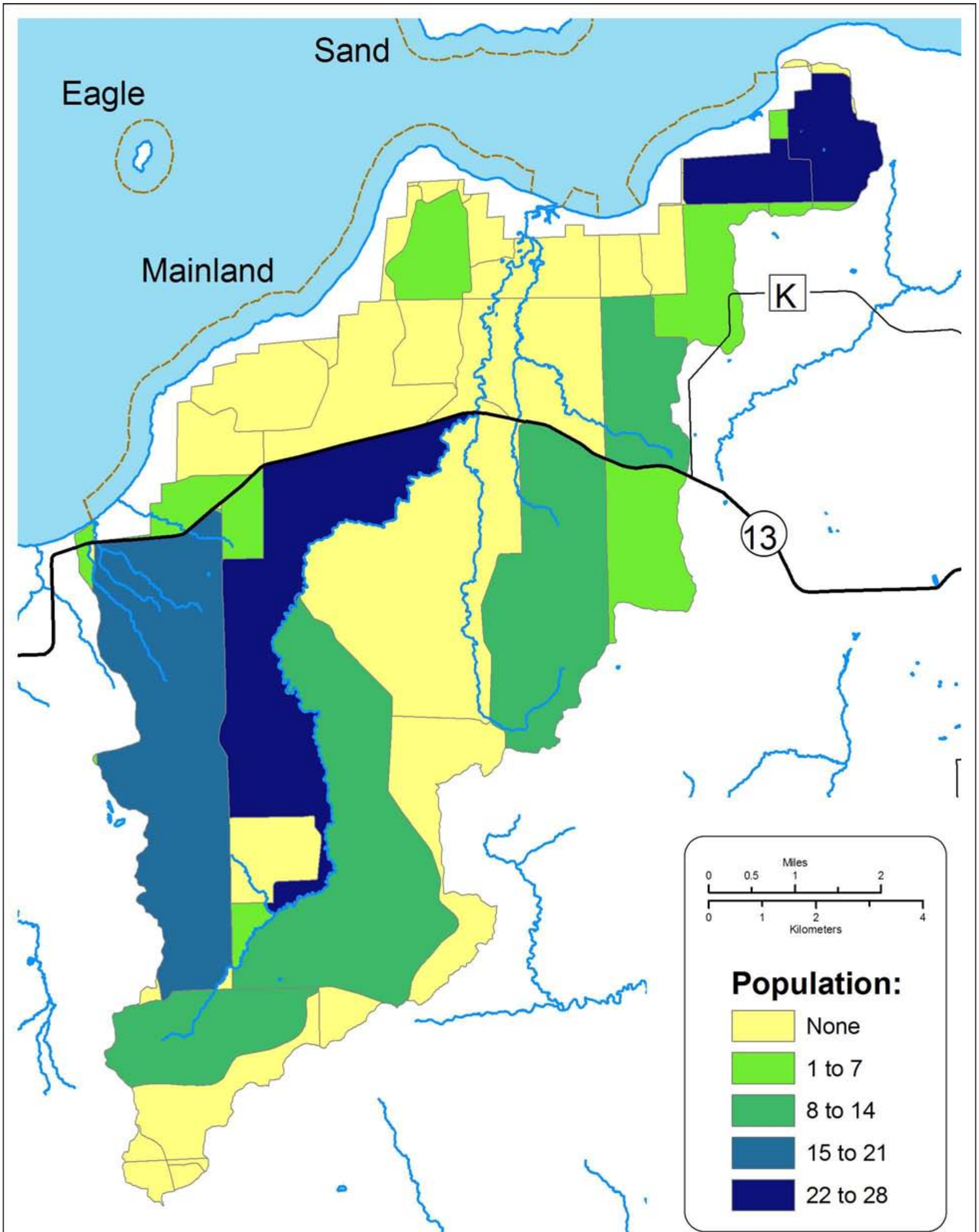


Figure 29. Population (number of residents per tract in the 2000 census) of the watershed above the mainland unit of the Apostle Islands National Lakeshore (U.S. Census Bureau 2006).

Forestry

The forests of Ashland and Bayfield counties, including many of the islands, were harvested during the cutover period that lasted from the late 1860s to the early 1930s in Wisconsin. Some of the damage created by this non-sustainable harvest included forest fires, stream sedimentation, and changes in forest structure, composition, and function (WDNR 2000a). After Wisconsin passed the Forestry Mill Tax Law in 1931, Ashland County established 13,000 ha, and Bayfield County 68,000 ha, of county forests on lands repossessed for tax delinquency after the logging boom and subsequent attempts at farming ended (Jordahl 1994). The Apostle Islands themselves were excluded from consideration as a National Park in the 1930s, in part because of the destruction of the forests and subsequent fires that "burn(ed) the thin soils down to the rocks" (Jordahl 1994).

Today, timber harvest continues on the county forest lands, including those in the mainland unit's watershed. In 2003, 49,200 cords were harvested from the Bayfield County Forest in the town of Bayfield (NWRPC 2005). Sustainable forestry practices include control of sediment, especially at stream crossings for forest roads and skid trails, removal of excessive organic debris from streams, proper use of nutrients and pesticides where needed, and avoidance of stream temperature increases caused by canopy removal (WDNR 2003b).

Surface Water Quality

Monitoring Programs

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 STORET system includes water quality parameter data, locations of sampling stations, and descriptive elements about stations and parameters. The report for APIS (commonly referred to as the Horizon Report after its contractor) was completed in 1999 and includes all STORET data through November 21, 1998. Samples were collected from 1968 - 1996 by the NPS, the USGS, the USEPA, and the WDNR. Two hundred twenty-two monitoring stations were identified in an area three miles lakeward and one mile downstream of the park boundary (Figure 30), and 20,681 water quality observations were noted for 479 separate parameters. Forty-four stations were located within the park boundary; however, none of them yielded useable long-term records (NPS 1999a).

Since the Horizon report was completed, the USGS has removed its data from STORET and now keeps it in its National Water Information System (NWIS) database (USGS 1998). We verified that all samples in the Horizon report are still either in STORET or NWIS. We identified one additional sampling location (the Onion River between Bayfield and Washburn, in 2001) in NWIS and some WDNR beach monitoring data for 2004 in modern STORET.

The WDNR developed a Water Resources Monitoring Strategy in 2005 (WDNR 2005f). However, no baseline monitoring or long-term monitoring sites for streams and lakes are located in the APIS vicinity (WDNR 2004a; WDNR, Jennifer Filbert, IS Data Services Professional, pers. comm. 2006)

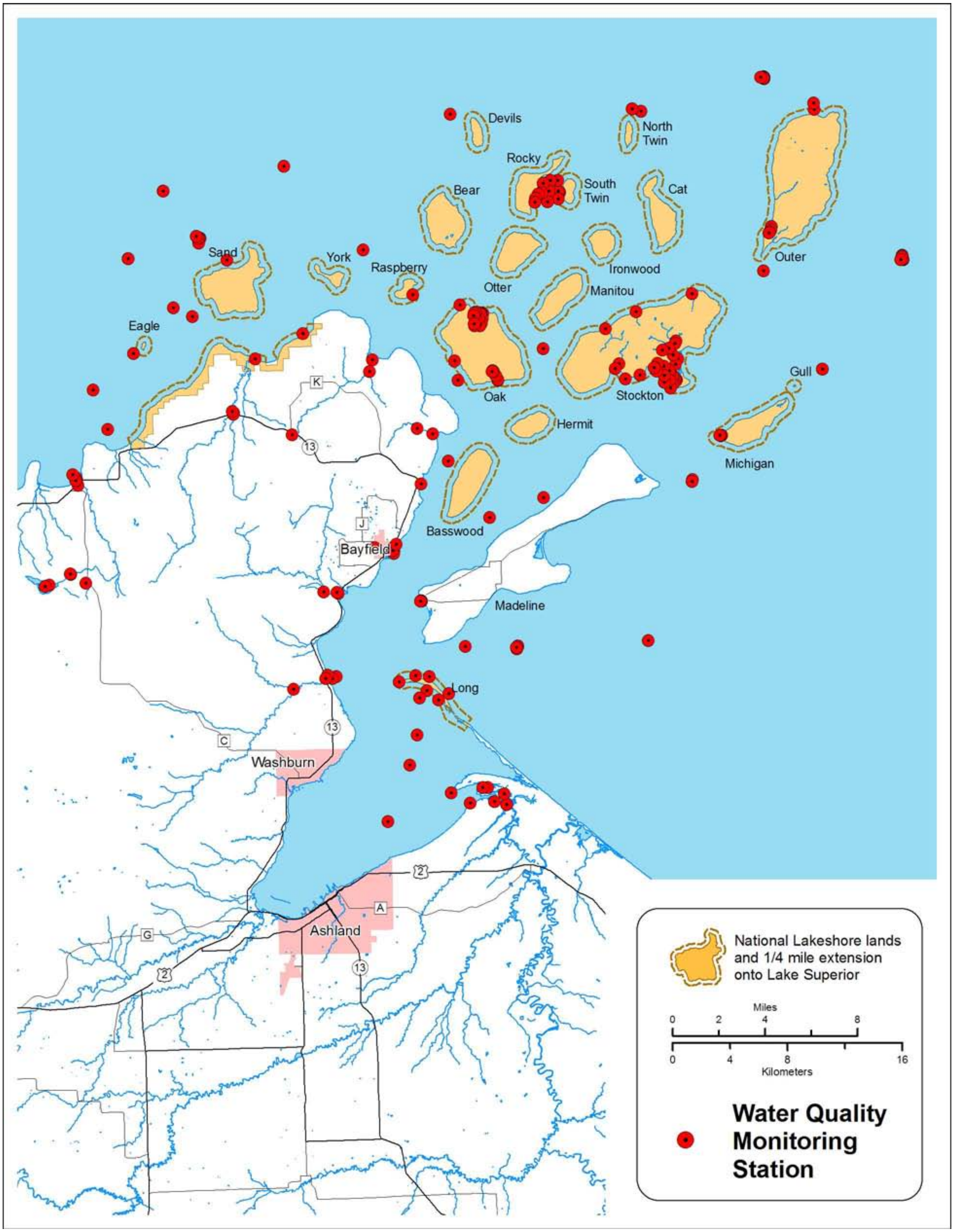


Figure 30. STORET water quality monitoring stations included in the Apostle Islands National Lakeshore baseline water quality data report (NPS 1999a).

WDNR). Wisconsin's water monitoring plan does include monitoring Lake Superior drinking water intakes according to the Safe Drinking Water Act; monitoring and modeling lake trout catch-at-age; biennial monitoring of fish contaminants at 11 sites around APIS (Figure 31, Table 27); and weekly beach monitoring for pathogen indicators (WDNR 2005f). Currently, the WDNR has issued contracts for the monitoring of seven Lake Superior beaches in Ashland County and 16 in Bayfield County (Richmond and Glymph 2005).

Rose (1988) noted that, based on measurements of sediment loading and phosphorus loading from the Sand River, Bayfield Peninsula runoff contributed, on average, 11,900 metric tons of sediment and 9,800 kg of phosphorus to the APIS area of Lake Superior each year from 1980 - 1984. The WDNR is currently developing a 5 - 8 year program to quantify the effects of erosion control practices on Lake Superior tributaries by monitoring suspended solids and flow (WDNR 2005f).

APIS has initiated a tiered water quality monitoring program which includes annual bacteria monitoring and bi-annual field monitoring at five Lake Superior sites and three lagoon sites for water temperature, pH, DO, specific conductance, oxidation-reduction potential, turbidity, and Secchi depth. In addition, every five years, data collection is expanded at these eight sites to include laboratory analysis of nitrogen, phosphorus, and chlorophyll a, as well as benthos and plankton monitoring (Burkman and Van Stappen 2003).

Monitoring schedules and parameters may change with the implementation of the NPS Great Lakes Inventory and Monitoring Network (GLKN) ecosystem-based Vital Signs monitoring program (Route and Elias 2006). The GLKN inland lakes protocol chooses index lakes and monitors them annually, three times during the open water season, at the deep hole. A Core Suite of parameters includes temperature, pH, specific conductance, dissolved oxygen, Secchi or transparency tube depth, and flow/water level. The Advanced Suite of parameters includes major ions, alkalinity, dissolved organic carbon, chlorophyll *a*, and nutrients (Route and Elias 2006).

GLKN contracted with the Natural Resources Research Institute (NRRI) to review field data collection by APIS staff and compare the data to that collected in 1996 by the Lake Superior Ecosystem Research Center. Subsequently, NRRI produced a report that compared the data they collected in summer 2004 to past data, including some, but not all, of the data examined for this report (Axler et al. 2006). They developed detailed recommendations for the timing and frequency of sampling Lake Superior sites and lagoon sites, which included sampling Core Suite parameters and chlorophyll *a* every two years. For Lake Superior, nutrients in Lake Superior were to be analyzed every five years, and major cations and anions every 10 years. Lagoons did not need Advance Suite monitoring, in their opinion, unless a specific water quality issue was noted. Recommendations for the frequency, timing, and locations of zooplankton and benthos sampling were also included (Axler et al. 2006).

Water Quality Monitoring Data and Results

Although numerous sampling efforts have been undertaken in and around APIS since 1968, few data sets exist that allow the tracking of water quality trends over time. Six of seven stations identified in the Horizon report as having long-term monitoring data have data only for metals,

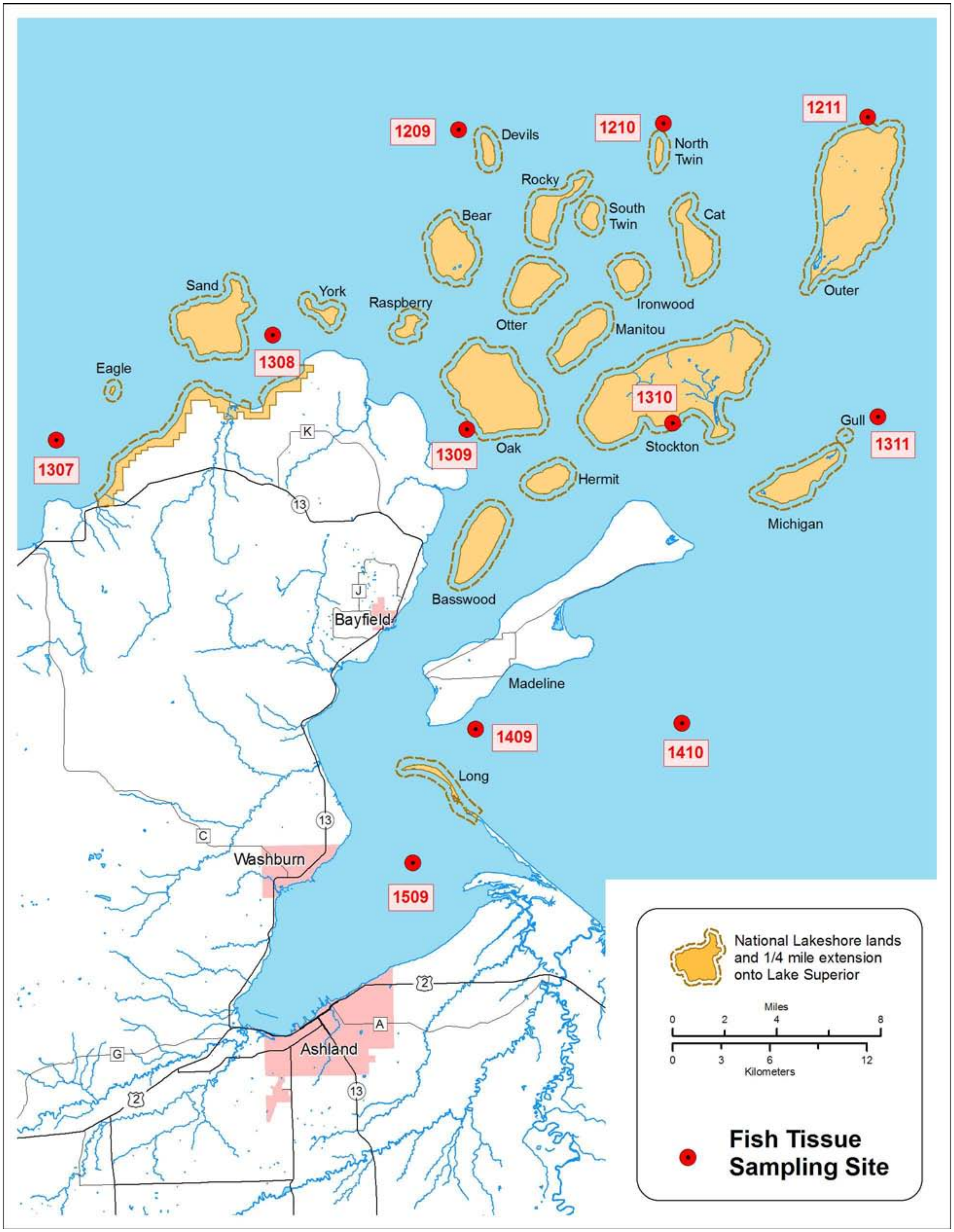


Figure 31. Locations for fish tissue contaminant sampling in the vicinity of Apostle Islands National Lakeshore, 1974-2005 (WDNR, Candy Schrank, Fish Contaminant and Toxicology Program Coordinator, pers. comm. 2006).

Table 27. Numbers of fish sampled for contaminants, and total number of analyses performed for each site (in parentheses) by WDNR each year at open water sites in Lake Superior around APIS, 1974-2005 (years without samples omitted) (WDNR, Candy Schrank, Fish Contaminant and Toxicology Program Coordinator, pers. comm. 2006).

	Grid 1209	Grid 1210	Grid 1211	Grid 1307	Grid 1308	Grid 1309	Grid 1310	Grid 1311	Grid 1409	Grid 1410	Grid 1509
1974											12 (20)
1976				9 (18)			3 (6)				
1977											2 (28)
1978											3 (41)
1979			4 (104)								7 (157)
1980			3 (39)								3 (78)
1982								20 (300)	2 (6)		2 (50)
1983							3 (61)			3 (18)	
1984	3 (21)	5 (129)	1 (25)			2 (52)		9 (76)	11 (140)		7 (83)
1985				17 (109)		1 (14)		5 (89)			
1986								1 (8)	3 (8)		5 (18)
1987				7 (93)					5 (40)		4 (18)
1988	6 (75)		3 (45)			1 (15)		2 (30)	2 (30)	2 (30)	8 (99)
1989						1 (14)					
1990								9 (54)			
1991	1 (13)		4 (52)					14 (173)		8 (105)	
1992	2 (28)	2 (28)	1 (14)				1 (14)		2 (28)		
1993								25 (350)			
1995		1 (14)					3 (39)	2 (26)		1 (13)	
1997		1 (13)				5 (70)		7 (97)	2 (4)	7 (91)	9 (18)
1998											18 (360)
1999		1 (14)		1 (14)		2 (28)		8 (110)		7 (91)	16 (190)
2001					18 (377)						9 (132)

Table 27. Numbers of fish sampled for contaminants, and total number of analyses performed for each site (in parentheses) by WDNR each year at open water sites in Lake Superior around APIS, 1974-2005 (years without samples omitted) (WDNR, Candy Schrank, Fish Contaminant and Toxicology Program Coordinator, pers. comm. 2006) (continued).

	Grid 1209	Grid 1210	Grid 1211	Grid 1307	Grid 1308	Grid 1309	Grid 1310	Grid 1311	Grid 1409	Grid 1410	Grid 1509
2002										1 (14)	
2003	11 (144)	4 (106)		2 (28)			7 (43)	3 (92)	2 (6)		10 (30)
2005	2 (n/a)			2 (n/a)	5 (n/a)	1 (n/a)		4 (n/a)	8 (n/a)	5 (n/a)	16 (n/a)
Some fish were sampled for more than one contaminant.											

PCBs, and pesticides in fish tissues. The seventh, a site on the Sand River near Red Cliff (APIS 0191) tracks water chemistry data from 1980 - 1984 (NPS 1999a). These data, though useful from a historical perspective, may not shed much light on current water quality in APIS.

In this report we will emphasize analysis of data collected by the NPS since 1996, since it is more recent and does represent long-term monitoring at specific locations. In general, the surface water resources of APIS are of good quality (Burkman and Van Stappen 2003), with some impact from natural and human sources (NPS 1999a). Results for individual parameters are examined in more detail below.

Local or Municipal Water Quality Management Plans

Wisconsin counties have both the authority and the responsibility to develop, approve, and implement Land and Water Resource Management plans (Pollek 2005). Both Ashland and Bayfield Counties have adopted such plans (Table 28). Four counties in northwestern Wisconsin (Ashland, Bayfield, Douglas, and Iron) share a land conservation department, so it is not surprising that Ashland and Bayfield Counties adopted plans that were nearly identical in their goals and objectives. The specific activities planned to meet these goals did vary by county. Both county plans place emphasis on protection of surface water, with emphasis on headwater areas and coastal wetlands. Both also seek to balance conservation and development, and to address problems of invasive species and forest fragmentation. Both also recognize that little is known about groundwater resources in these two counties (Stable Solutions 2005a, b).

The Land Use Plan for the Red Cliff Band of Lake Superior Chippewa similarly has goals related to fisheries management, air quality, water quality, forestry management, and controls on development near water resources. Goals specific to water resources are included in Table 29.

Table 28. Goals and Objectives in Land and Water Management Plans for Ashland and Bayfield Counties* (Stable Solutions 2005a, b).

SURFACE WATER INITIATIVE

Goal 1.0: Protect and improve lakes and streams.

Objective 1.1: *Manage subwatersheds using the most current watershed assessment tools.*
Objective 1.2: *Reduce nonpoint pollution.*
Objective 1.3: *Implement and refine land use regulations (i.e., zoning ordinances) to protect and improve lakes and streams.*

Goal 2.0: Balance Development with Conservation and Protection.

Objective 2.1: *Evaluate county zoning maps to determine whether there is a good balance between preservation and development.*
Objective 2.2: *Work with communities on stormwater management to minimize off-site impacts.*
Objective 2.3: *Develop long-range city growth plans that include environmental protection best management practices.*

WETLAND & HABITAT INITIATIVE

Goal 3.0: Improve shoreland management to protect environmental quality.

Objective 3.1: *Evaluate county zoning maps to determine whether there is a good balance between preservation and development.*
Objective 3.2: *Improve buffer area habitat on lakes, rivers, and streams.*

Goal 4.0: Reduce environmental impacts of recreational trails.

Objective 4.1: *Protect sensitive areas from the short and long-term effects of recreational trails.*

Goal 5.0: Increase understanding of metallic and non-metallic mining impacts.

Objective 5.1: *Continue offering programs to assist towns and contractors in developing nonmetallic mine reclamation plans.*
Objective 5.2: *Educate the public about the short and long-term affects of metallic and nonmetallic mining.*

Goal 6.0: Preserve large tracts of land to minimize forest fragmentation.

Objective 6.1: *Educate landowners about tax incentive programs and provide tax relief and incentives to keep large tracts of land intact.*
Objective 6.2: *Manage residential development in forested areas.*
Objective 6.3: *Provide copy of land and water resource management plan to Local Units of Government and local planning departments and committees.*
Objective 6.4: *Maintain large tracts of land for wildlife.*

Goal 7.0: Protect sensitive environmental areas.

Objective 7.1: *Protect coastal wetlands.*
Objective 7.2: *Educate the public about the importance of sensitive areas.*
Objective 7.3: *Protect headwater areas.*
Objective 7.4: *Continue to identify, classify, and research sensitive areas.*
Objective 7.5: *Continue multi-agency wetland restoration program.*
Objective 7.6: *Use native species when establishing long-term vegetation on conservation projects.*

Goal 8.0: Prevent the spread of invasive species.

Objective 8.1: *Develop a comprehensive invasive species management and control program.*
Objective 8.2: *Manage residential development in forested areas.*

Table 28. Goals and Objectives in Land and Water Management Plans for Ashland and Bayfield Counties* (Stable Solutions 2005a, 2005b) (continued).

Goal 9.0: Reduce the deer population.
Objective 9.1: *Educate landowners and hunters about deer population goals and impacts.*
Objective 9.2: *Act as a liaison to DNR regarding urban and agricultural deer damage.*

GROUNDWATER INITIATIVE
Goal 10.0: Protect and improve groundwater quality and quantity.
Objective 10.1: *Protect subwatershed groundwater recharge, discharge, and key soil transition areas from human induced impacts.*

COLLABORATION INITIATIVE
Goal 11.0: Continue to work with conservation partners to improve program delivery.
Objective 11.1: *Promote local partner activities.*
Objective 11.2: *Promote partner activities outside of the area.*

*Copied from Bayfield County plan. Ashland County goals and objectives were the same but sometimes in slightly different order.

Designated Beneficial Uses or Classifications
The state of Wisconsin has authority and responsibility to establish water quality standards for Wisconsin water bodies, including those within APIS (Ledder 2005). Lake Superior open waters must meet the criteria and requirements for public water supplies, while all waters of Lake Superior, including tributaries to it, must meet the standards for recreational use and fish and aquatic life (Wisconsin Administrative Code 2004). Within APIS, a tributary to Sand Bay in T51N R4W and Saxine Creek are designated as Class I Trout waters and Exceptional Resource Waters (ERW). ERW are surface waters which "provide outstanding recreational opportunities, support valuable fisheries, have unique hydrologic or geologic features, have unique environmental settings, and are not significantly impacted by human activities" (Wisconsin Administrative Code 1998).

Ecosystem Effects
Water Clarity: In 1848, Louis Agassiz noted the clarity of Lake Superior's water, and its clarity continues to be notable today (Matheson and Munawar 1978). Most nearshore areas have mean Secchi depths ranging from 5.6 - 11 m, although depths of 1.5 - 2.8 m occur along the red clay bluffs of the Wisconsin shoreline (Matheson and Munawar 1978; LSBP 2006). Since 1991, APIS staff has collected Secchi data at selected sites as part of the Lakewatch program (Van Stappen 1999). Results have been fairly consistent, and have generally fallen within or been slightly better than the lake averages (Burkman and Van Stappen 2003) (Table 30). In 1995 the lakewide average was 8 m, with a range of 0.2 to 19 m (Lake Superior Center 1997).

Table 29. Water resource-related goals in the Red Cliff Band of Lake Superior Chippewas Land Use Plan (2005).

Goal 2 : Protect the diverse natural resources on the Red Cliff Reservation.
Objectives:

- Identify and clearly designate prime forest areas.
- Inventory and protect old growth forest stands.
- Discourage fragmentation of large forest tracts.
- Manage Tribal forest lands in a sustainable way that provides for future generations.
- Maintain a diverse mix of plant and animal communities on the Red Cliff Reservation through sound ecosystem management strategies, habitat protection, and regulation.
- Maintain, restore, and enhance native fish communities in the waters of the Red Cliff Reservation and nearby waters of Lake Superior.
- Examine ways to control and reduce local sources of air pollution in order to maintain and improve existing air quality.

Goal 3: Protect and maintain the quality of the Reservation's surface and groundwater resources.
Objectives:

- Prevent development in sensitive environmental areas such as wetlands, water drainage areas, and filtering areas.
- Limit removal of natural vegetation along shorelines.
- Maintain forest buffer zones along streams and lakeshores.
- Develop appropriate provisions for building setbacks, building design, and size of development near surface waters.
- Discourage land use practices that could have a detrimental impact on the Reservation's water quality.
- Promote practices to minimize erosion and runoff.
- Promote Best Management Practices (BMPs) for forestry activities.
- Identify and cap open abandoned and unused wells.
- Identify and remove all old underground storage tanks.
- Enforce Tribal codes for septic systems.
- Implement a water quality monitoring program.

Table 30. Secchi depths (m) for sites monitored by Apostle Islands National Lakeshore staff, 1991-1995 (Lake Superior Center 1997) and 2000-2003 (Burkman and Van Stappen 2003).

	1991-1995	**Number of readings 1991-1995**	**2000 (average of 3 readings)**	**2002 (average of 3 readings)**	**2003 (average of 2 readings)**
Long Island	--	--	2	4	3
Rocky Island	--	--	10	9	--
Rocky Island	8.1	10	11	7	--
Stockton Island	11.5	19	12	9	--
Sand Island	7.0	15	9	8	8
Outer Island	11.8	13	15	12	10
Devils Island	8.6	13	--	--	--

Nutrients: Nutrients, most notably nitrogen and phosphorus, are important for the growth of both desirable and undesirable plants in surface water bodies. The 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.

APIS 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 400 µg/L (0.40 mg/L) for lakes and reservoirs, and 360 µg/L (0.36 mg/L) for rivers and streams (USEPA 2000b, 2001). Four of six Lake Superior samples, three lagoon samples, and one river sample exceeded this criterion in summer 2004 (Table 31) (Axler et al. 2006). Similarly, 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. The three APIS lagoon samples from summer 2004 had 10 µg/L phosphorus; the Lake Superior and Sand River samples were well below their criteria (Table 31) (Axler et al. 2006).

In addition, the ratio of total nitrogen to total 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). All ratios for summer 2004 were greater than 15:1, some by an order of magnitude, indicating phosphorus limitation in the APIS waterbodies sampled.

Table 31. Total nitrogen and phosphorus for sites in Apostle Islands National Lakshore, summer 2004. Number of samples was 3 except for Basswood Island and Sand River, where n=1 (Axler et al. 2006).

	Total nitrogen µg/L as N	**Total phosphorus, µg/L as P**	**N:P ratio**
LAKE SUPERIOR			
0.5 miles south of Outer Island	412	2	206
0.5 miles south of Presque Isle, Stockton Island	398	3	133
0.2 miles east of Rocky Island	409	2	205
2 miles south of Long Island	358	4	90
1 mile southwest of Sand Island	419	3	140
Between mainland and Basswood Island	404	2	202
LAGOONS			
Outer Island	708	10	71
Michigan Island	559	10	56
Stockton Island	572	10	57
RIVER			
Sand River mouth	445	6	75

Sampling during the summer of 1996 showed very low to non-detectable levels of dissolved orthophosphate and inorganic forms of nitrogen (Lake Superior Ecosystem Research Center 1997) (Table 32). The total and dissolved nutrient data support Lake Superior's status as an oligotrophic lake. However, some data suggest that the lakewide nitrate level has been slowly increasing over the period of record (LSBP 2006). Nitrate values at open water sites were one to two orders of magnitude greater than those at lagoon sites (Table 32).

Table 32. Dissolved orthophosphate, nitrate-nitrite nitrogen, and ammonia nitrogen values for Apostle Islands National Lakeshore sites, summer, 1996 (Lake Superior Ecosystem Research Center 1997).

	Dates	Dissolved orthophosphate mg/L as P	Dissolved nitrite plus nitrate, mg/L as N	Dissolved ammonia, mg/L as NH4
LAKE SUPERIOR				
0.5 miles south of Outer Island	6/10/96-8/20/96	<0.01	0.4-0.5	<0.01-0.04
0.5 miles south of Presque Isle, Stockton Island	6/11/96-8/21/96	<0.01-0.03	0.2-0.5	<0.01-0.01
0.2 miles east of Rocky Island	6/12/96-8/21/96	<0.01	0.3-0.4	<0.01-0.03
2 miles south of Long Island	6/11/96-8/21/96	<0.01-0.01	0.2-0.3	<0.01-0.18
1 mile southwest of Sand Island	6/12/96-8/21/96	<0.01-0.01	0.2-0.5	<0.01-0.03
LAGOONS				
Outer Island	06/11/96-08/20/96	<0.01-0.01	0.001-0.02	<0.01-0.03
Michigan Island	06/11/96-08/20/96	<0.01-0.01	0.003-0.02	<0.01-0.13
Stockton Island	06/10/96-08/20/96	<0.01-0.03 and one reading of 0.76	0.006-0.03	<0.01-0.20

Alkalinity, pH, and Susceptibility to Acid Rain: Surface waters, especially lakes, in the Upper Midwest are among the nation's most susceptible to acid precipitation (USEPA 2003b). The 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 these criteria, the Outer Island lagoon is categorized as moderately sensitive to acid rain (Table 33), and Stockton Island lagoon has low to no sensitivity to acid rain and is acidic at some times.

Table 33. pH and alkalinity measurements for open water sites and lagoon sites, Apostle Islands National Lakeshore (Rose 1988; Balcer and McCauley 1989; Lake Superior Ecosystem Research Center 1997; Burkman and Van Stappen 2003; Axler et al. 2006).

	Dates	pH	Alkalinity mg/L CaCO3
LAKE SUPERIOR			
0.5 miles south of Outer Island	7/8/2003 and 10/9/2003	7.95-8.6	--
0.5 miles south of Presque Isle, Stockton Island	6/11/96-8/21/96	7.12-7.95	--
Presque Isle Bay	8/12/86	6.8	42-43
	9/14/87	8.1	--
0.2 miles east of Rocky Island	6/12/96-8/21/96	7.29-8.0	--
2 miles south of Long Island	7/1/2003 and 10/14/2003	7.5-8.65	--
1 mile southwest of Sand Island	6/30/2003 and 10/17/2003	7.55-8.7	--
LAGOONS			
Outer Island	7/28/83	--	5.0
	6/10/86-9/22/87	6.0-7.1	3.7-6.4
	06/11/96-08/20/96	5.44-6.51	--
	6/30/04-10/12/04	6.83-7.05	2.4-3.2
Michigan Island	8/24/84	6.5	37
	6/10/86-9/22/87	5.5-6.9	25.3-51.0
	06/11/96-08/20/96	5.62-6.92	--
	6/30/04-10/12/04	6.82-7.34-	19-55
Stockton Island	6/30/86-10/8/87	6.0-7.1	11.0-16.5
	06/10/96-08/20/96	4.83-6.49	--
	7/1/04-10/12/04	7.18-7.73	23-49
STREAMS			
Oak Island	5/13/86-9/8/86	6.12-7.54	22.0-68.0

Exceedences of Aquatic Freshwater Life Criteria: Three parameters (DO, pH, and copper) were outside the range acceptable under USEPA criteria for the protection of freshwater aquatic life during the period of record (NPS 1999a). Low DO levels ($\leq$ 4 mg/L) were confined to streams and beaver ponds on Stockton Island and to the lagoons on Outer, Stockton, and Michigan Islands (Table 34) (NPS 1999a). Thirty-four stations within APIS had pH measurements less than 6.5 between 1980 and 1996 (NPS 1999a). Two monitoring stations in Lake Superior, west of Outer Island and west of Sand Island, equaled or exceeded the acute freshwater concentration for copper of 18 µg/L with values from 18 - 22 µg/L in 1971. In addition, turbidity exceeded the NPS screening criteria for freshwater aquatic life of 50 Jackson Candle/Formazin/Nephelometric Turbidity Units with three readings ranging from 53.3 – 58 Nephelometric Turbidity Units (NTU) in Lake Superior approximately one mile southwest of Sand Island in July 1996 (NPS 1999a).

Table 34. Dissolved oxygen measurements in lagoons on Outer, Stockton, and Michigan Islands in Apostle Islands National Lakeshore.

Lagoon/Data Source	Outer Island		Stockton Island		Michigan Island	
	Date	DO mg/L	Date	DO mg/L	Date	DO mg/L
Rose 1988	7/28/83	7.6-7.9			8/24/84	<1-4.7
Balcer and McCauley 1989	6/10/86	3.7-6.5	9/1/86	6.4-8.8	6/10/86	0.2-5.5
					8/22/86	3.0-4.6
	6/24/87	5.0-7.8	6/24/87	8.3-10.0	6/24/87	0.6-6.0
			10/8/87	12.0-12.8		
Lake Superior Ecosystem Research Center 1997	6/11/96-8/20/96	7.1-8.2	6/10/96-8/20/96	0.05-11.5	6/11/96-8/20/96	0.2-8.3
Axler et al. 2006	6/30/04-10/12/04	7.4-10.3	7/1/04-10/12/04	9.2-10.7 (means)	6/30/04-10/12/04	7.3-8.7 (means)

Exceedences of Human Health Criteria

Fecal indicator bacteria concentrations (fecal coliform) were measured 408 times at 36 monitoring stations from 1971 through 1988, and exceeded NPS screening limits of 200 Colony Forming Units/Most Probable Number (CFU) per 100 milliliters for freshwater bathing three times from 1986 - 1987, with values of 244 and 307 CFU/100 ml at Presque Isle Harbor at Stockton Island and 320 CFU/100 ml outside Chequamegon Bay north of Long Island (NPS 1999a). For 2003, seven samples of 194 from Ashland County beaches and five of 235 from Bayfield County beaches failed to meet current USEPA criteria of 235 CFU/100 ml. For 2004, the numbers were 16 of 159 Ashland County samples and five of 230 Bayfield County samples, and for 2005, seven of 152 Ashland County samples and 10 of 234 Bayfield County samples (Richmond and Glymph 2005). None of the unsafe samples were collected from any site in APIS or on Madeline Island. Bacteriological sampling conducted by APIS staff at Stockton Island Presque Isle and at Little Sand Bay in July, August, and September 2002 met State of Wisconsin standards (Burkman and Van Stappen 2003).

Sampling of Stockton and Outer Island lagoons in July 2005 revealed high concentrations of methylmercury in water (averaging 2.5 and 1.3 ng/L, respectively). Concentrations of mercury in northern pike (19 - 43 cm in length) ranged from 0.25 – 1.15 ppm and exceeded the USEPA health criterion for protection of human health (0.3 ppm) in 15 of 17 fish sampled (Rolfhus et al. in progress). In addition to these specific findings, all inland waters in Wisconsin have a general 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 and its tributaries up to the first impassable barrier have fish consumption advisories, especially for women and children, because of PCB contamination (Table 35). Siscowet also have restrictions because of high dioxin levels (WDNR 2005g).

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. Impaired water bodies are placed on a list often called a section 303(d) list, again after the pertinent subsection of the Act. These

Table 35. Fish consumption advisories for Wisconsin waters of Lake Superior and its tributaries up to their first impassable barrier (WDNR 2005g).

Species	Eat no more than 1 meal/week or 52 meals/year	Eat no more than 1 meal/month or 12 meals/year	Eat no more than 1 meal/2 months or 6 meals/year	Do not eat
Brown trout	All sizes (Hg/PCB)			
Chinook salmon	Less than 25” (PCB)	More than 25” (Hg/PCB)		
Coho salmon	More than 18” (Hg)			
Rainbow trout	All sizes (Hg/PCB)			
Lake herring	All sizes (PCB)			
Lake sturgeon		More than 50” (PCB)		
Lake trout	Less than 23” (PCB)	23-34” (PCB)	More than 34” (PCB)	
Lake whitefish	All sizes (PCB)			
Siscowet		Less than 25” (PCB)		More than 25” (dioxin)
Walleye		More than 26” (PCB)		

water bodies must have total maximum daily loads of pollution (TMDLs) established for them. No water bodies within APIS are listed, but in the APIS vicinity, Chequamegon Bay appears because of the contaminated coal tar sediment site at Ashland, and 10 inland lakes in Ashland County and 11 in Bayfield County are included because of atmospheric mercury contamination (WDNR 2004b).

Groundwater Quality and Monitoring Programs

In Wisconsin, public water supplies are monitored by the WDNR for contaminants on a schedule determined by state and federal regulations (WDNR 2004c). 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.

No violations of safe drinking water standards have been recorded for any of the public water supply wells in APIS for the period of record that began in 1993. Since 1993, one violation of the coliform bacteria standard was noted in the city of Bayfield, in September 1999, and one violation of treatment technique was noted for the city of Ashland, which uses surface water, in May 2001. No standards violation for any chemical parameter was reported for the cities of Ashland, Bayfield or Washburn (USEPA 2006d).

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. The Center for Watershed Science and Education's (CWSE) database contains relatively few private well water samples for Ashland County (22 from 1987 - 2006) and Bayfield County (62 from 1989 - 2005). Of those samples, only five of 68 contained nitrate and nitrite-nitrogen over 2 mg/L, and none exceeded the 10 mg/L public drinking water standard. Two of seven samples contained lead over the public water supply health action level of 15 µg/L, and none of three samples contained a detectable level of arsenic. From this small sampling, the quality of private drinking water wells appears to be good; however, because of well construction problems and the very local nature of some contaminants, a contaminated well could occur even in a relatively pristine region.

The USGS has monitored groundwater wells in and around APIS since 1945, but conducted the most concentrated monitoring from 1979 - 1984 as part of the investigation of APIS's water resources (Table 10) (Rose 1988). Eleven wells were each sampled once for pH, hardness, calcium, magnesium, sodium, potassium, alkalinity, carbon dioxide, sulfate, chloride, fluoride, silica, dissolved solids, nitrate and nitrite nitrogen, arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, and zinc. The water samples met all Wisconsin drinking water standards for these parameters (Rose 1988). Only well AS-52/02W/34-0110 at Quarry Bay on Stockton Island exceeded Wisconsin's secondary aesthetic standards for iron and manganese.

Other Areas of Concern

Water Use

In 2000, Ashland County used 177,309 $m^3 day^{-1}$ of water (173,183 $m^3 day^{-1}$ of surface water and 4,126 $m^3 day^{-1}$ of groundwater), while Bayfield County used 35,659 $m^3 day^{-1}$ (23,318 $m^3 day^{-1}$ of surface water and 12,340 $m^3 day^{-1}$ of groundwater) (Table 36) (Ellefson et al. 2002). The largest use of water in Ashland County was 167,429 $m^3 day^{-1}$ for thermoelectric power generation, while the largest use in Bayfield County was 30,359 $m^3 day^{-1}$ for agriculture. Total domestic use (roughly measured by domestic use plus public use and losses combined) is relatively small; 3,823 $m^3 day^{-1}$ in Ashland County and 3,294 $m^3 day^{-1}$ in Bayfield County.

Within APIS, the NPS operates three public transient non-community water supply wells, at the Little Sand Bay Visitor Center and on Stockton and Sand Islands (NPS n.d. a.; APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2006). Little Sand Bay had over 16,000 visitors in August 2006; Stockton Island and Sand Island had over 1,600 and nearly 800 campers, respectively, in that same month. In a recreational setting, water use is estimated to be 38-57 L/person/day (Handy and Twenter 1985), so peak total daily visitor water use may be between 23,300 and 35,000 L, or 23 - 35 $m^3 day^{-1}$. Some of that water is returned to the ground through on-site waste disposal systems. In addition, wells on Devils, Oak, Raspberry, and

Manitou Islands are operated for employee use only (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2006). As recently as 2001, APIS operated 23 wells and 20 water distribution systems (NPS 2002d).

Table 36. Water use in Ashland and Bayfield Counties in 2000 (Ellefson et al. 2002).

Type of use	**Water use by County, $m^3 day^{-1}$**	
	Ashland	**Bayfield**
Domestic	2,763	2,953
Agriculture	4,013	30,359
Irrigation	189	530
Industrial	1,060	1,173
Commercial	795	265
Thermoelectric	167,429	0
Public Use and Losses	1,060	341
Total	177,308 (173,183 surface water/ 4,126 groundwater)	35,659 (23,318 surface water/ 12,340 groundwater

Demographics and Development

Ashland and Bayfield Counties, where APIS is located, account for 4.6% of the total state land area but only 0.6% of its population, and have population densities of 8.5 and 10.2 persons per square mile, respectively (U.S. Census Bureau 2006). Ashland County's population peaked at 24,538 in 1920 and was estimated at 16,627 in 2005. Similarly, Bayfield County's population peaked at 17,201 in the same year and was estimated at 15, 013 in 2005 (Figure 32). Ashland County's population has been declining since about 1940, while Bayfield's has been increasing since 1970. Population trends observed in Bayfield County include a steady growth rate around small unincorporated towns along major roads; growth in rural towns around the City of Ashland; and a high growth rate in the town of Russell fueled by the Red Cliff Indian Reservation (Figure 33) (Laumann 2003).

Housing development in Bayfield County is outpacing population growth because of the growing popularity of the area for seasonal homes. The Bayfield County towns closest to APIS (Russell, Bayfield, and Bayview) are expected to double the number of housing units between 1990 and 2020, with the number of seasonal homes growing at a faster rate than year-round homes (Table 37) (Laumann 2003). Currently, 23.3% of homes in Bayfield County are served by public sewer systems, 66.4% are served by private onsite wastewater systems, and the remaining 10% are uncategorized (Laumann 2003). If those proportions carry forward into the future, as many as 700 more housing units may exist in unsewered areas of these towns in 2020 than existed in 1990. The buildout scenario for the town of Bayfield shows that a large number of unsewered building sites may be available in the upper reaches of the western part of the Sand River watershed (NWRPC 2005).

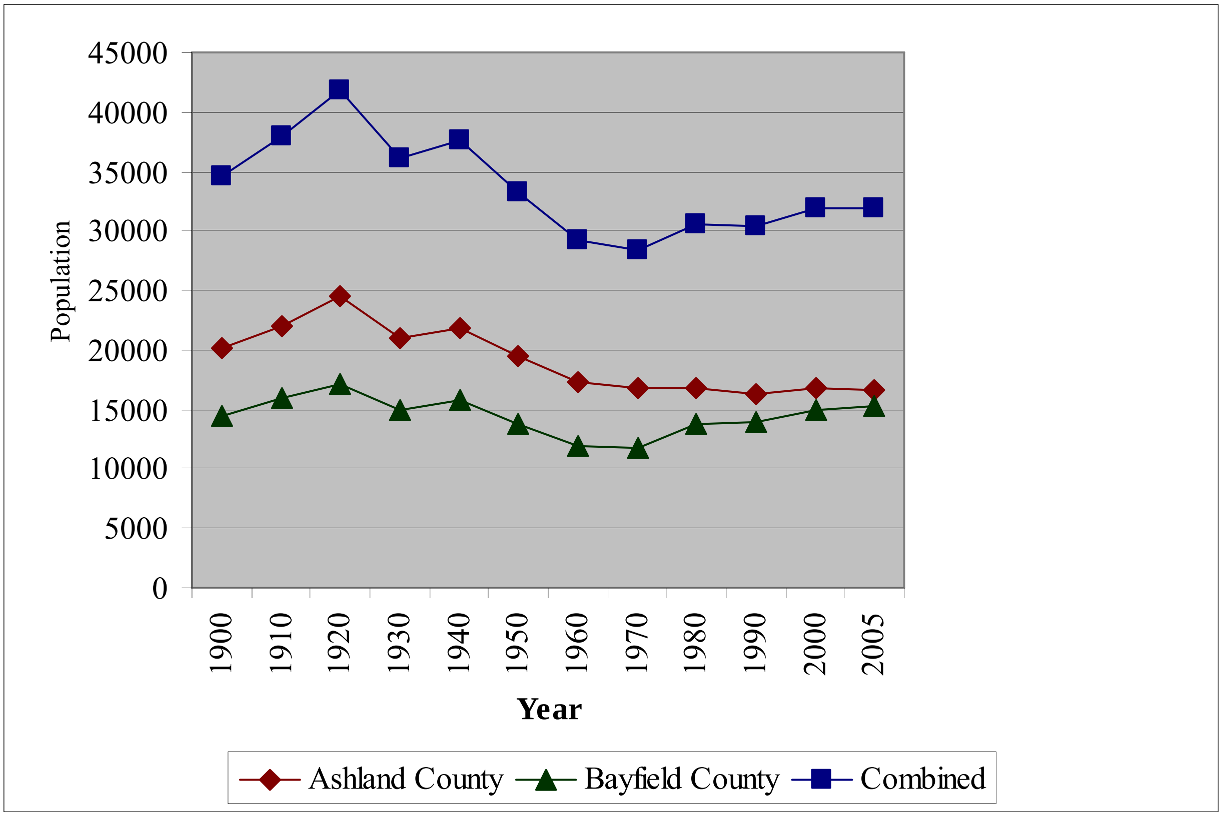


Figure 32. Population trends for Ashland and Bayfield Counties, Wisconsin, in the vicinity of Apostle Islands National Lakeshore (U.S. Census Bureau 2006).

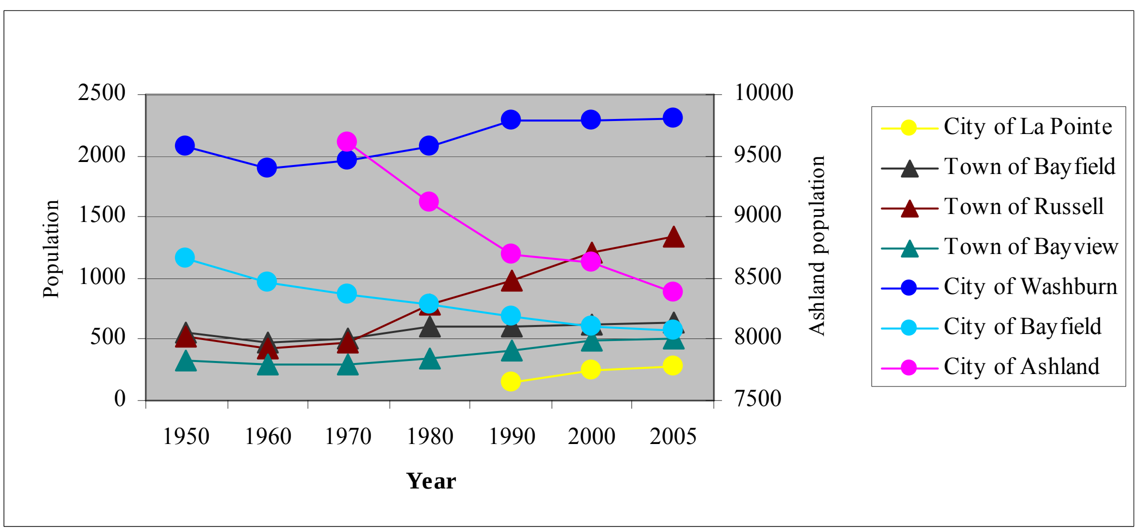


Figure 33. Population trends for towns and cities in the vicinity of Apostle Islands National Lakeshore, 1950-2005 (Ashland plotted on separate axis) (U.S. Census Bureau 2006).

Table 37. Current and projected numbers of year-round and seasonal housing in three Bayfield County townships closest to Apostle Islands National Lakeshore, 1980-2020 (Laumann 2003).

Town/ Year		1980	1990	2000	2005	2010	2015	2020	% change 1990-2020
Bayfield	year-round	202	220	261	272	287	301	316	44
	seasonal		97	200	224	259	294	329	239
Bayview	year-round	119	148	197	213	233	252	272	84
	seasonal		49	77	93	108	124	139	183
Russell	year-round	217	309	406	452	499	547	594	92
	seasonal		52	83	97	112	127	142	173
Total			875	1224	1351	1498	1645	1792	100

Around the nation, development pressures are affecting national parks, compromising views and increasing stormwater runoff problems, noise, and invasion by exotic species (Spillman 2006). In its 2001 Business Plan, APIS reported that "growth of private development in lands contiguous to the park has increased costs associated with resource protection" (NPS 2002d).

Visitor Use

In the last five years, APIS has evaluated visitor use patterns for a 2001 camping policy assessment, a wilderness environmental impact statement (NPS 2004a), and a fire management plan (NPS 2005a). From 1990 - 2001, APIS averaged 166,728 visitors per year (NPS 2004a), and in 2006, APIS had 189,050 visitors (APIS, Jim Nepstad, Chief of Planning and Resource Management, pers. comm. 2007). Many visitors tour the islands by tour boat or private boat, camp, and take tours of light stations and other offerings for visitors (Table 38). Recreational users of the park include "sailors, kayakers, motorboaters, hikers, sightseers, picnickers, swimmers, campers, fishers, hunters, photographers, birdwatchers, divers, skiers, snowshoers, berry pickers, nature students, and lighthouse buffs" (NPS 2004a). Most visitors to islands tend to stay along shorelines or in developed areas (NPS 2004a).

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 2005c). They may be terrestrial or aquatic. APIS is currently home to several terrestrial invasive species, including orange hawkweed (*Hieracium aurantiacum)*, spotted knapweed (*Centaurea maculosa*), and the gypsy moth (*Lymantria dispar*) (Burkman and Van Stappen 2003). Orange hawkweed is found on all 21 islands as well as the mainland unit in disturbed areas, but is a particular problem on the Oak Island sand spit. In 2003, spotted knapweed was found on Stockton Island, and a few plants were found at Little Sand Bay (Burkman and Van Stappen 2003). Gypsy moths were found on all islands in 2006 (except for North Twin, which was not sampled) with the highest concentrations on Stockton and Basswood Islands (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2007).

Table 38. Estimates of the number of people visiting specific areas at Apostle Islands National Lakeshore in 2006 (APIS, Jim Nepstad, Chief of Planning and Resource Management, pers. comm. 2007).

Island or Mainland Area	Day Users	Campers	Overnight Boaters	Total
Basswood Island	0	890	0	890
Bear Island	0	141	0	141
Cat Island	0	143	0	143
Devils Island	1,438	312	240	1,990
Hermit Island	0	52	0	52
Ironwood Island	0	189	0	189
Long Island	0	4	0	4
Manitou Island	0	171	0	171
Michigan Island	1,447	163	80	1,690
Oak Island	552	3,131	656	4,339
Otter Island	0	268	0	268
Outer Island	0	182	0	182
Raspberry Island	0	14	0	14
Rocky Island	60	807	68	935
Sand Island Light	0	190	0	190
Sand Island East Bay	1,535	2,597	1,040	5,172
South Twin Island	0	408	0	408
Stockton Island Presque Isle	6,291	3,168	7,016	16,475
Stockton Island Quarry Bay	0	1,316	0	1,316
York Island	0	854	0	854
Mainland West		111		
Total	11,323	15,111	9,100	35,534
Grand Tour (concessionaire boat)	25,950			25,950
Little Sand Bay	64,650		1,464	66,114
Meyers Beach	37,266			37,266
Sea Caves	~18,633			
Bayfield Visitor Center	24,186			24,186
Total				189,050

Aquatic invasive species may threaten the diversity or abundance of native species or the ecological stability of the waters into which they are introduced, or impair the water for some human use (MIDEQ 2002). 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). A new exotic species is discovered in the Great Lakes every 28 weeks (Ricciardi 2006).

Some non-native species have been deliberately introduced to Lake Superior. For example, of the lake's seven top predator fish, only three are native species (lake trout, burbot, and walleye), while the other four are introduced species (coho salmon, Chinook salmon, rainbow trout, and brown trout) (GLFC 2001). 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 Lake Superior. Other non-native species have been accidentally introduced, and some of these may be major threats to APIS aquatic resources.

Aquatic Invasives in the APIS Vicinity: Six aquatic invasive species are currently known to exist in the APIS vicinity: the sea lamprey (*Petromyzon marinus*), the Eurasian ruffe (*Gymnocephalus cernuus*), the threespine stickleback (*Gasterosteus aculeatus*), the spiny water flea (*Bythotrephes longimanus*), the Eurasian watermilfoil (*Myriophyllum spicatum*), and purple loosestrife (*Lythrum salicaria)*

Sea Lamprey**:** Probably the best known exotic species in Lake Superior is the sea lamprey. 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 - 17 years before migrating into the lake. Adults parasitize fish, especially lake trout. Lamprey were found in the Sand River in the past, and regular monitoring for them continues, although treatment is no longer necessary (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2007).

Eurasian Ruffe: Ruffe 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, and have been found in the Sand River since 1992 (Keppner et al. 1997). They were also found in a recent survey of APIS nearshore waters (Gorman and Moore 2006). Their population in the Great Lakes has grown explosively, threatening the populations of walleye, perch, and other smaller forage fish species (USGS 2004).

Threespine Stickleback: The threespine stickleback has been known in Lake Superior since at least 1994. It was found in APIS nearshore waters in a recent survey (Gorman and Moore 2006). It eats zooplankton, 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).

Spiny Water Flea: Spiny water flea 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 Presque Isle Bay in 1996 (Lake Superior Ecosystem Research Center 1997). 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 water flea 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 the spiny water flea (Jarnigan 1998).

***Eurasian Watermilfoil*:** The aquatic macrophyte Eurasian watermilfoil 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 watermilfoil has been established in Chequamegon Bay for more than 10 years (WDNR 2006d) and was found in Superior Bay near Barkers Island Marina in 2006 (MDNR 2006).

Purple Loosestrife: Purple loosestrife 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. 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). Purple loosestrife has been common on Long Island since 1988, and APIS initiated an intensive eradication program in 1992 (Judziewicz and Koch 1993).

Encroaching Aquatic Invasives: Numerous aquatic invasive species may be considered to be encroaching on APIS. Some of these may already be present, since extensive monitoring has not yet been conducted (Lafrancois and Glase 2005). Species known to exist in Lake Superior include the alewife (*Alosa pseudoharengus)*, zebra mussel (*Dreissenia polymorpha*), Asian clam (*Corbicula fluminea*), New Zealand mudsnail (*Potamopyrgus antipodarum*), round goby (*Neogobius melanstomus*), and white perch (*Morone americana*). Other species that are Great Lakes region invaders include quagga mussel (*Dreissenia bugensis*), fishhook waterflea (*Cercopagis pengoi*), the zooplankter *Daphnia lumholtzi*, rusty crayfish (*Orconectes rusticus*), the parasitic copepod *Neoergasilus japonicus*, European frog-bit (*Hydrocharis morsus-ranae*), curly-leaf pondweed (*Potamogeton crispus*), and flowering rush (*Botumus umbellatus*).

Alewife: The alewife 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).

***Zebra Mussel, Quagga Mussel, and Asian Clam*:** Invasions of zebra mussels and quagga mussels are a major concern in the Great Lakes 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) and live at greater depths and on softer substrates than zebra mussels (Dermott and Kerec 1997). The Asian clam 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 the Ashland harbor of

Chequamegon Bay in 1998, but appear to have disappeared by 2003 (USFWS 2003). Quagga mussels were first found in Lake St. Clair in 1988 (Minnesota Sea Grant 2006b) and are widespread in Lake Michigan (WDNR 2006e). 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).

New Zealand Mud Snail: The New Zealand mud snail is a tiny snail first discovered in the Duluth-Superior harbor in fall, 2005, probably introduced via ballast water from ocean-going ships. A tiny snail that reproduces asexually, it outcompetes important forage species for native trout and other fishes, but provides little nutrition to these fish (MDNR 2007).

***Round Goby*:** The round goby, 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).

***White Perch*:** The white perch, 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 the harbor 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).

***Fishhook Waterflea*:** The fishhook waterflea is an exotic species from the Caspian Sea. It is similar to the spiny water flea 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).

***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).

***Rusty Crayfish*:** The rusty crayfish has been invading northern lakes and streams, including 31 lakes and streams in 11 counties in Wisconsin (Gunderson 2006). They were reported in the Duluth – Superior Harbor in 1999, but have not yet been officially reported in the APIS watershed (HUC 04010301) (USGS 2007). They are easily transported as live fish bait, in bait bucket water, and in live wells, although it is illegal to use them as bait in Wisconsin inland waters. 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).

European Frogbit: The European frogbit, 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 was found in a canal at the edge of Lake St. Clair in 1997 (Hart et al. 2000).

***Curly-leaf Pondweed*:** Curly-leaf pondweed 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).

Flowering Rush: Another Eurasian aquatic macrophyte, the flowering rush, 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).

Introduction Pathways and Control Strategies: Numerous pathways, both natural and human-made, exist to transfer aquatic species from one location to another. Ludwig 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.

The three most apparent pathways for the further introduction of aquatic invasives at APIS are ballast water from commercial ships, recreational boating, and bait buckets. The WDNR has established the control of ballast water discharges as its highest priority for preventing the spread of aquatic invasive species (WDNR 2003c). 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). Wisconsin has established a goal of participating in the development of a national or regional ballast water management program, along with committing itself to assist in the search for ballast water treatment technologies (WDNR 2003c). However, a proposal known as HWY H2O could double the volume of freight shipped on the Great Lakes by increasing the number of freighters moving through the St. Lawrence Seaway, possibly further increasing the threat of exotic invasive species (Associated Press 2006). The U.S. and Canadian governments are also currently conducting a joint study to evaluate the infrastructure needs of the Great Lakes St. Lawrence Seaway system. A final report on the study, initiated in 2003, is due in spring 2007 (GLSLS Study Team 2006).

In the area of recreational boating, Wisconsin's "Clean Boats, Clean Waters" program uses volunteers to educate the public and to check boats and trailers for invasive species (UWEX 2006). Wisconsin law prohibits the placement of any boat, trailer or equipment in navigable water if it has aquatic plants or zebra mussels attached (WDNR 2003c).

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 was 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 2000 study conducted by the USFWS 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. A 1994 study estimated that Wisconsin's bait industry generates an estimated $29.5 million of retail business annually, and that 61% of the bait volume is harvested from the wild (Meronek 1994).

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). Wisconsin is currently examining these protocols for possible implementation (WDNR 2003c). Some APIS staff attended a workshop held to train GLKN parks in the HACCP process in spring 2006.

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 39) (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 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. Lake Superior fisheries resources in Wisconsin are managed by the WDNR (WDNR 2000b) and guided by its Lake Superior Basin Plan, with emphasis on natural reproduction, habitat protection, and prevention of further additions of nonindigenous species, as emphasized in the GLFC's Fish Community Objectives for Lake Superior (Horns et al. 2003). With some notable exceptions in embayments and tributaries, the status of fish habitat in the lake is generally good at this time (GLFC 2001).

Table 39. 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

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 from Michigan and Wisconsin, at a value of $151,258. Lake herring, chub, smelt, and siscowet were also commercially important species in 2000, although the market for siscowet has declined because of its high fat content.

In 2004, 27 charter boat captains were active on the Wisconsin waters of Lake Superior, carrying 2,510 anglers for a total of 14,614 angler hours. These numbers are fairly consistent with previous years' numbers, but are down from the high of 49 captains and 5,174 anglers reached in 1989 (Zunker 2004). In 2004, lake trout accounted for 86.7% of the catch (3,967 fish), with coho salmon and Chinook salmon making up 4.5% and 5.3% of the catch, respectively (Zunker 2004). Private anglers made 3,179 ice fishing trips in the APIS management unit of Lake Superior during 2004 and caught 2,882 fish, with lake trout making up 62.1% of the catch, followed by siscowet (19.2%) and whitefish (15.9%) (Zunker 2004). The WDNR also estimates that 239 anglers took 236 lake trout from open water at Sand Bay in 2004.

Although Gorman and Moore (2006) assessed APIS nearshore fish population densities and community structures, their report did not provide insight into whether fish populations were increasing or declining, or what a sustainable harvest might be. Stockwell et al. (2005) examined fish population trends for all of Lake Superior from 1978 – 2004 and found that mean biomass of all fish species caught in bottom trawls increased in 2004, halting a downward trend that began in the early 1990s. Many of Stockwell's sites were around APIS; further evaluation of this data along with Gorman and Moore's data and older data (such as the National Biological Survey's 1995 report) may provide site and species-specific answers that would be useful in evaluating APIS fish resources.

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 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 people 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. Lower oxygen levels and warmer temperatures in inland waters may promote phosphorus release and increase mercury release and uptake by biota (Kling et al. 2003). Non-point source pollution may also increase because of higher intensity precipitation events. Lake Superior may also experience increased salinity because of evaporative water loss combined with its long residence time (McCarthy et al. 2001).

Overall, biological productivity will likely increase as temperatures increase, but existing natural communities may be greatly changed. However, Lake Superior's productivity may decrease because of a longer summer stratification period and a decrease in nutrient regeneration rates

(Kling et al. 2003). Populations of coldwater fish may decline. Whitefish reproduction may be threatened with loss of winter ice cover (Kling et al. 2003). Some habitats may be reduced, especially wetlands and their vegetation communities. Species that depend on alpine or arctic habitats may be unable to survive (Malcolm and Pitelka 2000), while invasive species may be more successful (Kling et al. 2003).

The physical effects of climate change are discussed with other physical processes in the following section.

Impacts of Physical Processes

APIS's sandscapes and other landscapes are influenced to a large extent by physical processes, including erosion and deposition moderated by changes in lake levels and climate, and human uses. In a 1901 report titled "Wisconsin Shore of Lake Superior," prominent Wisconsin geologist and anthropologist George Lucius Collie wrote: "The (Apostle) islands are simply a phase in the history of the lake, their existence or their obliteration depending on relatively slight fluctuations of the lake level" (Collie 1901). Lake Superior levels are influenced by numerous factors, including isostatic rebound, fluctuations in precipitation, or water diversions, such as the one from Hudson Bay (Engstrom 1985).

Postglacial isostatic rebound is raising the northern and eastern shores of Lake Superior more rapidly than the southwestern shore (Engstrom 1985), causing an estimated rise in lake level in the Duluth area, near APIS, of 0.21 m/century (LSBP 2006). Consequences of this rising lake level may include the separation of Gull Island from Michigan Island in the mid-1800s, the presence of lagoons on the interiors of spits and cuspate forelands, and the disappearance of rapids from streams on the Wisconsin shoreline of Lake Superior (Engstrom 1985). A rise in average lake level of 0.12 m between 1970 and 1983 is also credited with "widespread erosion" of spit and cuspate foreland beaches (Engstrom 1985).

Most climate models examined by Lofgren et al. (2002) predict that Lake Superior levels will drop from 0.01 – 0.47 m in this century, although one model predicts a lake level increase of 0.11 m because of increased precipitation. Collie noted that lower lake levels (outside the range currently being predicted) could cause some islands to become larger, while others would disappear as islands and become part of the mainland: "A lowering of the lake to the amount of 10 feet (3 m) would cause Sand Island to be joined to the mainland. A reduction in level of 50 feet (15 m) would result in the obliteration of the following islands: Raspberry, York, Oak, and Basswood. If the lake should be lowered 60 feet (18 m), Bear Island would be joined to Raspberry, Otter to Oak, South Twin to Rocky, Michigan to Madeline, and Madeline to the mainland" (Collie 1901). Park staff have concerns about such possible large-scale land configuration changes, since the park has a fixed boundary (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2007).

However, climate change may also lead to increased erosion by creating a longer ice-free season (Kling et al. 2003). Ice cover protects the beaches from the strong west/northwesterly storm winds and waves of winter, and the mild winter of 1982-83 may also have increased beach erosion by decreasing ice cover (Engstrom 1985). Erosion is also an issue for APIS's glacial till and clay bluffs. Increased wave action, as well as vegetation loss and overland flow, could increase the likelihood of mass wasting and threaten historic light stations on Outer, Raspberry, and, to a lesser extent, Michigan Islands (Van Stappen 1999).

An assessment of the potential for coastal change associated with climate change was conducted for APIS and two other national lakeshores by the USGS in 2006 (Pendleton et al. 2006). Three geologic variables (geomorphology, historic shoreline change rate, and regional slope) and three physical process variables (significant wave height, annual ice cover, and lake-level change) were used to develop a Change Potential Index (CPI). For APIS, the most influential variables were geomorphology, coastal slope, and significant wave height. In general, areas of unconsolidated sediment with low regional coastal slope and high wave energy were considered most likely to experience change.

Nearly 300 km of APIS shoreline were evaluated; 21% was classified as being at very high change potential, including Long Island and parts of Cat, Devils, Ironwood, Michigan, North Twin, Outer, Rocky, South Twin, and Stockton Islands (Figure 34). An additional 30% was classified as having high change potential, including parts of Bear, Cat, Devils, Ironwood, Michigan, North Twin, Oak, Otter, Outer, Rocky, South Twin, and Stockton Islands. The remaining 49% was classified as having moderate and low change potential, including the flatter and more sheltered islands (Basswood, Eagle, Hermit, Manitou, Raspberry, Sand, and York Islands), portions of islands (Bear, Oak, and Otter Islands), and all of the mainland unit.

In addition to these major geologic processes, human activities affect the rates of erosion and deposition in APIS. Historical disturbances in APIS included cordwood docks, logging camps, cabins, boat docks, and sand mining (Van Stappen 1999), and human impacts continue today. For example, in 1987 a solid dock was built in front of the Michigan Island light station. The area to the west of the dock appeared to be eroding at a very high rate in the next several years. After monitoring, the Michigan Island dock was modified in 1993 to reduce its impact on erosion and to increase its usefulness for docking. Before the modifications, the entire dock was periodically engulfed by sand (Van Stappen 1999). However, problems at the dock continue, and further modifications may yet be needed (APIS, Julie Van Stappen, Branch Chief, Natural Resources, pers. comm. 2007).

Visitor use on sandscapes is relatively high, and sandscape vegetation is readily damaged by human trampling that occurs during the growing season (Van Stappen 1999). Several researchers have assessed the effects of human foot traffic on the islands; Middleton (1980), on Raspberry, Oak, Outer, and Rocky Island sandscapes, and Kraft (1982) and Milfred and Kraft (1984, 1987), on the Stockton Island tombolo (as summarized in Van Stappen 1999). As a result, all APIS sandscapes are monitored for human-caused erosional damage on a regular schedule (Van Stappen 1999).

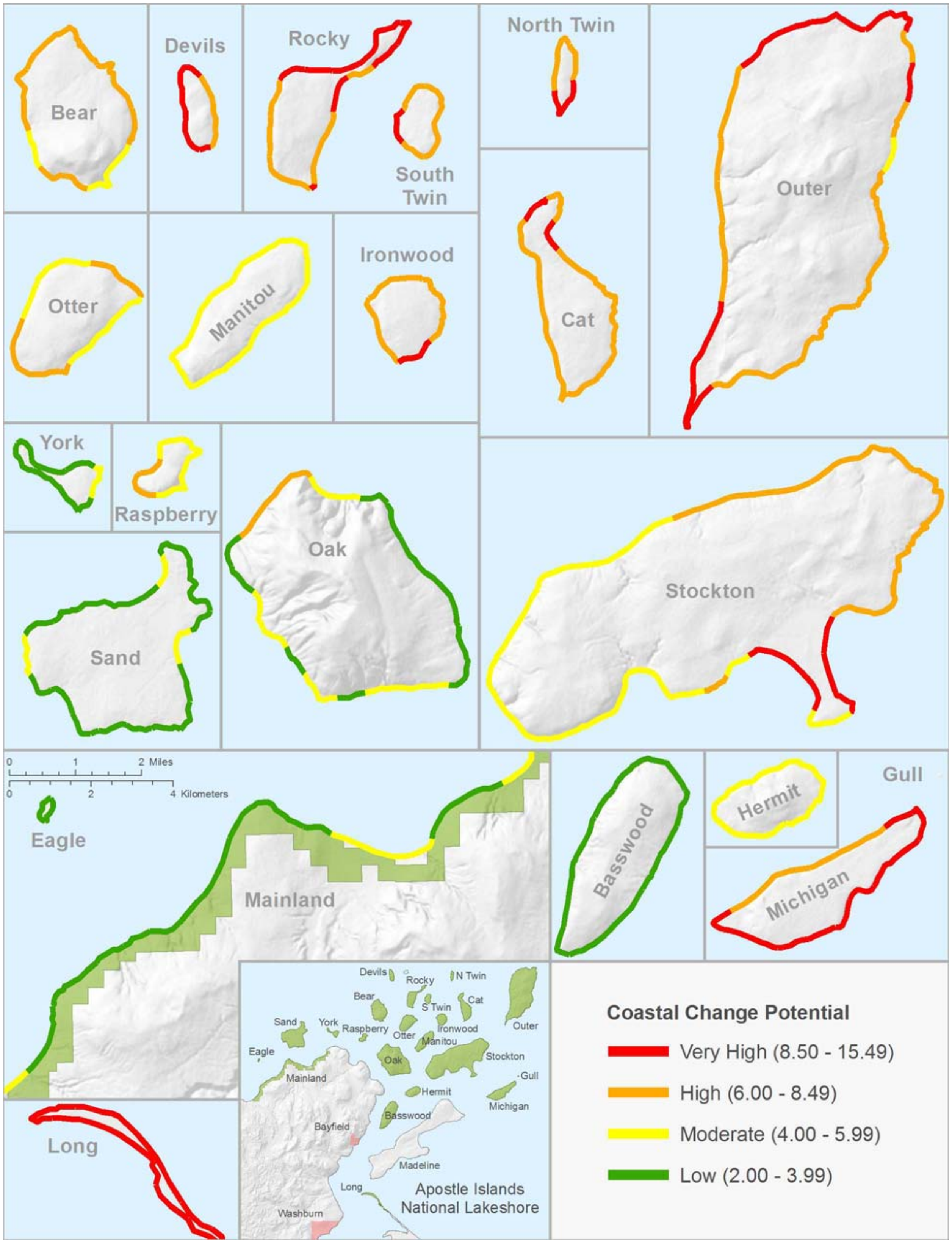


Figure 34. Classifications of relative coastal change potential for Apostle Islands National Lakeshore (after Pendleton et al. 2006).

Conclusions

Table 40 indicates the current condition of APIS water resources and potential for degradation. 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 lakewide impacts. The main lakewide contamination issue is regional atmospheric deposition of persistent bio-accumulative chemicals, including PCBs, dioxins/furans, and mercury. The Northern States Power Company – Wisconsin Bay Front facility at Ashland is a local source of mercury and dioxins, as well as PAHs. 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. Indicators such as dissolved oxygen and water clarity continue to reflect that status, although water clarity is sometimes compromised by sediment losses from the Bayfield Peninsula. A recent study has suggested an increase in the proportion of the zooplankton biomass contributed by cladocerans in western Lake Superior. Other data show that lakewide nitrate has been slowly increasing over the historical period. These trends need further investigation to determine how much change may occur in the lake's trophic status. In addition, climate change may affect the lake in as yet unknown ways, including changes in water levels, water chemistry, and biological communities.

Aquatic invasive species are also an increasing problem in western Lake Superior, especially in the Duluth area. 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. Recreational boats could cause physical damage to sensitive shoreline resources as well as providing an additional source of invasive species.

Mainland Unit Streams

Mainland unit streams are generally of high quality, flow through undeveloped forested areas, and support high quality biological communities. However, the Sand River periodically experiences flash floods which affect aquatic organism habitat and carry tons of high-phosphorus sediment into Sand Bay, and similar heavy sediment losses have been noted on other Bayfield Peninsula streams. The fish consumption advisory for Lake Superior fish extends to the first impassible barrier on the lake's tributaries, reflecting the movement of many species of fish to and from the lake, but perhaps indicating that atmospheric deposition of regional and even local pollutants also occurs in these watersheds. Invasive species are rated as an existing problem because of the presence of Eurasian ruffe in the Sand River.

The mainland unit's watershed is sparsely populated at this time, but increased residential development using septic systems could decrease the quality of stream baseflow. Residential development or road building could increase the runoff of contaminants into the streams. Increased logging on county, state, tribal or private forest land without implementation of best management practices could have similar effects. The effects of a closed landfill in the Town of

Table 40. Potential for degradation of water resources in Apostle Islands National Lakeshore.

Stressor/ Environmental Indicator	Lake Superior open waters	Mainland Unit Lake Superior coastline and bays	Mainland Unit streams	Islands Lake Superior coastline and bays	Islands inland waters and wetlands
Water quality indicators					
Water clarity	OK	PP	EP	EP	NA
Nutrients	PP	PP	EP	PP	PP
Dissolved oxygen	OK	OK	OK	PP	EP
Fecal bacteria	OK	OK	NA	PP	OK
Sediment	OK	PP	EP	EP	NA
Biological indicators					
Zooplankton populations	PP	PP	NA	PP	PP
Fish consumption advisories	EP	EP	EP	EP	EP
Land use-related stressors					
Regional atmospheric deposition and air pollution	EP	EP	EP	EP	EP
Local air pollution sources	PP	PP	PP	PP	PP
Wastewater discharges covered by NPDES permits	OK	NA	NA	PP	NA
Stormwater	OK	OK	OK	PP	NA
Agriculture	OK	OK	OK	OK	NA
Landfills	OK	PP	PP	OK	NA
Septic systems	OK	PP	PP	OK	OK
Residential development	OK	PP	PP	PP	NA
Road building	OK	PP	PP	NA	NA
Logging	OK	PP	PP	NA	NA
Recreational and commercial use					
Land-based visitor use intensity	NA	PP	OK	EP	OK
Recreational boating	PP	PP	NA	PP	NA
Commercial tour boating	PP	OK	OK	PP	NA
Commercial fishery	OK	OK	NA	OK	NA
Great Lakes shipping	EP	PP	NA	PP	NA
Invasive species	EP	EP	EP	EP	EP
Climate change	PP	PP	PP	PP	PP

Definitions: EP= existing problem; PP = potential problem; OK= no detectable problem
shaded =limited data; NA= not applicable.

Russell on the Sand River is unknown. No communities discharge stormwater in the mainland unit's watershed, and agriculture is a minor land use.

Mainland Unit Lake Superior Coastline and Bays

The coastline and bays of the mainland unit are generally thought to be of high quality, although supporting data are sparse. However, these water resources occur at the intersection of the mainland unit streams with the open waters of Lake Superior, and so share the stressors of both those environments. The impact on bays of the high level of sediment and phosphorus carried by streams during runoff events is largely unknown, although a sediment bar has formed in Sand Bay reaching out toward Sand Island. Residential development, road building, and logging impacts on the streams would also affect the bays. Recreational boating use could result in fuel spills, human waste or other discharges, physical damage to shorelines and submerged aquatic vegetation, and the introduction of aquatic invasive species. Land-based visitor use is rated as a potential problem because of the heavy use of Meyers Beach and its lack of sanitary facilities.

Island Lake Superior Coastlines and Bays

Island coastlines and bays are contiguous with Lake Superior open waters and subject to the same stressors, including changes in the zooplankton community, nitrate enrichment, and climate change. In addition, stressors may arise from land use conditions and practices on each island. The current designation of many of the islands as wilderness limits internal land use changes. However, many island coastlines and bays receive intense recreational boating use, which could result in fuel spills, human waste or other discharges, physical damage to shorelines and submerged aquatic vegetation, and the introduction of aquatic invasive species.

Generally, island bays exhibit good water quality and healthy biota, and show limited impact from recreational use in the studies done to date. Existing problems include atmospheric deposition of persistent bio-accumulative pollutants, fish consumption advisories resulting from those pollutants, and invasive species such as the spiny water flea in Stockton Island's Presque Isle Bay. Sediment plumes from the Peninsula associated with large storm events have been observed to extend out into the islands. Human trampling is an existing problem on some island sandscapes that is currently being monitored, and shoreline erosion is a major problem on many islands, especially on the open-lake sides.

Additional potential problems specific to the islands include human population growth in and around the mainland communities of Ashland, Bayfield, Washburn, and Red Cliff, which may increase the number or size of wastewater treatment plants and their associated discharges and the volume of stormwater runoff, and risks associated with fuel or other spills from commercial tour boats. We also ranked fecal bacteria, nutrients, and dissolved oxygen as potential problems because we believe they are worthy of expanded or continued monitoring in intensively used bays.

Island Inland Waters and Wetlands

Island inland waters and wetlands are numerous but generally small and not well documented. The lagoons on Michigan, Outer, and Stockton Islands are shallow, acidic, and oligotrophic, and sometimes low in dissolved oxygen. The phytoplankton and zooplankton communities often overlap with those of Lake Superior, which indicates that wave washover is a source of at least part of the lagoons' water. Water level changes (either positive or negative) caused by climate change could lead to the disappearance of these lagoons.

Most of the numerous small wetlands found on the islands have not been studied in detail. A few of the larger streams on Oak and Stockton Islands have been sampled, but most of the ephemeral streams on all islands remain unstudied. Vernal pools have been noted on some islands, but these are also largely undocumented. Potential threats to island inland waters include atmospheric deposition of persistent bio-accumulative contaminants and possibly nitrate, and invasive species that may enter from Lake Superior waters. Invasive species are rated as an existing problem because of the purple loosestrife problem on Long Island. Fish contamination advisories are also rated as an existing problem because, although formal advisories have not been issued, game fish (northern pike) in Stockton and Outer Island lagoons have contained mercury in excess of the USEPA health criterion.

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 APIS (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 APIS. A table comparing our monitoring recommendations with the vital signs monitoring program is included as Table 41.

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 APIS. We concur with many of those and incorporate some of them in the following recommendations.

Water quality and biotic evaluation and monitoring:

- Routine water quality monitoring for Lake Superior and lagoon sites should continue as outlined in GLKN protocols and Axler et al. (2006). Consideration should be given to including mainland bay sites, such as Little Sand Bay and Mawikwe Bay. Regular monitoring is necessary to understand the condition of water resources and to detect and react to changes in a timely manner. The monitoring plan has been designed to examine sets of standard parameters at regular intervals with limited resources. Monitoring results should be examined to determine whether additional APIS-specific parameters or increased sampling frequency are warranted.

- The potentially ecologically significant vernal pools and the abundant and diverse wetland resources need additional study and long-term monitoring. Vernal pools may provide important habitat for rare and endangered species, including but not limited to amphibians and invertebrates, but their locations and functions are not currently well known. Meeker’s work (1998, 2000, 2002) has documented wetland flora and established permanent sampling transects for many of the major wetlands, but wetland flora for minor wetlands, and wetland plankton and invertebrate fauna, are nearly undocumented for APIS.

- An assessment of all APIS 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 APIS. 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 degradation, through examination of periphyton, benthic macroinvertebrates, and fish assemblages, and assessing the quality of the physical habitat structure. The GLKN protocol for wadeable streams should be considered for application to the Sand River, Saxine Creek, and perennial streams on Stockton and Oak Islands.

Table 41. 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
Continued updating of Lake Superior water quality data, including nearshore areas, bays and lagoons	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 APIS-specific parameters or increased sampling frequency are warranted.
Wetland conditions and biota assessment	Water level fluctuations, aquatic plant communities	Wetland plankton and invertebrate fauna are not well known.
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)	Protocol for wadeable streams should be considered for application to the Sand River, Saxine Creek, and perennial streams on Stockton and Oak Islands.
Water quality and biotic investigations of intermittent streams	Core water quality suite, advanced water quality suite (including macroinvertebrate indices)	These may be refugia for rare invertebrates, fish, and organisms with unique physical adaptations.
Aquatic invasives monitoring and control program	Plant and animal exotics	
Monitoring of 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.

Table 41. Crosswalk of report recommendations with the Vital Signs Monitoring program of the NPS Great Lakes Inventory and Monitoring Network (Route and Elias 2006) (continued).

Recommendation	Vital Signs	Comments
Evaluation of local and regional air pollutant impacts	Air quality, trophic bioaccumulation	
Water and sediment montitoring 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	
Monitoring human impacts on sandscapes	Land use - fine scale	

- Intermittent streams at APIS need further water quality and biological investigation and monitoring; they have unique hydrologic regimes, may serve as refugia for rare or endangered invertebrates and fish, and may be home to organisms with novel physiological adaptations that have not been investigated (Lafrancois and Glase 2005).

- Continued cooperation with WDNR, USFWS, and the tribes is encouraged to ensure that resource protection goals for APIS fish populations are met.

- The genetic makeup of coaster brook trout stocks around the islands should be investigated, and the need for a locally developed brood stock more appropriate to the islands should be evaluated (Lafrancois and Glase 2005).

Stressor monitoring, evaluation, and management:

- Surveys for known and encroaching aquatic invasive species in APIS 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. The spread of existing invasive species on the islands from around disturbed areas, especially lighthouses and other high use areas, should be monitored.

- Specific pollutants in local and regional air emissions and their potential effects on APIS water resources should be evaluated, and monitoring should be conducted where warranted. Persistent bio-accumulative pollutants are one of the major stressors for APIS resources.

- Water level fluctuations should be monitored at unique island habitats such as splash pools and temporary beach habitats, and losses should be documented. Climate change is projected to decrease lake levels as well as increase erosion.

- Water and sediment monitoring should be evaluated for heavily-used recreational boating areas, including Presque Isle Bay, 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 (Clements and Cox 2006).

- Locations of stormwater discharges on the Bayfield Peninsula should be documented and evaluated for potential impacts. Stormwater contains a number of potentially toxic and damaging substances, and their impacts on APIS are currently undocumented.

- The WDNR proposal to quantify the effects of erosion control practices on Lake Superior tributaries by monitoring suspended solids and flow (WDNR 2005f) should be supported, and the results examined for possible impacts or mitigation opportunities for mainland unit streams. Monitoring efforts should include sediment transport during major storm events, and the resulting sediment plume should be tracked in Lake Superior to determine the extent of sediment travel within APIS. Sediment loss from Bayfield Peninsula streams are a major source of turbidity after large storms, and the effects of phosphorus and other possible nutrient loading is undocumented.

- Population trends in the watershed of the mainland unit should be monitored, and ways to monitor the effects of local land use practices (logging, road building, and residential development) on APIS mainland unit waters should be developed and implemented in proportion to increased use.

- Effects of recreation on shoreline habitat and shoreline processes should continue to be monitored at heavily visited sites. In particular, physical damage to sensitive shoreline resources from boat wakes, groundings, or other recreational boating impacts need to be assessed and monitored.

- The town of Russell landfill should be discussed with WDNR specialists to define whether or not it is in the Sand River basin and to determine if further investigation of the site is warranted. Landfill leachate contains oxygen-depleting as well as toxic substances that could affect the Sand River or Sand Bay.

Planning:

- A plan should be developed to mitigate impacts of future climate change where feasible strategies can be identified. APIS is located at the contact zone between the northern hardwood and the boreal forest types, so changes in climate may produce significant changes in vegetation. Other risks include changes in water levels, losses of rare species, and increased pressure from exotic species.

Education:

- Emphasis should be placed on boater education about current regulations and risks posed by fuel spills, human waste discharge, or discharge of bilge water or bait buckets into nearshore Lake Superior waters. Boater activity is the largest easily controllable source of pollutants to island bays.

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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 from Environmental Systems Research Institute, Inc. (ESRI). Maps are shown in the NAD 1983 UTM Zone 15N coordinate system. Spatial data obtained in other datums or coordinate systems were re-projected using ArcGIS. Wisconsin based spatial data were in the WTM system, a UTM-like system optimized for the state and based on NAD 1983, 1991 adjustment. GIS data obtained from the Michigan Center for Geographic Information Data Library were typically in the Michigan GeoRef coordinate system based on NAD 1983 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:

Civil divisions, such as villages and cities, are from the Wisconsin Office of Land Information Services (OLIS 1999). State and county roads are from the Wisconsin Local Roads (WISLR) database from the Wisconsin Department of Transportation as prepared by the Wisconsin Department of Natural Resources (WDNR 2004d). National Lakeshore boundaries (the 0.4 km extension onto Lake Superior and the mainland unit interior boundary) are from the National Park Service (NPS 2001). Streams, lakes, and shorelines on most maps are from the Wisconsin Department of Natural Resources 1:24000 hydrology coverage for the state (WDNR 2005j). Given the scale of most maps, only the perennial streams at the 1:24k source are shown. Figures at a larger scale (5, 10, 11, 13, 14, 15, and 16) display perennial, intermittent, and drainages included in the 1:12000 stream coverage developed by the NRCS as part of the soil survey process (NRCS 2005). The hillshade image used in Figures 1 and 11 is from the WDNR, 2001.

The Midwest regional location map frame in Figure 1 utilized lake, state, county, and province data obtained from ESRI, 1999, ESRI Data & Maps Series. The western Lake Superior location map in Figure 1 utilized county boundaries for Wisconsin, Minnesota, and Michigan (WDNR 1992, MDNR 1993, and Michigan Center for Geographic Information 2006, respectively).

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 the wilderness areas boundary in Figure 2 and the Pleistocene geology in Figure 8.

In some cases, geoprocessing tools were applied to cited data sources to derive new map features. These sources were qualified with “derived from”. The bedrock geology shown in Figure 7 was created by merging the three digital maps cited. Lake Superior bathymetry in Figure 9 was derived by interpolating depth soundings and depth contours from NOAA electronic navigation charts. The watershed population in Figure 22 was created by intersecting census blocks with the watershed boundary.

Several new point feature maps (Figure 17 air releases, Figure 18 NPDES permits, and Figure 21 docks) were developed by starting with available coordinate information, such as latitude and longitude coordinates for some discharge points, and refining the locations as possible using orthophotos, topographic maps, addresses, textual descriptions, and small scale printed maps.

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Appendix C. Soil associations for individual islands, Apostle Islands National Lakeshore (NRCS 2006a, b).

SOIL MAPPING UNITS		ISLAND NAME AND NUMBER OF HECTARES				
NUMBER	**NAME**	**RASPBERRY**	**YORK**	**EAGLE**	**SAND**	**DEVILS**
226A	ALLENDALE LOAMY FINE SAND, 0 TO 3 PERCENT SLOPES	0.0	0.0	0.0	63.7	0.0
3403A	LOXLEY, BESEMAN, AND DAWSON SOILS, 0 TO 1 PERCENT SLOPES	0.8	0.0	0.0	57.6	3.6
3423A	RIFLE PEAT, 0 TO 1 PERCENT SLOPES	0.0	1.2	0.0	0.0	0.0
3608	DEERTON-BROWNSTONE COMPLEX, 0 TO 15 PERCENT SLOPES, VERY STONY	0.0	4.9	0.0	51.9	17.2
3826B	ALLENDALE-WAKELEY-KINROSS COMPLEX, 0 TO 6 PERCENT SLOPES	2.2	10.5	0.0	0.0	0.0
405A	LUPTON, CATHRO, AND TAWAS SOILS, 0 TO 1 PERCENT SLOPES	1.2	0.0	0.0	38.0	0.0
479A	LERCH-HERBSTER COMPLEX, 0 TO 3 PERCENT SLOPES	0.0	0.0	0.0	13.6	0.0
480B	PORTWING-HERBSTER COMPLEX, 0 TO 6 PERCENT SLOPES	34.6	0.0	0.0	405.3	0.0
481	CORNUCOPIA SILT LOAM, 6 TO 45 PERCENT SLOPES	0.0	0.0	0.0	4.0	0.0
597A	MEEHAN SAND, BEACHES, 0 TO 2 PERCENT SLOPES	0.4	0.0	0.0	0.0	0.0
5A	ARNHEIM MUCKY SILT LOAM, 0 TO 1 PERCENT SLOPES, FREQUENTLY FLOODED	0.0	0.0	0.0	9.7	0.0
603B	REDRIM VERY COBBLY SAND, 0 TO 6 PERCENT SLOPES, VERY STONY	0.0	5.1	0.0	9.8	20.8
605B	LAPOIN LOAM, 0 TO 6 PERCENT SLOPES	0.0	0.0	0.0	9.3	0.0
610B	ZEBA SANDY LOAM, 0 TO 6 PERCENT SLOPES, VERY STONY	0.0	0.0	0.0	76.2	33.2
611B	ABBAYE-LAPOIN COMPLEX, 0 TO 6 PERCENT SLOPES	0.0	10.5	8.4	31.4	0.0
705	CUBLAKE-CROSWELL-ASHWABAY COMPLEX, 0 TO 15 PERCENT SLOPES	5.0	0.0	0.0	0.0	3.4
713	KELLOGG-ALLENDALE-ASHWABAY COMPLEX, 2 TO 15 PERCENT SLOPES	44.1	23.1	0.0	31.5	38.2
753B	SEDGWICK-MUNUSCONG COMPLEX, 0 TO 6 PERCENT SLOPES	0.0	4.2	0.0	300.3	0.0
756	SUPERIOR-SEDGWICK COMPLEX, 0 TO 15 PERCENT SLOPES	8.5	41.8	0.0	20.7	0.0
7C	BEACHES, 2 TO 12 PERCENT SLOPES	1.2	2.1	0.0	5.1	0.0
92F	UDORTHENTS, RAVINES AND ESCARPMENTS, 25 TO 60 PERCENT SLOPES	17.2	6.8	0.0	22.5	9.4
	Totals	115.1	110.2	8.4	1150.4	125.9

Appendix C. Soil associations for individual islands, Apostle Islands National Lakeshore (NRCS 2006a, b) (continued).

SOIL MAPPING UNITS		**ISLAND NAME AND NUMBER OF HECTARES**				
NUMBER	**NAME**	**OUTER**	**NORTH TWIN**	**ROCKY**	**CAT**	**SOUTH TWIN**
1385B	CUBLAKE-KEWEENAW STONY COMPLEX, 0 TO 6 PERCENT SLOPES	0.0	0.0	26.7	0.0	0.0
203	WAKEFIELD FINE SANDY LOAM, 1 TO 18 PERCENT SLOPES, STONY	328.9	0.0	0.0	0.0	0.0
226A	ALLENDALE LOAMY FINE SAND, 0 TO 3 PERCENT SLOPES	20.7	0.0	52.8	0.0	45.7
319A	TONKEY SANDY LOAM, 0 TO 2 PERCENT SLOPES	46.7	0.0	0.0	0.0	0.0
3403A	LOXLEY, BESEMAN, AND DAWSON SOILS, 0 TO 1 PERCENT SLOPES	0.0	0.0	4.5	0.0	0.0
3423A	RIFLE PEAT, 0 TO 1 PERCENT SLOPES	24.7	0.0	0.0	0.0	0.0
3512D	MENOMINEE LOAMY SAND, 15 TO 30 PERCENT SLOPES	1.3	0.0	0.0	0.0	0.0
3608	DEERTON-BROWNSTONE COMPLEX, 0 TO 15 PERCENT SLOPES, VERY STONY	127.3	28.0	46.7	93.7	0.0
376B	TULA FINE SANDY LOAM, 1 TO 6 PERCENT SLOPES, STONY	81.1	0.0	0.0	0.0	0.0
3826B	ALLENDALE-WAKELEY-KINROSS COMPLEX, 0 TO 6 PERCENT SLOPES	13.8	0.0	0.0	0.0	0.0
405A	LUPTON, CATHRO, AND TAWAS SOILS, 0 TO 1 PERCENT SLOPES	61.4	0.0	1.7	7.7	0.0
480B	PORTWING-HERBSTER COMPLEX, 0 TO 6 PERCENT SLOPES	0.0	23.8	4.7	0.0	0.0
481	CORNUCOPIA SILT LOAM, 6 TO 45 PERCENT SLOPES	1.2	0.0	0.0	0.0	0.0
500B	CROSWELL SAND, 0 TO 6 PERCENT SLOPES	10.5	0.0	0.0	0.0	0.0
509B	GOGEBIC FINE SANDY LOAM, 1 TO 6 PERCENT SLOPES, VERY STONY	0.0	0.0	0.0	0.0	44.4
514B	IOSCO LOAMY SAND, 0 TO 4 PERCENT SLOPES	585.9	0.0	38.1	0.0	0.0
597A	MEEHAN SAND, BEACHES, 0 TO 2 PERCENT SLOPES	2.7	0.0	27.5	0.0	0.0
598A	WURTSMITH SAND, BEACHES, 0 TO 3 PERCENT SLOPES	0.0	0.7	4.5	0.0	2.0
599C	GRAYLING SAND, BEACHES, 2 TO 12 PERCENT SLOPES	21.0	0.0	0.0	0.0	0.0
5A	ARNHEIM MUCKY SILT LOAM, 0 TO 1 PERCENT SLOPES, FREQUENTLY FLOODED	21.5	0.0	0.0	0.0	0.0
603B	REDRIM VERY COBBLY SAND, 0 TO 6 PERCENT SLOPES, VERY STONY	0.0	9.7	0.0	7.4	0.0
610B	ZEBA SANDY LOAM, 0 TO 6 PERCENT SLOPES, VERY STONY	19.0	0.0	0.0	21.4	0.0
611B	ABBAYE-LAPOIN COMPLEX, 0 TO 6 PERCENT SLOPES	0.0	2.0	0.0	0.0	0.0
614B	ABBAYE-ZEBA COMPLEX, 0 TO 6 PERCENT SLOPES, VERY STONY	0.0	0.0	0.0	76.3	0.0
705	CUBLAKE-CROSWELL-ASHWABAY COMPLEX, 0 TO 15 PERCENT SLOPES	105.0	0.0	4.1	1.6	24.0
712	MORGANLAKE LOAMY SAND, 0 TO 15 PERCENT SLOPES	719.5	0.0	0.0	0.0	0.0

Appendix C. Soil associations for individual islands, Apostle Islands National Lakeshore (NRCS 2006a, b) (continued).

SOIL MAPPING UNITS		**ISLAND NAME AND NUMBER OF HECTARES**				
NUMBER	**NAME**	**OUTER**	**NORTH TWIN**	**ROCKY**	**CAT**	**SOUTH TWIN**
713	KELLOGG-ALLENDALE-ASHWABAY COMPLEX, 2 TO 15 PERCENT SLOPES	314.5	0.0	79.0	103.6	17.4
753B	SEDGWICK-MUNUSCONG COMPLEX, 0 TO 6 PERCENT SLOPES	65.0	0.0	0.0	144.6	0.0
756	SUPERIOR-SEDGWICK COMPLEX, 0 TO 15 PERCENT SLOPES	248.9	0.0	114.0	65.0	0.0
7C	BEACHES, 2 TO 12 PERCENT SLOPES	23.3	0.0	8.7	3.3	1.3
805E	SULTZ-ASHWABAY-RUBICON COMPLEX, 15 TO 45 PERCENT SLOPES	9.9	0.0	0.0	0.0	0.0
813E	MANISTEE-KELLOGG-ASHWABAY COMPLEX, 15 TO 45 PERCENT SLOPES	25.7	0.0	2.6	0.0	0.0
874	KEWEENAW, STONY-RUBICON COMPLEX, 0 TO 30 PERCENT SLOPES	173.9	2.6	0.0	0.0	0.0
92F	UDORTHENTS, RAVINES AND ESCARPMENTS, 25 TO 60 PERCENT SLOPES	98.8	0.0	5.3	10.9	0.0
W	WATER	19.4	0.0	0.0	0.0	0.0
	Totals:	3171.6	66.8	420.9	535.5	134.9

Appendix C. Soil associations for individual islands, Apostle Islands National Lakeshore (NRCS 2006a, b) (continued).

SOIL MAPPING UNITS		ISLAND NAME AND NUMBER OF HECTARES			
NUMBER	**NAME**	**BEAR**	**IRONWOOD**	**OTTER**	**MANITOU**
226A	ALLENDALE LOAMY FINE SAND, 0 TO 3 PERCENT SLOPES	0.0	0.0	15.9	8.7
3403A	LOXLEY, BESEMAN, AND DAWSON SOILS, 0 TO 1 PERCENT SLOPES	2.2	0.0	7.2	0.0
3608	DEERTON-BROWNSTONE COMPLEX, 0 TO 15 PERCENT SLOPES, VERY STONY	177.9	20.7	68.8	0.0
3609C	ABBAYE LOAMY SAND, 6 TO 15 PERCENT SLOPES	0.0	1.8	16.7	26.0
376B	TULA FINE SANDY LOAM, 1 TO 6 PERCENT SLOPES, STONY	4.9	0.0	0.0	0.0
480B	PORTWING-HERBSTER COMPLEX, 0 TO 6 PERCENT SLOPES	99.1	0.0	0.0	30.4
481	CORNUCOPIA SILT LOAM, 6 TO 45 PERCENT SLOPES	4.1	0.0	0.0	35.5
509B	GOGEBIC FINE SANDY LOAM, 1 TO 6 PERCENT SLOPES, VERY STONY	0.0	0.0	2.5	0.0
514B	IOSCO LOAMY SAND, 0 TO 4 PERCENT SLOPES	7.4	0.0	0.0	19.5
598A	WURTSMITH SAND, BEACHES, 0 TO 3 PERCENT SLOPES	2.5	0.0	1.5	1.9
603B	REDRIM VERY COBBLY SAND, 0 TO 6 PERCENT SLOPES, VERY STONY	15.8	0.0	11.4	0.0
610B	ZEBA SANDY LOAM, 0 TO 6 PERCENT SLOPES, VERY STONY	23.5	0.0	51.5	2.9
611B	ABBAYE-LAPOIN COMPLEX, 0 TO 6 PERCENT SLOPES	141.9	17.6	104.2	81.7
614B	ABBAYE-ZEBA COMPLEX, 0 TO 6 PERCENT SLOPES, VERY STONY	0.0	7.9	0.0	71.8
705	CUBLAKE-CROSWELL-ASHWABAY COMPLEX, 0 TO 15 PERCENT SLOPES	68.3	0.0	0.0	26.1
712	MORGANLAKE LOAMY SAND, 0 TO 15 PERCENT SLOPES	0.0	0.0	34.2	93.4
713	KELLOGG-ALLENDALE-ASHWABAY COMPLEX, 2 TO 15 PERCENT SLOPES	53.3	7.6	64.0	0.0
753B	SEDGWICK-MUNUSCONG COMPLEX, 0 TO 6 PERCENT SLOPES	0.0	6.0	0.0	39.1
756	SUPERIOR-SEDGWICK COMPLEX, 0 TO 15 PERCENT SLOPES	6.0	194.9	113.7	79.7
7C	BEACHES, 2 TO 12 PERCENT SLOPES	1.4	0.7	0.4	0.0
805E	SULTZ-ASHWABAY-RUBICON COMPLEX, 15 TO 45 PERCENT SLOPES	13.7	0.0	0.0	11.8
813E	MANISTEE-KELLOGG-ASHWABAY COMPLEX, 15 TO 45 PERCENT SLOPES	0.0	0.0	3.0	0.0
874	KEWEENAW, STONY-RUBICON COMPLEX, 0 TO 30 PERCENT SLOPES	88.0	0.0	17.8	0.0
92F	UDORTHENTS, RAVINES AND ESCARPMENTS, 25 TO 60 PERCENT SLOPES	22.7	8.1	18.8	8.2
	Totals:	732.6	265.3	531.4	536.8

Appendix C. Soil associations for individual islands, Apostle Islands National Lakeshore (NRCS 2006a, b) (continued).

SOIL MAPPING UNITS		ISLAND NAME AND NUMBER OF HECTARES			
NUMBER	**SOIL ASSOCIATION NAME**	**STOCKTON**	**OAK**	**GULL**	**MICHIGAN**
1385B		78.1	0.0	0.0	0.0
203	WAKEFIELD FINE SANDY LOAM, 1 TO 18 PERCENT SLOPES, STONY	0.0	13.0	0.0	0.0
226A	ALLENDALE LOAMY FINE SAND, 0 TO 3 PERCENT SLOPES	65.5	0.0	0.0	2.6
3403A	LOXLEY, BESEMAN, AND DAWSON SOILS, 0 TO 1 PERCENT SLOPES	194.0	0.0	0.0	5.7
3423A	RIFLE PEAT, 0 TO 1 PERCENT SLOPES	50.8	0.0	0.0	0.0
3608	DEERTON-BROWNSTONE COMPLEX, 0 TO 15 PERCENT SLOPES, VERY STONY	122.3	13.1	0.0	0.0
3609C	ABBAYE LOAMY SAND, 6 TO 15 PERCENT SLOPES	7.8	0.0	0.0	0.0
3826B	ALLENDALE-WAKELEY-KINROSS COMPLEX, 0 TO 6 PERCENT SLOPES	69.9	76.4	0.0	0.0
405A	LUPTON, CATHRO, AND TAWAS SOILS, 0 TO 1 PERCENT SLOPES	16.0	0.0	0.0	42.3
479A	LERCH-HERBSTER COMPLEX, 0 TO 3 PERCENT SLOPES	7.9	0.0	0.0	45.4
480B	PORTWING-HERBSTER COMPLEX, 0 TO 6 PERCENT SLOPES	286.3	9.6	0.0	82.0
481	CORNUCOPIA SILT LOAM, 6 TO 45 PERCENT SLOPES	70.5	0.0	0.0	0.0
509B	GOGEBIC FINE SANDY LOAM, 1 TO 6 PERCENT SLOPES, VERY STONY	12.9	0.0	0.0	0.0
514B	IOSCO LOAMY SAND, 0 TO 4 PERCENT SLOPES	6.3	0.0	0.0	0.0
597A	MEEHAN SAND, BEACHES, 0 TO 2 PERCENT SLOPES	16.0	0.0	0.0	0.0
598A	WURTSMITH SAND, BEACHES, 0 TO 3 PERCENT SLOPES	32.1	0.0	0.0	24.2
599C	GRAYLING SAND, BEACHES, 2 TO 12 PERCENT SLOPES	30.9	0.0	0.0	0.0
5A	ARNHEIM MUCKY SILT LOAM, 0 TO 1 PERCENT SLOPES, FREQUENTLY FLOODED	32.0	0.0	0.0	0.0
603B	REDRIM VERY COBBLY SAND, 0 TO 6 PERCENT SLOPES, VERY STONY	19.9	0.0	0.0	0.0
610B	ZEBA SANDY LOAM, 0 TO 6 PERCENT SLOPES, VERY STONY	28.3	0.0	0.0	0.0
611B	ABBAYE-LAPOIN COMPLEX, 0 TO 6 PERCENT SLOPES	10.5	21.2	0.0	0.0
614B	ABBAYE-ZEBA COMPLEX, 0 TO 6 PERCENT SLOPES, VERY STONY	12.0	0.0	0.0	0.0
705	CUBLAKE-CROSWELL-ASHWABAY COMPLEX, 0 TO 15 PERCENT SLOPES	12.6	437.3	0.0	0.0
712	MORGANLAKE LOAMY SAND, 0 TO 15 PERCENT SLOPES	363.1	38.8	0.0	64.3
713	KELLOGG-ALLENDALE-ASHWABAY COMPLEX, 2 TO 15 PERCENT SLOPES	772.2	573.6	0.0	0.0
753B	SEDGWICK-MUNUSCONG COMPLEX, 0 TO 6 PERCENT SLOPES	434.1	4.6	0.0	194.2
756	SUPERIOR-SEDGWICK COMPLEX, 0 TO 15 PERCENT SLOPES	947.7	175.2	0.0	80.7
7C	BEACHES, 2 TO 12 PERCENT SLOPES	25.2	1.9	1.1	9.3

Appendix C. Soil associations for individual islands, Apostle Islands National Lakeshore (NRCS 2006a, b) (continued).

SOIL MAPPING UNITS		**ISLAND NAME AND NUMBER OF HECTARES**			
NUMBER	**SOIL ASSOCIATION NAME**	**STOCKTON**	**OAK**	**GULL**	**MICHIGAN**
805E	SULTZ-ASHWABAY-RUBICON COMPLEX, 15 TO 45 PERCENT SLOPES	0.0	190.6	0.0	0.0
813E	MANISTEE-KELLOGG-ASHWABAY COMPLEX, 15 TO 45 PERCENT SLOPES	38.8	113.7	0.0	0.0
874	KEWEENAW, STONY-RUBICON COMPLEX, 0 TO 30 PERCENT SLOPES	10.7	42.3	0.0	0.0
92F	UDORTHENTS, RAVINES AND ESCARPMENTS, 25 TO 60 PERCENT SLOPES	214.4	316.4	0.0	52.1
M-W	MISCELLANEOUS WATER	0.0	0.0	0.0	2.3
W	WATER	5.0	0.0	0.0	0.0
	Totals:	3994.1	2027.7	1.1	605.2

Appendix C. Soil associations for individual islands, Apostle Islands National Lakeshore (NRCS 2006a, b) (continued).

SOIL MAPPING UNITS		ISLAND NAME AND NUMBER OF HECTARES		
Number	**Name**	**HERMIT**	**BASSWOOD**	**LONG**
3423A	RIFLE PEAT, 0 TO 1 PERCENT SLOPES	0.0	0.0	16.5
3608	DEERTON-BROWNSTONE COMPLEX, 0 TO 15 PERCENT SLOPES, VERY STONY	1.4	80.6	0.0
3609C	ABBAYE LOAMY SAND, 6 TO 15 PERCENT SLOPES	6.6	0.0	0.0
3826B	ALLENDALE-WAKELEY-KINROSS COMPLEX, 0 TO 6 PERCENT SLOPES	10.6	1.7	0.0
479A	LERCH-HERBSTER COMPLEX, 0 TO 3 PERCENT SLOPES	13.9	0.0	0.0
480B	PORTWING-HERBSTER COMPLEX, 0 TO 6 PERCENT SLOPES	26.6	9.2	0.0
597A	MEEHAN SAND, BEACHES, 0 TO 2 PERCENT SLOPES	0.0	0.0	24.0
598A	WURTSMITH SAND, BEACHES, 0 TO 3 PERCENT SLOPES	0.0	0.0	10.1
599C	GRAYLING SAND, BEACHES, 2 TO 12 PERCENT SLOPES	0.0	0.0	29.9
610B	ZEBA SANDY LOAM, 0 TO 6 PERCENT SLOPES, VERY STONY	33.7	0.0	0.0
611B	ABBAYE-LAPOIN COMPLEX, 0 TO 6 PERCENT SLOPES	12.7	0.0	0.0
614B	ABBAYE-ZEBA COMPLEX, 0 TO 6 PERCENT SLOPES, VERY STONY	52.6	0.0	0.0
705	CUBLAKE-CROSWELL-ASHWABAY COMPLEX, 0 TO 15 PERCENT SLOPES	76.2	0.0	0.0
712	MORGANLAKE LOAMY SAND, 0 TO 15 PERCENT SLOPES	1.5	60.0	0.0
713	KELLOGG-ALLENDALE-ASHWABAY COMPLEX, 2 TO 15 PERCENT SLOPES	16.3	325.1	0.0
753B	SEDGWICK-MUNUSCONG COMPLEX, 0 TO 6 PERCENT SLOPES	0.0	10.1	0.0
756	SUPERIOR-SEDGWICK COMPLEX, 0 TO 15 PERCENT SLOPES	28.3	199.0	0.0
7C	BEACHES, 2 TO 12 PERCENT SLOPES	0.0	0.0	57.2
805E	SULTZ-ASHWABAY-RUBICON COMPLEX, 15 TO 45 PERCENT SLOPES	3.7	0.0	0.0
813E	MANISTEE-KELLOGG-ASHWABAY COMPLEX, 15 TO 45 PERCENT SLOPES	0.0	13.2	0.0
874	KEWEENAW, STONY-RUBICON COMPLEX, 0 TO 30 PERCENT SLOPES	11.7	0.0	0.0
92F	UDORTHENTS, RAVINES AND ESCARPMENTS, 25 TO 60 PERCENT SLOPES	20.6	82.6	0.0
	Totals:	316.3	781.7	137.6

Appendix D. Lake Superior shoreline types and mileage for islands and the mainland unit, Apostle Islands National Lakeshore (USEPA Region 5 2000).

Shoreline Type	**Number of miles of shoreline**										
	Main-land Unit	**Bass-wood Island**	**Bear Island**	**Cat Island**	**Devils Island**	**Eagle Island**	**Gull Island**	**Hermit Island**	**Iron-wood Island**	**Long Island**	**Mani-tou Island**
1A Exposed Rocky Cliffs	4.16	3.39	3.35	2.50	1.65	0.87		1.91	2.25		2.51
1B Exposed, Solid Man-made Structures	0.02										
2 Shelving Bedrock Shores	0.16		0.61	0.75	1.04	0.02		0.12	0.03		0.22
6B Riprap Revetments, Groins and Jetties	0.07				0.08						0.04
3 Eroding Scarps in Unconsolidated Sediments	0.08										
4 Sand Beaches	3.17	0.08	0.41	0.94				0.06	0.27	7.49	0.32
4/2 Sand Beaches/Shelving Bedrock Shores											
5 Mixed Sand and Gravel Beaches	1.71	0.53	0.64	2.45	0.08		0.27	0.95	1.35		2.30
5/2 Mixed Sand and Gravel Beaches/ Shelving Bedrock Shores				0.07							
6A Gravel Beaches	1.27	3.69	2.24	0.99	0.35		0.07	1.44	0.07		1.17
6A/2 Gravel Beaches/Shelving Bedrock Shores	0.26			0.37							
8B Sheltered, Solid Man-made Structures	0.04										
9A Sheltered, Vegetated Low Banks	0.12										
10A Fringing Wetlands	0.13										
10B Extensive Wetlands	1.34									0.15	
Totals:	12.52	7.69	7.24	8.08	3.21	0.89	0.33	4.48	3.98	7.64	6.56

Appendix D. Lake Superior shoreline types and mileage for islands and the mainland unit, Apostle Islands National Lakeshore (USEPA Region 5 2000) (continued).

Shoreline Type	Number of miles of shoreline										
	Michigan Island	North Twin Island	Oak Island	Otter Island	Outer Island	Rasp-berry Island	Rocky Island	Sand Island	South Twin Island	Stockton Island	York Island
1A Exposed Rocky Cliffs		0.35	2.90	2.67	6.20	0.07		1.74		4.79	0.20
1B Exposed, Solid Man-made Structures					0.06						
2 Shelving Bedrock Shores		0.86	0.18	0.04	1.18	0.40		2.17		1.93	1.50
6B Riprap Revetments, Groins and Jetties	0.04					0.05		0.29			
3 Eroding Scarps in Unconsolidated Sediments											
4 Sand Beaches	0.45		1.18	0.09	3.03	0.33	1.75	1.52	0.17	6.05	0.65
4/2 Sand Beaches/Shelving Bedrock Shores					0.10						
5 Mixed Sand and Gravel Beaches	7.04	0.05	4.24	0.80	6.84	0.36	1.74	1.75	1.48	7.00	1.27
5/2 Mixed Sand and Gravel Beaches/ Shelving Bedrock Shores					0.14			0.09			
6A Gravel Beaches	0.26	0.55	3.05	2.20	0.08	1.49	4.13	2.75	1.28	1.48	0.38
6A/2 Gravel Beaches/Shelving Bedrock Shores	0.36	0.76		0.18	0.09	0.48	0.15	0.42		0.43	0.11
8B Sheltered, Solid Man-made Structures											
9A Sheltered, Vegetated Low Banks											
10A Fringing Wetlands											
10B Extensive Wetlands										3.08	
Totals:	8.15	2.57	11.55	5.98	17.71	3.17	7.77	10.73	2.93	24.77	4.10

Appendix E. 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
Plantae	Bacillariophyta	Fragilariophyceae	Fragilariales	Fragilariaceae	*Asterionella*	sp.	Diatoms
					Fragilaria	sp.	
			Tabellariales	Tabellariaceae	*Tabellaria*	sp.	
	Chrysophyta	Chrysophyceae	Chromulinales	Dinobryaceae	*Dinobryon*	sp.	Yellow-brown algae

Appendix E. Classifications and scientific and common names of species listed in this report (continued).

Zooplankton (Alberti et al. 2005)

Phylum	**Class**	**Subclass**	**Order**	**Suborder**	**Family**	**Genus**	**Species**	**Common name**
Rotifera	Monogononta		Flosculariacea		Conochiliidae	*Conochilus*	spp.	Rotifer
			Ploima		Asplanchnidae	*Asplanchna*	spp.	Rotifer
					Brachionidae	*Brachionus* *Kellicottia* *Keratella*	spp. *longispina* spp.	Rotifer
Arthropoda	Crustacea	Malacostraca	Amphipoda	Gammaridea	Pontoporeiidae	*Diporeia*	*affinis*	Amphipod
			Mysidacea		Mysidae	*Mysis*	*relicta*	Opossum shrimp
Arthropoda	Crustacea			Cladocera	Bosminidae	*Bosmina*	*longirostris*	Cladoceran
					Cercopagididae	*Bythotrephes* *Cercopagis*	*longimanus* *pengoi*	Spiny water flea Fishhook water flea
Arthropoda	Crustacea			Cladocera	Chydoridae	*Acroperus* *Alona* *Chydorus* *Chydorus* *Chydorus* *Eurycercus* *Pleuroxus*	*harpae* *affinis* *gibbus* *sphaericus* sp. spp. *denticulatus*	Cladoceran
					Daphniidae	*Ceriodaphnia* *Daphnia* *Daphnia* *Simocephalus*	spp. *lumholtzi* spp. *vetulus*	Cladoceran
					Holopedidae	*Holopedium*	spp.	Cladoceran
					Leptodoridae	*Leptodora*	sp.	Giant waterflea
					Polyphemidae	*Polyphemus*	sp.	Cladoceran

Appendix E. Classifications and scientific and common names of species listed in this report (continued).

Zooplankton (Alberti et al. 2005) (continued)

Phylum	Class	Subclass	Order	Suborder	Family	Genus	Species	Common name
Arthropoda	Crustacea			Cladocers	Sididae	*Diaphanosoma*	*brachyurum*	
						Diaphanosoma	spp.	
Arthropoda	Crustacea	Copepoda	Cyclopoida		Cyclopidae	*Cyclops*	*varicans rubellus*	Cyclopoid copepod
						Cyclops	spp.	
						Eucyclops	*agilis*	
						Mesocyclops	*edax*	
					Ergasilidae	*Neoergasilus*	*japonicus****	Parasitic copepod
			Calanoida		Aetideidae	*Senecella*	sp.	Calanoid copepod
					Centropagidae	*Limnocalanus*	sp.	Calanoid copepod
					Diaptomidae	*Diaptomus*	*oregonensis*	Calanoid copepod
						Diaptomus	*sicilis*	
						Diaptomus	spp.	
					Temoridae	*Epischura*	sp.	Calanoid copepod

Appendix E. Classifications and scientific and common names of species listed in this report (continued).

Benthos (after Pictured Rocks National Lakeshore, Lora Loope, Aquatic Ecologist, pers. comm. 2005)

Phylum	**Class**	**Order**	**Family**	**Genus**	**Species**	**Common name**
Coelenterata	Hydrozoa	Hydroida		*Hydra*		Hydra
Porifera						Freshwater sponges
Annelida	Hirudinea			*Piscicola*	sp.	Leeches
	Clitellata (Oligochaeta)		Enchytraeidae			
			Lumbriculidae			
			Tubificidae			
Mollusca	Bivalvia (Pelecypoda)	Veneroida	Corbiculidae	*Corbicula*	*fluminea*	Asian clam
			Dreissenidae	*Dreissena*	*bugensis*	Quagga mussel
			Sphaeriidae	*Dreissena*	*polymorpha*	Zebra mussel
				Pisidium	sp.	Clam
				Sphaerium	sp.	Clam
	Gastropoda	Neotaenioglossa	Hydrobiidae	*Potamopyrgus*	*antipodarum*	New Zealand mud snail
		Unionidae		*Anodonta*	*cataracta marginata*	Gaspe floater
				Anodonta	*grandis grandis*	Unionid mussel
		Heterostropha	Valvatidae	*Valvata*	*sincera*	Snail
Arthropoda	Crustacea	Decapoda	Cambaridae	*Orconectes*	*rusticus*	Rusty crayfish
		Ostracoda				Seed shrimp
	Insecta	Ephemeroptera				Mayflies
			Ephemerellidae	*Timpanoga*	*simplex*	
		Plecoptera				Stoneflies
		Odonata	Zygoptera			Damselflies
			Anisoptera			Dragonflies
				Cordulegaster	*obliqua*	
		Trichoptera	Hydropsychidae	*Cheumatopsyche*	sp.	Caddisflies
			Limniphilidae	*Onocosmoecus*	*quadrinotatus*	
				Psychoglypha	*subborealis*	
			Rhyacophilidae	*Rhyacophila*	*acropedes*	
		Diptera	Ceratopogonidae			No-see-um fly
			Chironomidae			Midges
			Empididae			Dance flies
		Coleoptera	Dytiscidae	*Hydroporus*	*pseudovilis*	Predaceous diving beetles
				Oreodytes	*scitulus*	

Appendix E. Classifications and scientific and common names of species listed in this report (continued).

	Scientific name	Common name
Plants	*Abies balsamea*	Balsam fir
	Acer rubrum	Red maple
	Acer saccharum	Sugar maple
	Acorus calamus	Sweet flag
	Alisma spp.	Water-plantains
	Alnus incana subsp. *rugosa*	Speckled alder
	Alnus viridis subsp. *crispa*	Green alder
	Amelanchier spp.	Juneberries
	Ammophilia brevigulata	Beach grass
	Andromeda glaucophylla	Bog rosemary
	Arethusa bulbosa	Swamp-pink
	Artemisia stelleriana	Beach wormwood
	Aster puniceus	Purple-stemmed aster
	Aster urophyllus	Arrow-leaved aster
	Betula alleghaniensis	Yellow birch
	Betula papyrifera	White birch
	Betula pumila	Bog birch
	Bidens spp.	Sticktights
	Botumus umbellatus	Flowering rush
	Brasenia schreberi	Water-shield
	Calamagrostis canadensis	Blue-joint
	Calla palustris	Calla-lily
	Callitriche hermaphroditica	Water starwort
	Calopogon tuberosus	Grass pink
	Caltha palustris	Marsh marigold
	Campanula aparinoides	Marsh bellflower
	Carex chordorrhiza	Cord-root sedge
	Carex crinita	Fringed sedge
	Carex disperma	Soft-leaf sedge
	Carex exilis	Coast sedge
	Carex intumesces	Greater bladder sedge
	Carex lacustris	Lake sedge
	Carex lasiocarpa	Woolly sedge
	Carex lenticularis	Lenticular sedge
	Carex limosa	Muck sedge
	Carex livida var *radicaulis*	Livid sedge
	Carex michauxiana	Michaux's sedge
	Carex oligosperma	Few-seeded hop sedge
	Carex pauciflora	Few-flowered bog sedge
	Carex prasina	Drooping sedge
	Carex scabrata	Eastern rough sedge

Appendix E. Classifications and scientific and common names of species listed in this report (continued).

	Scientific name	Common name
Plants	*Carex trisperma*	Three-fruited sedge
	Carex vesicara	Blister sedge
	Carex viridula	Green yellow sedge
	Centaurea maculosa	Spotted knapweed
	Chamaedaphne calyculata	Leatherleaf
	Cicuta bulbifera	Bulblet water-hemlock
	Cicuta maculata	Common water-hemlock
	Cicuta spp.	Water-hemlock
	Cladium mariscoides	Twig rush
	Cornus stolonifera	Red-osier dogwood
	Cyptotaenia canadensis	Honewort
	Deschampsia cespitosa	Tufted hairgrass
	Deschampsia flexulosa	Crinkled hairgrass
	Diervilla lonicera	Bush-honeysuckle
	Drosera anglica	English sundew
	Drosera intermedia	Intermediate sundew
	Drosera linearis	Linear-leaved sundew
	Drosera spp.	Sundews
	Dulichium arundinaceum	Three-way sedge
	Eleocharis elliptica	Elliptic spike-rush
	Eleocharis robbinsii	Robbins spike-rush
	Eleocharis smallii	Common spike-rush
	Epilobium cilatum	Northern willow-herb
	Epilobium coloratum	Purple-leaved willow-herb
	Epilobium leptophyllum	Narrow-leaved willow herb
	Epilobium palustre	Marsh willow-herb
	Epilobium strictum	Downy willow-herb
	Equisetum fluviatile	Marsh horsetail
	Equisetum variegatum	Variegated horsetail
	Eriocaulon septangulare	Pipewort
	Eriophorum spp.	Cotton-grasses
	Eupatorium perfoliatum	Boneset
	Fraxinus nigra	Black ash
	Galium obtusum	Wild madder
	Galium tinctorium	Southern three-lobed bedstraw
	Galium trifidum	Northern three-lobed bedstraw
	Glyceria canadensis	Rattlesnake-grass
	Glyceria striata	Fowl meadow-grass
	Glyceria spp.	Manna-grasses
	Hieracium aurantiacum	Orange hawkweed

Appendix E. Classifications and scientific and common names of species listed in this report (continued).

	Scientific name	Common name
Plants	*Hudsonia tomentosa*	Beach heather
	Hydrocharis morsus-ranae	European frog-bit
	Ilex verticillata	Winterberry holly
	Impatiens capensis	Spotted touch-me-not
	Impatiens pallida	Pale touch-me-not
	Iris versicolor	Blue flag
	Juncus balticus	Arctic rush
	Juncus spp.	Rush
	Juniperus communis	Dwarf juniper
	Kalmia polifolia	Bog rosemary
	Larix laricina	Tamarack
	Lathyrus japonicus	Beach pea
	Lemna minor	Duckweed
	Libertia sp.	
	Listera convallarioides	Broad-leaved twayblade
	Lycopus uniflorus	Northern bugleweed
	Lysimachia punctata	Yellow loosestrife
	Lysimachia terrestris	Yellow loosestrife
	Lysimachia thyrsiflora	Tufted loosestrife
	Lythrum salicaria	Purple loosestrife
	Mentha arvensis	Field-mint
	Menyanthes trifoliata	Bogbean
	Myrica gale	Sweet gale
	Myriophyllum heterophyllum	Watermilfoil
	Myriophyllum spicatum	Eurasian watermilfoil
	Nuphar lutea	Yellow pond-lily
	Nymphaea odorata	White water-lily
	Phragmites australis	Giant reed
	Picea glauca	White spruce
	Picea mariana	Black spruce
	Pilea pumila	Clearweed
	Pinus banksiana	Jack pine
	Pinus resinosa	Red pine
	Pinus strobus	White pine
	Platanthera orbiculata	Large roundleaf orchid
	Poa palustris	Fowl meadow-grass
	Pogonia ophioglossoides	Rose pogonia
	Pontederia cordata	Pickerel-weed
	Populus tremuloides	Trembling aspen
	Potamogeton berchtoldii	Pondweed
	Potamogeton crispus	Curly-leaf pondweed

Appendix E. Classifications and scientific and common names of species listed in this report (continued).

	Scientific name	Common name
Plants	*Potamogeton illinoiensis*	Pondweed
	Potentilla palustris	Marsh cinquefoil
	Primula mistassinica	Bird's eye primrose
	Prunus pumila	Sand cherry
	Quercus ellipsoidalis	Northern pin oak
	Quercus rubra	Northern red oak
	Rhynchospora alba	White beak-rush
	Rhynchospora fusca	Sooty beak-rush
	Ribes glandulosum	Skunk current
	Ribes triste	Swamp red current
	Rosa blanda	Rose
	Rubus pubescens	Dwarf red raspberry
	Rubus strigosus	Raspberry
	Rumex orbiculatus	Great water dock
	Salix bebbiana	Beaked willow
	Salix candida	Sage willow
	Salix discolor	Pussy willow
	Salix gracilis	Meadow willow
	Salix humilis	Prairie willow
	Salix pedicellaris	Bog willow
	Salix pellita	Satiny willow
	Salix planifolia	Flat-leaved willow
	Sagittaria latifolia	Arrowheads
	Sagittaria rigida	Arrowheads
	Sagittaria spp.	Arrowheads
	Sarracenia purpurea	Pitcher plant
	Scheuchzeria palustris	Pod grass
	Scirpus acutus	Hard-stem bulrush
	Scirpus fluviatilis	River bulrush
	Scirpus hudsonianus	Hudson-Bay cotton grass
	Scirpus validus	Great bulrush
	Scutellaria lateriflora	Mad-dog skullcap
	Sium suave	Water-parsnip
	Smilacina trifolia	Three-leaved false Solomon's–seal
	Sparganium chlorocarpum	Narrow leaved bur-reed
	Sparganium spp.	Bur-reed
	Spiranthes spp.	Ladies-tress orchids
	Spirodela polyrhiza	Greater duckweed
	Sphagnum spp.	Sphagnum moss
	Stachys tenuifolia	Rough hedge-nettle
	Taxus canadensis	Canada yew

Appendix E. Classifications and scientific and common names of species listed in this report (continued).

	Scientific name	Common name
Plants	*Thalictrum dasycarpum*	Tall meadow-rue
	Thalictrum dioicum	Early meadow-rue
	Thuja occidentalis	White cedar
	Triglochin maritima	Bog arrow-grass
	Trisetum spicatum	Narrow false oats
	Tsuga canadensis	Hemlock
	Typha spp.	Cattail
	Utricularia cornuta	Beaked bladderwort
	Utricularia intermedia	Intermediate bladderwort
	Utricularia resupinata	Purple bladderwort
	Utricularia vulgaris	Common bladderwort
	Vaccinium angustifolium	Blueberry
	Vaccinium oxycoccos	Cranberries
	Xyris montana	Yellow-eyed grass

	Scientific name	Common name
Insects	*Boloria eunomia*	Bog fritillary
	Cicindela hirticollis rhodensis	Beach-dune tiger beetle
	Lycaena epixanthe	Bog copper
	Lymantria dispar	Gypsy moth
	Melanoplus flavidus	Blue-legged grasshopper
Fish	For fish of Lake Superior, see Appendix F	
	Chrosomus eos	Northern redbelly dace
	Notemigonus crysoleucas	Golden shiner
	Sander vitreus	Walleye
	Umbra lima	Central mudminnow

Appendix E. Classifications and scientific and common names of species listed in this report (continued).

	Scientific name	Common name
Amphibians	*Acrisgryllus crepitans*	Northern cricket frog
	Ambystoma laterale	Blue-spotted salamander
	Ambystoma maculatum	Spotted salamander
	Bufo americanus americanus	Eastern American toad
	Hemidactylium scutatum	Four-toed salamander
	Heterodon platirhinos	Eastern hog-nosed snake
	Hyla chrysoscelis	Cope's gray treefrog
	Hyla crucifer	Spring peeper
	Hyla versicolor	Eastern gray tree frog
	Necturus maculosus maculosus	Mud puppy
	Notophthalmus viridescens louisianensis	Central newt
	Plethodon cinereus cinereus	Eastern red-backed salamander
	Pseudacris crucifer crucifer	Northern spring peeper
	Pseudacris sp.	Chorus frogs
	Rana catesbeiana	American bullfrog
	Rana clamitans melanota	Green frog
	Rana pipiens	Northern leopard frog
	Rana septentrionalis	Mink frogs
	Rana sylvatica	Wood frog
	Rana sylvatica cantobrigensis	Eastern wood frog
Reptiles	*Chelydra serpentina serpentina*	Snapping turtle
	Chrysemys picta	Painted turtle
	Diadophis punctatus edwardsii	Northern ring-necked snake
	Opheodrys vernalis	Smooth greensnake
	Storeria occipitomaculata occipitomaculata	Northern red-bellied snake
	Thamnophis sirtalis sirtalis	Common garter snake
Birds	*Bucephala clangula*	Common goldeneye
	Catharus ustulatus	Swainson's thrush
	Charadrius melodus	Piping plover
	Circus cyaneus	Northern harrier
	Coccothraustes vespertinus	Evening grosbeak
	Dendroica fusca	Blackburnian warbler
	Falco columbarius	Merlin
	Haliaeetus leucocephalus	Bald eagle
	Mergus serrator	Red-breasted merganser
	Mergus merganser	Common merganser
	Oporornis agilis	Connecticut warbler
	Perisoreus canadensis	Gray jay
	Vermivora peregrine	Tennessee warbler

Appendix F. Fish species list for Lake Superior. N = native; I =introduced and reproducing; R = reported to occur but non-reproducing; P = possible occurrence, native; U = reported but unlikely occurrence. (table reproduced from GLFC 2001).

Family	Scientific name	Common name	Type
Petromyzontidae	*Ichthyomyzon unicuspis*	Silver lamprey	N
	I. fossor	Northern brook lamprey	N
	Lampetra appendix	American brook lamprey	N
	Petromyzon marinus	Sea lamprey	I
Acipenseridae	*Acipenser fulvescens*	Lake sturgeon	N
Lepisosteidae	*Lepisosteus osseus*	Longnose gar	N
Amiidae	*Amia calva (bowfin)*	bowfin	P
Anguillidae	*Anguilla rostrata*	American eel	R
Clupeidae	*Alosa pseudoharengus*	Alewife	I
	Dorosoma cepedianum	Gizzard shad	I
Cyprinidae	*Couesius plumbeus*	Lake chub	N
	Cyprinus carpio	Common carp	I
	Luxilus cornutus	Common shiner	N
	Margariscus margarita	Pearl dace	N
	Nocomis biguttatus	Hornyhead chub	N
	Notemigonus crysoleucas	Golden shiner	N
	Notropis atherinoides	Emerald shiner	N
	N. buccatus	Silverjaw minnow	U
	N. dorsalis	Bigmouth shiner	P
	N. heterodon	Blackchin shiner	N
	N. heterolepis	Blacknose shiner	N
	N. hudsonius	Spottail shiner	N
	N. rubellus	Rosyface shiner	P
	N. stramineus	Sand shiner	N
	N. volucellus	Mimic shiner	N
	Opsopoeodus emiliae	Pugnose minnow	U
	Phoxinus eos	Northern redbelly dace	N
	P. neogaeus	Finescale dace	N
	Pimephales notatus	Bluntnose minnow	N
	P. promelas	Fathead minnow	N
	Rhinichthys atratulus	Blacknose dace	N
	R. cataractae	Longnose dace	N
	Semotilus atromaculatus	Creek chub	N
Catostomidae	*Catostomus catostomus*	Longnose sucker	N
	C. commersoni	White sucker	N
	Moxostoma anisurum	Silver redhorse	N
	M. macrolepidotum	Shorthead redhorse	N
	M. valenciennesi	Greater redhorse	N

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Family	Scientific name	Common name	Type
Ictaluridae	*Ameiurus melas*	Black bullhead	N
	A. natalis	Yellow bullhead	N
	A. nebulosus	Brown bullhead	N
	Ictalurus punctatus	Channel catfish	N
	Noturus flavus	Stonecat	N
	N. gyrinus	Tadpole madtom	N
	N. miurus	Brindled madtom	U
Esocidae	*Esox lucius*	Northern pike	N
	E.masquinongy	Muskellunge	N
Osmeridae	*Osmerus mordax*	Rainbow smelt	I
Salmonidae	*Coregonus artedi*	Lake herring	N
	C. clupeaformis	Lake whitefish	N
	C. hoyi	Bloater	N
	C. kiyi	Kiyi	N
	C. zenithicus	Shortjaw cisco	N
	Oncorhynchus kisutch	Coho salmon	I
	O. gorbuscha	Pink salmon	I
	O. mykiss	Rainbow trout	I
	O. tshawytscha	Chinook salmon	I
	Prosopium coulteri	Pygmy whitefish	N
	P. cylindraceum	Round whitefish	N
	Salmo trutta	Brown trout	I
	Salvelinus fontinalis	Brook trout	N
	S. namaycush	Lake trout	N
	S. namaycush siscowet	Siscowet	N
Percopsidae	*Percopsis omiscomaycus*	Trout perch	N
Gadidae	*Lota lota*	Burbot	N
Atherinidae	*Labidesthes sicculus*	Brook silverside	R
Gasterosteidae	*Apeltes quadracus*	Fourspine stickleback	I
	Culaea inconstans	Brook stickleback	N
	Gasterosteus aculeatus	Threespine stickleback	I
	Pungitius pungitius	Ninespine stickleback	N
Cottidae	*Cottus bairdii*	Mottled sculpin	N
	Cottus cognatus	Slimy sculpin	N
	Cottus ricei	Spoonhead sculpin	N
	Myoxocephalus thompsoni	Deepwater sculpin	N
Moronidae	*Morone*	White perch	I
	amer mericanaone chrysops	White bass	N

Appendix F. Fish species list for Lake Superior. N = native; I =introduced and reproducing; R = reported to occur but non-reproducing; P = possible occurrence, native; U = reported but unlikely occurrence. (table reproduced from GLFC 2001) (continued).

Family	**Scientific name**	**Common name**	**Type**
Centrarchidae	*Ambloplites rupestris*	Rock bass	N
	Lepomis cyanellus	Green sunfish	N
	L. gibbosus	Pumpkinseed	N
	L. macrochirus	Bluegill	N
	Micropterus dolomieu	Smallmouth bass	N
	M. salmoides	Largemouth bass	N
	Pomoxis annularis	White crappie	P
	P. nigromaculatus	Black crappie	N
Percidae	*Etheostoma exile*	Iowa darter	N
	E. flabellare	Fantail darter	N
	E. microperca	Least darter	N
	E. nigrum	Johnny darter	N
	Gymnocephalus cernuus	Ruffe	I
	Perca flavescens	Yellow perch	N
	Percina caprodes	Logperch	N
	P. maculata	Blackside darter	U
	Sander canadensis	Sauger	N
	S. vitreus	Walleye	N
Sciaenidae	*Aplodinotus grunniens*	Freshwater drum	I
Gobiidae	*Neogobius melanostomus*	Round goby	I

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.

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