WATER RESOURCES MANAGEMENT PLAN

SLEEPING BEAR DUNES NATIONAL LAKESHORE, MICHIGAN

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EXECUTIVE SUMMARY

Sleeping Bear Dunes National Lakeshore, 71,189 acres in size, is located in the northwest part of Michigan's Lower Peninsula in Benzie and Leelanau counties and borders Lake Michigan. Two nearby islands, South Manitou and North Manitou, are in the park.

The park contains 64 miles of Lake Michigan shoreline – 31 on the mainland, 13 miles on South Manitou Island and 20 miles on North Manitou Island. It also contains numerous lakes that are primarily shallow and small, ranging in size from 2 to 248 acres. Streams within the lakeshore include all of Otter Creek, parts of Shalda Creek and Crystal River, and 4.6 miles of the Platte River. The Crystal River is listed on the National Rivers Inventory for consideration under the Wild and Scenic Rivers Act for its scenic, geologic, and wildlife values.

The land-sculpting effect of continental glaciation in northwest Michigan is clearly illustrated in the geologic features of the Sleeping Bear Dunes. The evidence indicates that the Wisconsin ice age lasted from approximately 50,000 to 10,000 years before present, with the ice having disappeared from the Sleeping Bear region about 11,800 years ago. During and following glacial retreat, the water levels of the Great Lakes fluctuated as they sought the lowest outlets, with the final adjustment as we know them today taking place about 3,000 years ago.

Immense headlands, characteristic of the Lake Michigan shoreline in the vicinity of Sleeping Bear Dunes, for the most part, resisted the force of the advancing ice and steered the ice lobes into the valleys. The ice lobes gouged debris from the valley floors and deposited it along the sides of the valleys when the ice finally melted, creating prominent moraines. Generally, these moraines and the valleys between them are oriented in a north-south direction.

Glacial deposits, primarily moraines and outwash areas, in the lakeshore range from 500 to 700 feet thick. Lakebeds formed after glacial retreat and during the post-glacial variations in the Lake Michigan water level. The deposits closest to the land surface and the physiography, in general are the result of glacial advance and retreat during the last glacial period, the Wisconsin. The study of the underlying bedrock has been infrequent because of the thickness of the glacial deposits.

A U.S. Geological Survey gaging station at Honor, MI (Platte River) is the only extant gaging station close to the national lakeshore. The hydrograph for this station shows a fairly uniform flow regime, with an average range from 120 to 180 cfs. Peak flows occur typically in the spring with low flows occurring in the late summer/early fall. The hydrograph also shows the effect of the drought years of the late 1990s – more uniform flow across the year and the range of flows reduced to 100 to 130 cfs on average. Given the limited discharge data on the other lakeshore streams, this Platte River hydrograph should be considered representative of the hydrographs for these streams.

Because the apparent contribution of ground water is high, the four streams of the lakeshore, Platte River, Crystal River, Otter Creek and Shalda Creek, appear to have high flow stability and a low susceptibility to drying. In addition, it appears (based only on the Honor, MI station) that these streams also have low flow variability (i.e., low coefficient of variation of daily flows). Based on these conditions, national lakeshore streams would be classified as either Stable Groundwater or Superstable Groundwater, based on a recent classification system. The difference between the two types is a matter of the degree of flow stability, and susceptibility to drying, seasonal predictability of flooding, and the seasonal predictability of low flows. In either case, the high flow stability of the lakeshore's streams would translate into biological communities that are less likely physically controlled through environmental variability – biological control, through competition, predation, etc., is probably more important in these streams.

The lakes of the national lakeshore experience a range of stratification regimes. Glen, Loon, Platte and Narada are dimictic lakes that maintain stratification between spring and fall overturns (mid-April to mid-October). Hypolimnetic oxygen depletion usually occurs in all four lakes. Other dimictic lakes include North Bar, Manitou, Bow Lakes (north), Deer and Bass (Benzie). All remaining lakes are polymictic, circulating frequently during the summer, but may stratify beneath winter ice. Shallow water depth prevented any stratification in some lakes (Shell and Tucker lakes) whereas Otter Lake stratifies periodically, but does not maintain stratification throughout the summer. A degree of hypolimnetic oxygen depletion is present at times in Otter Lake.

All water resources within the designated boundaries of Sleeping Bear Dunes National Lakeshore are considered high quality waters that are designated as outstanding state resource waters (OSRW) by the State of Michigan. This designation provides that the level of water quality necessary to protect existing uses shall be maintained and protected. Furthermore, where designated uses of a water body are not attained, there shall be no lowering of the water quality with respect to the pollutant or pollutants that are causing the non-attainment. This designation also calls for controls on pollutant sources to OSRW waters so that water quality is not lowered in the OSRW.

The National Park Service conducted surface water quality retrievals for Sleeping Bear Dunes National Lakeshore from six of the U.S. Environmental Protection Agency's national databases, including STORET the national water quality database. The results of these retrievals for the study area (limits include 3 miles upstream and 1 mile downstream of park boundary) covered the years 1962 to 1996 and included 149 water quality monitoring stations, three industrial/municipal discharge sites (only two of which are in the watersheds represented in the national lakeshore), 12 water impoundments (only one of importance to national lakeshore), and four active or inactive U.S. Geological Survey gaging stations. Of the 149 stations, 10 stations were established but contained no data. Seventy-six stations were located within the national lakeshore boundary. Twenty stations are located in Lake Michigan waters; however, 17 stations have data older than 1985 and three show no data. Presently, there are no active stations on the Lake Michigan waters of the lakeshore to determine existing water quality and water quality trends.

Most of the remaining monitoring stations represent either one-time or intensive single-year sampling efforts by collection entities or discontinued stations. Sixty-two stations represent data collected before January 1985 and are of little use in an assessment of current water quality of the park. Forty-seven national lakeshore stations show data collected from 1985 to 1996; 23 of these stations each represent less than 10 total water quality observations over this period and are of little use in determining water quality trends; however, parameter values indicate no water quality impairment. Of the remaining 24 stations in the national lakeshore, all represent data collected no later than 1995 and represent not monitoring stations *per se* but several multi-year assessments. Only 12 lakes (out of 26) were consistently sampled over a 5-year time frame (1990-1995); however, parameter values are consistent with hard-water lakes and show no obvious indications of impaired water quality. For national lakeshore streams at least one station on each stream was sampled consistently over a 5-year time frame (1990-1995). As with the lakes, no streams show any obvious water quality impairments.

The National Wetland Inventory of the U.S. Fish and Wildlife Service identified, classified (according to Cowardin et al. 1979), and mapped wetlands of the lakeshore. A total number of wetlands in excess of 300 (several wetland types were too numerous to count), representing 32 wetland types, was identified. Sleeping Bear Dunes National Lakeshore is dominated by palustrine wetlands (approximately 80 percent of the total number of wetlands). There are primarily three classes of palustrine wetlands in the national lakeshore: emergent; forested; and scrub-shrub. For the national lakeshore it is difficult to determine the predominance among these wetland classes because each class has its own wetland type that was ‘too numerous to count’. Based on professional judgement, forested and scrub-shrub wetlands are co-dominant with persistent, emergent wetlands not far behind.

Prior to 1988, information on the composition, distribution and ecology of aquatic macrophytes within the lakeshore was primarily limited to qualitative or anecdotal comments in a few studies. However, more focused studies the early 1990s greatly added to the knowledge of aquatic macrophytes within the lakeshore. A total of 42 species of aquatic macrophytes is known from the national lakeshore. Species richness ranged from a low of one species (Tamarack Lake) to a high of 23 species (Platte River). Waterbodies of high species richness, besides the Platte River, included Otter Lake (20 species); Bass Lake (Benzie; 19); Otter Creek (18); and Tucker Lake, School Lake and the Crystal River (all with 15 species). Waterbodies of low species richness included the Hidden Lake (4);

Florence Lake (4); the Bow Lakes (5); Mud Lake (6); and Loon Lake (6). Among the four lakeshore streams, Shalda Creek had the lowest species richness (7).

A total of 76 fish species occurs in the national lakeshore. The Platte River watershed has the highest species richness with 53 total species, followed by Shalda Creek watershed (45 species), Crystal River watershed (35), and the Otter Creek watershed (27). The total fish species richness for lakes within or adjacent to the lakeshore ranges from a high in Big Glen Lake (18 species) to a low at Hidden Lake (3). The Lake Michigan shoreline of the national lakeshore yielded a total of 34 fish species.

Past studies in the Sleeping Bear Dunes area listed 32 species of herptiles – 17 amphibian and 15 reptiles. A systematic survey of herptiles has yet to be accomplished for the lakeshore; however, distribution records from the University of Michigan's Museum of Zoology show that a total of 23 herptiles inhabit the lakeshore -- 11 species of frogs and toads; 4 species of salamanders; 1 lizard; 5 snakes; and 2 turtles.

A recent study of limnetic zooplankton at nine lakes represents the most comprehensive, spatiotemporal look at the structure of zooplankton communities in the national lakeshore. Eighty-five zooplankton taxa were identified. Only 32 of these taxa comprised one percent or greater of the average abundance for any lake. The total number of genera was relatively similar among the lakes, generally falling between 30 and 40; however, total zooplankton density varied greatly among the lakes.

In recent years the contribution of air pollution to water quality in the Great Lakes region has been the subject of increased scientific study and concern. This increased study is a direct result of 30 years of data collection showing that toxic chemicals released into the air can travel long distances and be deposited on land or water at locations far from their original sources.

The Integrated Atmospheric Deposition Network (IADN) is a joint effort of the US and Canada to measure atmospheric deposition of toxic materials to the Great Lakes. There is one master monitoring station on each lake that measures air, rain and particles for a suit of chemicals, including PCBs, PAHs (polyaromatic hydrocarbons), chlorinated pesticides (DDT) and trace metals including lead, arsenic and cadmium. The master station on Lake Michigan is located at Sleeping Bear Dunes National Lakeshore.

Water is an important resource for the functioning of natural systems and providing for visitor use in Sleeping Bear Dunes National Lakeshore. Water manifests itself into a diversity of geomorphic and habitat types that allow the national lakeshore to support diverse biological resources. Maintaining this diversity depends at least partially upon the careful safeguarding of the lakeshore's water resources and water-dependent environments, and minimizing stresses that can affect these resources from both inside and outside of the lakeshore's boundaries.

Specific management objectives pertaining to water resources and water-dependent environments within Sleeping Bear Dunes National Lakeshore include:

- Manage waters of the lakeshore and water-dependent environments in a manner designed to maintain the highest degree of biological diversity and ecosystem integrity;
- Natural fluvial and lacustrine processes will be allowed to proceed unimpeded, to the extent possible;
- Assure that park development and operations do not adversely affect the lakeshore's water resources and water-dependent environments;
- Acquire sufficient knowledge about water quality to effectively participate in state and local management planning and seek the highest level of protection under state water quality standards appropriate for the lakeshore;
- Acquire appropriate baseline information to adequately understand and manage water resources and meet National Park Service inventory and monitoring requirements;
- If possible, control or eradicate non-native species with an emphasis on the protection and restoration of native species;
- Promote public awareness and understanding of current and potential human impacts upon water resources;
- Provide for quality, environmentally sensitive recreational opportunities (e.g. fishing, canoe/kayak) and
- Detect and evaluate external influences on natural upland processes that may impact lakeshore water resources and water-related attributes.

Because Sleeping Bear Dunes National Lakeshore is largely a hydrological phenomenon, water-related issues naturally dominate. For that reason, land use within and adjacent to the lakeshore as well as land use anywhere in the watersheds, connected by either ground water or surface water, has the potential to affect the lakeshore. While information exists concerning the water resources in the lakeshore, systematically collected information and adequate analysis addressing the water resources is lacking. The primary purpose of this Water Resources Management Plan for Sleeping Bear Dunes National Lakeshore is to assist park managers with water-related decisions by providing information on potential threats to water resources and guidance on immediate actions that can prevent or mitigate water resource degradation. In this regard, the plan provides an exhaustive overview of existing water resource information; identifies and discusses a number of water-related issues and management concerns; and, recommends a course of action for addressing high priority water-related issues and achieving the above water resource management objectives. Project statements that address critical water resource issues are included and can be incorporated into the park's Resource Management Plan for future funding consideration. These project statements address the water resource issues within the context of the water-related management objectives.

The National Park Service Water Resources Division and Sleeping Bear Dunes National Lakeshore personnel held a water resources scoping meeting at the national lakeshore in May 1997. The purpose of this meeting was to identify and prioritize water resource issues and management concerns. A total of 16 water resource issues were identified at the water resources scoping meeting, and prioritized into six high priority, three medium priority, and seven low priority issues. An additional site visit in 2000 led to modification of the original list of water resource issues. This modification resulted in the following water resource issues. Management actions to address these issues were developed for only the highest priority issues. This was considered prudent, given current funding and personnel constraints, i.e. the national lakeshore would only be capable of addressing high priority issues over the life span of this plan.

<u>High Priority</u>

Need for a permanent, full-time water resource professional;

Lack of an adequate inventory and characterization of national lakeshore wetlands;

Revise current water quality monitoring program via development of a comprehensive water quality monitoring plan;

Are national lakeshore waters affected by bacteriological contamination?;

Crystal River flow below Glen Lake Association Dam under drought conditions;

Recreational use of national lakeshore streams;

Need for an adequate baseline of amphibians and reptiles in the national lakeshore;

<u>Medium Priority</u>

Are high nitrogen values in Otter Creek natural or anthropogenic?;

Potential effects of phosphorus loadings on national lakeshore waters from Platte River Anadromous Fish Hatchery;

Restoration of Waterwheel Site on Platte River;

Platte River Dredging;

Low Priority

Tucker Lake hazardous waste site;

Condition of Day Mill Pond;

Beaver Colonization of national lakeshore watersheds;

Sleeping Bear Dunes National Lakeshore's Water Resources Management Plan and NEPA

The National Environmental Policy Act (NEPA) mandates that federal agencies prepare a study of the impacts of major federal actions having a significant effect on the human environment and alternatives to those actions. The adoption of formal plans may be considered a major federal action requiring NEPA analysis if such plans contain decisions affecting resource use, examine options, commit resources or preclude future choices. Lacking these elements, national lakeshore's Water Resources Management Plan (WRMP) has no measurable impacts on the human environment and is categorically excluded from further NEPA analysis.

According to Director's Order (DO) #12 Handbook (section 3.4), water resources management plans normally will be covered by one or more of the following Categorical Exclusions:

- 3.4.B (1) Changes or amendments to an approved plan when such changes have no potential for environmental impact.
- 3.4.B (4) Plans, including priorities, justifications, and strategies, for non-manipulative research, monitoring, inventorying, and information gathering.
- 3.4.B (7) Adoption or approval of academic or research surveys, studies, reports and similar documents that do not contain and will not result in National Park Service recommendations.
- 3.4.E (2) Restoration of non-controversial native species into suitable habitats within their historic range.
- 3.4.E (4) Removal of non-historic materials and structures in order to restore natural conditions when the removal has no potential for environmental impacts, including impacts to cultural landscapes or archeological resources.
- 3.4.E (6) Non-destructive data collection, inventory, study, research, and monitoring activities.
- 3.4.E (7) Designation of environmental study areas and research natural areas, including those closed temporarily or permanently to the public, unless the potential for environmental (including socioeconomic) impact exists.

These Categorical Exclusions require that formal records be completed (Section 3.2, D0-12 Handbook) and placed in park files. It is the responsibility of national lakeshore to complete the documentation for the applicable Categorical Exclusion(s) when the WRMP is approved and published.

INTRODUCTION

Whether supporting natural systems or providing for visitor use, water is a significant resource in units of the national park system. Consistent with its fundamental purpose, the National Park Service seeks to protect surface and ground waters as integral components of a park's aquatic and terrestrial ecosystems by carefully managing the consumptive use of water. The National Park Service also strives to maintain the natural quality of surface and ground waters in accordance with all applicable federal, state, and local laws and regulations. Water-based recreation such as fishing, as well as aquatic ecosystem health is dependent upon the maintenance of adequate water quality and quantity.

Water is a dominant landscape element for national parks of the Great Lakes region. Given the region's legacy of environmental problems, the ongoing insults from anthropogenic sources, and the increases in population density, it has become paramount that the preservation and conservation of water resources be seen as critical to the maintenance of the parks' biological diversity.

Because Sleeping Bear Dunes National Lakeshore is largely a hydrological phenomenon, water-related issues naturally dominate. For that reason, land use within and adjacent to the lakeshore as well as land use anywhere in the watersheds, connected by either ground water or surface water, has the potential to affect the lakeshore. While information exists concerning the water resources in the lakeshore, systematically collected information and adequate analysis addressing the water resources is lacking. The primary purpose of this Water Resources Management Plan for Sleeping Bear Dunes National Lakeshore is to assist park managers with water-related decisions by providing information on potential threats to water resources and guidance on immediate actions that can prevent or mitigate water resource degradation. In this regard, the plan provides an exhaustive overview of existing water resource information; identifies and discusses a number of water-related issues and management concerns; and, recommends a course of action for addressing high priority water-related issues at the national lakeshore. Project statements that address critical water resource issues are included and can be incorporated into the park's Resource Management Plan for future funding consideration. These project statements address the water resource issues within the context of water-related management objectives. This connection between management actions, issues, and management objectives is the cornerstone of issue-driven planning.

PARK LOCATION AND DESCRIPTION

Sleeping Bear Dunes National Lakeshore, 71,189 acres in size, is located in the northwest part of Michigan's Lower Peninsula in Benzie and Leelanau counties and borders Lake Michigan (Figure 1). Two nearby islands, South Manitou and North Manitou, are in the park.

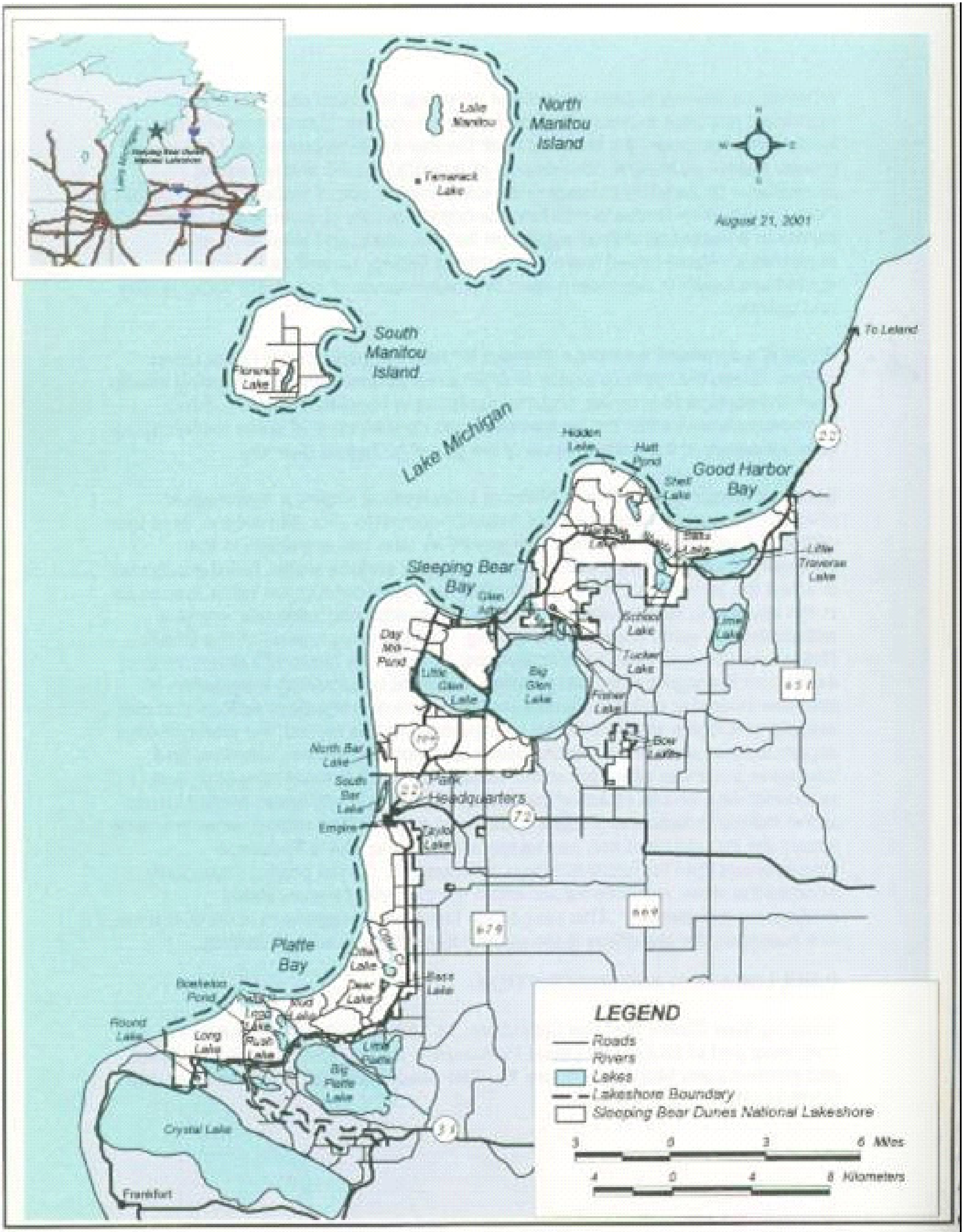


Figure 1. Sleeping Bear Dunes National Lakeshore and vicinity.

The park contains 64 miles of Lake Michigan shoreline – 31 on the mainland, 13 miles on South Manitou Island and 20 miles on North Manitou Island. It also contains numerous lakes that are primarily shallow and small, ranging in size from 2 to 248 acres. Streams within the lakeshore include all of Otter Creek, parts of Shalda Creek and Crystal River, and 4.6 miles of the Platte River.

The national lakeshore takes it name from Sleeping Bear Dune, a landmark that can be seen for miles from many directions. This dune-capped, morainal plateau rises as much as 440 feet above Lake Michigan. Throughout the park the land surface is rolling; from an altitude of 579 feet above sea level (asl) along the shores of Lake Michigan, the surface forms 200- to 300-foot (asl) bluffs at several locations and rises to more than 1,000 feet (asl) at a few places.

The lakeshore was established as part of the national park system in 1970. In an administrative history of the national lakeshore, Karamanski (2000) summarizes the intent leading to the creation of the national lakeshore as well as overall management concerns as follows:

> The National Park Service conceived the Sleeping Bear Dunes lakeshore at a time when the shores of Lake Michigan were rapidly undergoing privatization. Subdivisions of vacation and year round homes threatened to keep ordinary citizens from enjoying Michigan's broad, sandy shoreline…
>
> Congress conceived the national lakeshore parks of the Great Lakes region as experiments in public recreation management. The requirements of managing small, often non-contiguous parks carved out of private holdings required adjustments by administrators whose primary experience had been earned in large, isolated western national parks. The managers of Sleeping Bear have been further challenged by the dynamic evolution of the environmental movement during the 1970s and 1980s. The requirements of wilderness, environmental protection, endangered species, and historic preservation have meant that … a variety of resource management issues [are] in direct competition with values of public recreation and visitor safety.

PARK PURPOSE AND SIGNIFICANCE

Congress established Sleeping Bear Dunes National Lakeshore to preserve outstanding natural features, including forests, beaches, dune formations, and ancient glacial phenomena in their natural setting and protect them from developments and uses that would destroy the scenic beauty and natural character of the area.

Significance statements (National Park Service 2001) describe the lakeshore's distinctiveness and help to place it in its regional and national context:

- The lakeshore contains accessible and compactly grouped features of continental glaciation, including post glacial shoreline adjustment, wind formed dunes and examples of plant succession.
- The lakeshore area is one of the most scenic portions of the Lake Michigan shoreline. Its massive glacial headlands, diverse habitats and superb water resources offer a broad range of recreational and inspirational experiences.
- The lakeshore's historic maritime, recreation and agricultural landscapes are of a size and quality that are unique on the Great Lakes and rare elsewhere on the US coastline.
- The lakeshore includes regionally important native flora and fauna that have declined to either an endangered, threatened or rare status in the Great Lakes ecosystem.

WATER RESOURCE MANAGEMENT OBJECTIVES

Water is an important resource for the functioning of natural systems and providing for visitor use in Sleeping Bear Dunes National Lakeshore. Water manifests itself into a diversity of geomorphic and habitat types that allow the national lakeshore to support diverse biological resources. Maintaining this diversity depends at least partially upon the careful safeguarding of the lakeshore's water resources and water-dependent environments, and minimizing stresses that can affect these resources from both inside and outside of the lakeshore's boundaries.

Specific management objectives (developed by the lakeshore as part of the water resources planning process) pertaining to water resources and water-dependent environments within Sleeping Bear Dunes National Lakeshore include:

- Manage waters of the lakeshore and water-dependent environments in a manner designed to maintain the highest degree of biological diversity and ecosystem integrity;
- Natural fluvial and lacustrine processes will be allowed to proceed unimpeded, to the extent possible;
- Assure that park development and operations do not adversely affect the lakeshore's water resources and water-dependent environments;
- Acquire sufficient knowledge about water quality to effectively participate in state and local management planning and seek the highest level of protection under state water quality standards appropriate for the lakeshore;
- Acquire appropriate baseline information to adequately understand and manage water resources and meet National Park Service inventory and monitoring requirements;

- If possible, control or eradicate non-native species with an emphasis on the protection and restoration of native species;
- Promote public awareness and understanding of current and potential human impacts upon water resources;
- Provide for quality, environmentally sensitive recreational opportunities (e.g. fishing, canoe/kayak) and
- Detect and evaluate external influences on natural upland processes that may impact lakeshore water resources and water-related attributes.

This Water Resources Management Plan provides a recommended course of management action for achieving these objectives.

LEGISLATIVE CONSTRAINTS

Numerous federal and state laws, policies, and executive orders mandate specific regulatory considerations with regard to protection and management of water-related resources in and adjacent to the national lakeshore. Additionally, policies and guidelines of the National Park Service broadly require management of natural resources of the national park system to maintain, rehabilitate and perpetuate the inherent integrity of aquatic resources.

Federal

National Park Service Organic Act of 1916

Through this act, Congress established the National Park Service and mandated that it “shall promote and regulate the use of the federal areas known as national parks, monuments, and reservations by such means and measures as conform to the fundamental purpose of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of future generations.” Congress, recognizing that the enjoyment by future generations of the national parks can be ensured only if the superb quality of park resources and values is left unimpaired, has provided that when there is a conflict between conserving resources and values and providing for enjoyment of them, conservation is to be predominant. This is how courts have consistently interpreted the Organic Act.

The General Authorities Act of 1970 reinforced this act -- all parklands are united by a common preservation purpose, regardless of title or designation. Hence, federal law protects all water resources in the national park system equally, and it is the fundamental duty of the National Park Service to protect those resources unless otherwise indicated by Congress.

Redwood National Park Act

In 1978 an act expanding Redwood National Park further amended the general authorities of the National Park Service to mandate that all park system units be managed and protected "in light of the high public value and integrity of the national park system." Furthermore, no activities should be undertaken "in derogation of the values and purposes for which these various areas have been established", except where specifically authorized by law or as may have been or shall be directly and specifically provided for by Congress. Thus, by amending the general Authorities Act of 1970, this act reasserted system-wide the high standard of protection prescribed by Congress in the Organic Act.

National Parks Omnibus Management Act of 1998

Recognizing the ever increasing societal pressures being placed upon America's unique natural and cultural resources contained in the national park system, this act attempts to improve the ability of the National Park Service to provide state-of-the-art management, protection, and interpretation of and research on the resources of the national park system by:

- assuring that management of units of the national park system is enhanced by the availability and utilization of a broad program of the highest quality science and information;
- authorizing the establishment of cooperative agreements with colleges and universities and the establishment of cooperative study units to conduct multi-disciplinary research and develop integrated information products on the resources of the national park system;
- undertaking a program of inventory and monitoring of national park system resources to establish baseline information and to provide information on the long-term trends in the condition of national park system resources; and
- taking such measures as are necessary to assure the full and proper utilization of the results of scientific study for park management decisions. In each case in which an action undertaken by the National Park Service may cause a significant adverse effect on a park resource, the administrative record shall reflect the manner in which unit resource studies have been considered. The trend in the condition of resources of the national park system shall be a significant factor in the annual performance.

Sleeping Bear Dunes National Lakeshore (1970)

The national lakeshore was established for the purpose of preserving this portion of Lake Michigan shoreline for the inspiration, education, and recreational use and enjoyment of the American people, while at the same protecting the area from development. Hunting and fishing are allowed in accordance with the State of Michigan. No hunting zones (with associated regulations) may be established for reasons of public safety, administration or public use and enjoyment.

Wilderness Act of 1964

The Wilderness Act established the National Wilderness Preservation System, composed of federal lands designated as wilderness areas. A wilderness, in contrast with those areas where man and his own works dominate the landscape, is … an area where the earth and its community of life are untrammeled by man… an area of undeveloped federal land retaining its primeval character and influence… which is protected and managed so as to preserve its natural conditions that:

- appear to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable;
- provide outstanding opportunities for solitude or a primitive and unconfined type of recreation; and,
- has at least 5,000 acres of land or are of sufficient size as to make practicable their preservation and use in an unimpaired condition.

Except as provided by law, there are no permanent roads within any wilderness area. Except as needed for administrative purposes, there are to be no temporary roads or use of motorized vehicles or motorized equipment, no landing of aircraft, no other form of mechanical transport, and no structure or installation within any wilderness area.

Approximately, 46 percent of the national lakeshore is, by law, managed as wilderness, and includes the following areas:

- all of North Manitou Island except 26 acres;
- all of South Manitou Island except 145 acres;
- approximately 4,288 acres of the Pyramid Point/Good Harbor Bay;
- approximately 5,767 acres in the Otter Creek watershed; and,
- approximately 2,960 acres in the Platte River watershed.

The management of these areas as wilderness could constrain water resource management activities, such as ease of access to monitoring stations and the need for structures for purposes of mitigation or reclamation. Additionally, existing drinking water wells are being closed to comply with the Act; visitors will be forced to carry or purify water. This could pose a visitor safety problem on North and South Manitou islands, where various types of waste (including biological) have been washing up on the shores of the islands with increasing frequency.

Endangered Species Act of 1973

The Endangered Species Act requires the National Park Service to identify and promote the conservation of all federally listed endangered, threatened, or candidate species within any park unit boundary. This act requires all entities using federal funding to consult with the Secretary of Interior on activities that potentially impact endangered flora and fauna. It requires agencies to protect endangered and threatened species as well as designated critical habitats. While not required by legislation, it is the policy of the National Park Service to also identify state and locally listed species of concern and support the preservation and restoration of those species and their habitats.

Coastal Zone Management Act of 1972

The Coastal Zone Management Act enables coastal states, including Great Lakes states, to develop a coastal management program that would improve protection of sensitive shoreline resources, identify coastal areas appropriate for development, designate areas hazardous to development and improve public access to the coastline.

Michigan was among the first states to have its coastal program approved in 1978. The program, administered by the Michigan Department of Environmental Quality, includes local pass-through grants, administration of coastal sections of Michigan's Natural Resource and Environmental Protection Act of 1994, and review of federal agency activities for consistency with Michigan's approved program.

National Environmental Policy Act

Congress passed the National Environmental Policy Act (NEPA) in 1969. Environmental compliance in the National Park Service encompasses the mandates of NEPA and all other federal environmental laws that require evaluation, documentation and disclosure, and public involvement, including the Endangered Species Act, Clean Water Act, Executive Orders on Floodplains and Wetlands, and others.

All natural resource management and scientific activities are subject to environmental analysis under NEPA through the development of environmental assessments and environmental impact statements. Parks are encouraged to participate as cooperating agencies in the environmental compliance process to the fullest extent possible when National Park Service resources may be affected, and as set forth in Council on Environmental Quality (CEQ) regulations. Participation by the National Park Service in the environmental compliance processes of other agencies and jurisdictions is an important management tool. It can provide the National Park Service with information that will allow the Service to respond to possible external threats to a park well before they occur.

Section 102 of NEPA sets forth a procedural means for compliance. The CEQ regulations further define the requirements for compliance with NEPA.

An environmental assessment is not included as part of this water resources management plan because this plan provides a general direction for the water resources program for the national lakeshore. Compliance with NEPA will be undertaken for specific actions resulting from this plan, where appropriate, when it becomes apparent that individual actions or groups of actions will be implemented.

Clean Air Act of 1970, as amended

The Clean Air Act regulates airborne emissions of a variety of pollutants from area, stationary, and mobile sources. The 1990 amendments to this act were intended primarily to fill the gaps in the earlier regulations, such as acid rain, ground level ozone, stratospheric ozone depletion and air toxics. The amendments identify a list of 189 hazardous air pollutants. The U.S. Environmental Protection Agency must study these chemicals, identify their sources, determine if emissions standards are warranted, and promulgate appropriate regulations. That list includes PCBs; dioxins and furans; chlordane, mercury compounds; lead compounds; cadmium compounds; toxaphene; and trichlorobenzene, to name a few.

The Clean Air Act directs the U.S. Environmental Protection Agency to monitor, assess, and report on the deposition of toxic air pollutants to the "Great Waters," which include the Great Lakes. Activities include establishing a deposition monitoring network, investigating sources of pollution improving monitoring methods, evaluating adverse effects, and sampling for the pollutants in aquatic plants and wildlife.

Federal Water Pollution Control Act of 1972 (Clean Water Act)

The Federal Water Pollution Control Act, more commonly known as the Clean Water Act, was first promulgated in 1972 and amended several times since (e.g. 1977, 1987 and 1990). This law is designed to restore and maintain the chemical, physical and biological integrity of the nation's waters, including the waters of the national park system. To achieve this, the act called for a major grant program to assist in the construction of municipal sewage treatment facilities, and a program of effluent limitations designed to limit the amount of pollutants that could be discharged. Effluent limitations are the basis for permits issued for all point source discharges, known as the National Pollutant Discharge Elimination System (NPDES).

As part of the act, Congress recognized the primary role of the states in managing and regulating the nation's water quality. Section 313 requires that all federal agencies comply with the requirements of state law for water quality management, regardless of other jurisdictional status or landownership. States implement the protection of water quality under the authority granted by the Clean Water Act through best management practices and through water quality standards. Standards are based on the designated uses of a water body or segment of water, the water quality criteria necessary to protect that use or uses, and an anti-degradation provision to protect the existing water quality.

A state's antidegradation policy is a three-tiered approach to maintaining and protecting various levels of water quality. Minimally, the existing uses of a water segment and the quality level necessary to protect the uses must be maintained. The second level provides protection of existing water quality in segments where quality exceeds the fishable/swimmable goals of the Clean Water Act. The third level provides protection of the state's highest quality waters where ordinary use classifications may not suffice; these are classified as Outstanding National Resources Waters (ONRW). In Michigan the State designates Outstanding State Resource Waters (OSRW).

The State of Michigan designates all waters of the national lakeshore as OSRW. Because of this designation water quality controls shall be applied on pollutant sources to the waters of the national lakeshore so that water quality is not lowered in the national lakeshore. Specifically, for all waters in the national lakeshore the level of water quality necessary to protect existing uses shall be maintained and protected. Where designated uses are not attained, there shall be no lowering of water quality with respect to the pollutant or pollutants that are causing the nonattainment. A short term, temporary lowering of water quality in the national lakeshore may be permitted by the State on a case by case basis. Conversely, where for individual pollutants the quality of water is better than the water quality standards that water shall be considered high quality and that quality shall be maintained and protected. Finally, the national lakeshore is eligible to apply for an OSRW designation for waters that are outside its boundaries, ensuring the protection of water that flows into the national lakeshore.

Section 303 of the act requires the promulgation of water quality standards by the states. Additionally, each state is required to review its water quality standards at least once every three years. This section also requires the listing of those waters where effluent limitations are not stringent enough to implement any water quality standard [so called 303(d) list]. Each state must establish, for each of the waters listed, total maximum daily loads for applicable pollutants.

Section 401 requires that any applicant for a federal license or permit to conduct an activity which will result in a discharge into waters of the U.S., shall provide the federal agency, from which a permit is sought, a certificate from the state water pollution control agency stating that any such discharge will comply with applicable water quality standards. Federal permits that require Water Quality Certification from the State of Michigan include 404 permits from the U.S. Army Corps of Engineers for the discharge of dredged or fill material.

Section 404 of the Clean Water Act further requires that a permit be issued for discharge of dredged or fill materials in waters of the U.S., including wetlands. The U.S. Army Corps of Engineers administers the Section 404 permit program with oversight and veto powers held by the U.S. Environmental Protection Agency.

It was the 1987 amendment to the Clean Water Act that finally established stringent nonpoint source control mandate. Subsequent amendments further developed this mandate by requiring that states develop regulatory controls over nonpoint sources of pollution and over stormwater runoff from industrial, municipal, and construction activities. Many of the National Park Service's construction activities are regulated by the Clean Water Act under the stormwater permitting requirements.

<u>Section 10 of the Rivers and Harbors Appropriations Act of 1899, as amended</u>

This was the first general legislation giving the U.S. Army Corps of Engineers jurisdiction and authority over the protection of navigable waters. Navigable waters of the U.S. are those waters that are subject to the ebb and flow of the tide and/or are presently used, or have been used in the past, or may be susceptible for use to transport interstate or foreign commerce. U.S. Army Corps of Engineers permits are required under section 10 for structures and/or work in or affecting navigable waters of the U.S.

The U.S. Army Corps of Engineers began regulation of wetlands under this act, and then received a much broader grant of jurisdictional authority under the Clean Water Act. Because of the broader geographic reach of "waters of the U.S." jurisdiction under the Clean Water Act, Rivers and Harbors Act jurisdiction will usually not be of significance to wetlands regulation in current cases. There are, however, several situations in which Rivers and Harbors Act jurisdiction alone will be available: when an exemption from section 404 coverage applies, and when activities, as opposed to waters, are covered by the Rivers and Harbors Act and not the Clean Water Act. For instance, the mooring of houseboats in a bay may require a permit under the Rivers and Harbors Act, but would not under the Clean Water Act.

<u>National Invasive Species Act of 1996</u>

The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 was re-authorized through this 1996 act. Under the 1990 act, the Great Lakes became the first area where ballast water regulations were imposed. The 1996 act extends the ballast management program to the national level and enhances other national monitoring, management and control programs.

Fish and Wildlife Coordination Act of 1965

This act requires federal agencies to consult with the U.S. Fish and Wildlife Service or the National Marine Fisheries Service and with parallel state agencies whenever water resource development plans result in alteration of a body of water. The Secretary of the Interior is authorized to assist and cooperate with federal agencies to "provide that wildlife conservation shall receive equal consideration and be coordinated with other features of water-resource development programs."

Safe Drinking Water Act and Amendments

This act directs the U.S. Environmental Protection Agency to publish and enforce regulations on maximum allowable contaminant levels in drinking water. The act requires the Environmental Protection Agency to issue regulations establishing national primary drinking water standards. Primary enforcement responsibilities lie with the states. The act also protects underground sources of drinking water with primary enforcement responsibilities again resting with the states. Federal agencies having jurisdiction over public water systems must comply with all requirements to the same extent as any non-governmental entity.

The 1996 amendments to the Safe Drinking Water Act initiated a new era in cost-effective protection of drinking water quality, state flexibility, and citizen involvement. Source water assessment and protection programs, provided under these amendments, offer tools and opportunities to build a prevention barrier to drinking water contamination. Source water protection means preventing contamination and reducing the need for treatment of drinking water supplies. Source water protection also means taking positive steps to manage potential sources of contaminants and contingency planning for the future by determining alternative sources of drinking water.

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

This act commonly referred to as Superfund, was enacted in 1980. It creates a federal Superfund to clean up uncontrolled or abandoned hazardous waste sites as well as accidents, spills and other emergency releases of pollutants. The act contains an extensive list of hazardous substances that are subject to release reporting regulations. The National Response Center must be notified immediately by the person in charge of a vessel or facility when there is a release of any environmental media of a designated hazardous substance exceeding the predefined reportable quantity within any 24-hr period. The reporting quantities are determined on the basis of aquatic toxicity, reactivity, chronic toxicity, and carcinogenicity, with possible adjustments based upon biodegradation, hydrolysis, and photolysis.

Resource Conservation and Recovery Act

This act, enacted in 1976, establishes a regulatory structure for handling, storage, treatment, and disposal of solid and hazardous wastes. Many products and materials are regulated under this at, including commercial chemical products; manufactured chemical intermediates; contaminated soil, water, or other debris resulting from the cleanup of a spill into water or on dry land; and containers and inner liners of the containers used to hold waste or residue.

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)

Congress originally passed this act of 1947 as a consumer protection statute focused on the registration and labeling of pesticides. It now also regulates the sale, distribution, use, and cancellation of pesticides within the United States. Under this act, the U.S. Environmental Protection Agency has the authority to study the consequences of pesticide use and to require users to register when purchasing pesticides.

Executive Order 13112 – Invasive Species

Signed in 1999, this E.O. complements and builds upon existing federal authority to aid in the prevention and control of invasive species.

Executive Order for Floodplain Management (E.O. 11988)

The objective of E. O. 11988 (Floodplain Management) is "… to avoid to the extent possible the long- and short-term adverse impacts associated with the occupancy and modification of floodplains and to avoid direct and indirect support of floodplain development wherever there is a practicable alternative." For non-repetitive actions, the E.O. states that all proposed facilities must be located outside the limits of the 100-year floodplain. If there were no practicable alternative to construction within the floodplain, adverse impacts would be minimized during the design of the project. National Park Service guidance pertaining to this E.O. can be found in Director's Order #77-2, Floodplain Management (currently under draft review). It is National Park Service policy to recognize and manage for the preservation of floodplain values, minimize potentially hazardous conditions associated with flooding, and adhere to all federally mandated laws and regulations related to the management of activities in flood-prone areas. Particularly, it is the policy of the National Park Service to:

- restore and preserve natural floodplain values;
- avoid to the extent possible, the long- and short-term environmental impacts associated with the occupancy and modification of floodplains, and avoid direct and indirect support of floodplain development wherever there is a practicable alternative;

- minimize risk to life and property by design or modification of actions in floodplains, utilizing non-structural methods when possible, where its is not otherwise practical to place structures and human activities outside of the floodplain; and,
- require structures and facilities located in a floodplain to have a design consistent with the intent of the Standards and Criteria of the National Flood Insurance Program (44 CFR 60).

<u>Executive Order for Wetlands Protection (E.O. 11990)</u>

Executive Order 11990, entitled "Protection of Wetlands", requires all federal agencies to "minimize the destruction, loss or degradation of wetlands, and preserve and enhance the natural and beneficial values of wetlands." Unless no practical alternatives exist, federal agencies must avoid activities in wetlands that have the potential for adversely affecting the integrity of the ecosystem. National Park Service guidance for compliance with E.O. 11990 can be found in Director's Order #77-1 and Procedural Manual #77-1, "Wetlands Protection." Particularly, it is the policy of the National Park Service to:

- avoid to the extent possible the long- and short-term adverse impacts associated with the destruction or modification of wetlands;
- preserve and enhance the natural and beneficial values of wetlands;
- avoid direct or indirect support of new construction in wetlands wherever there is a practicable alternative;
- adopt a goal of no net loss of wetlands and strive to achieve a longer-term goal of net gain of wetlands servicewide;
- conduct or obtain parkwide wetland inventories to help assure proper planning with respect to management and protection of wetland resources;
- use "Classification of Wetlands and Deepwater Habitats of the United States " (Cowardin et al. 1979) as the standard for defining, classifying and inventorying wetlands;
- employ a sequence of first avoiding adverse wetland impacts to the extent practicable; second, minimizing impacts that could not be avoided; and lastly, compensating for remaining unavoidable adverse wetland impacts at a minimum 1:1 ratio via restoration of degraded wetlands;
- prepare a Statement of Findings to document compliance with Director's Order #77-1 when the preferred alternative addressed in an environmental assessment or environmental impact statement will result in adverse impacts on wetlands; and,
- restore natural wetland characteristics or functions that have been degraded or lost due to previous or ongoing human activities, to the extent appropriate and practicable.

National Park Service Management Policies and Guidelines

The National Park Service Management Policies (2001) provide broad policy guidance for the management of units of the national park system. Topics include park planning, land protection, natural and cultural resource management, wilderness preservation and management, interpretation and education, special uses of the parks, park facilities design, and concessions management.

With respect to water resources, it is the policy of the National Park Service to determine the quality of park surface and ground water resources and avoid, whenever possible, the pollution of park waters by human activities occurring within and outside of parks. In particular the National Park Service will work with appropriate governmental bodies to obtain the highest possible standards available under the Clean Water Act for protection of park waters; take all necessary actions to maintain or restore the quality of surface and ground waters within the parks consistent with the Clean Water Act and all applicable laws and regulations; and, enter into agreements with other agencies and governing bodies, as appropriate, to secure their cooperation in maintaining or restoring the quality of park water resources.

The National Park Service will also manage watersheds as complete hydrologic systems, and will minimize human disturbance to the natural upland processes that deliver water, sediment and woody debris to streams. The National Park Service will manage streams to protect stream processes that create habitat features such as floodplains, riparian systems, woody debris accumulations, terraces, gravel bars, riffles and pools.

The National Park Service will achieve the protection of watershed and stream features primarily by avoiding impacts to watershed and riparian vegetation and by allowing natural fluvial processes to proceed unimpeded. When conflicts between infrastructure (such as bridges) and stream processes are unavoidable, park managers will first consider relocating or redesigning facilities, rather than manipulating streams. Where stream manipulation is unavoidable, managers will use techniques that are visually non-obtrusive and that protect natural processes to the greatest extent practicable.

Additionally, natural shoreline processes (such as erosion, deposition, dune formation, and shoreline migration) will be allowed to continue without interference. Where human activities or structures have altered the nature or rate of natural shoreline processes, the National Park Service will investigate alternatives for mitigating the effects of such activities or structures. The National Park Service will comply with the provisions of Executive Order 11988 and state coastal zone management plans prepared under the Coastal Zone Management Act.

Recommended procedures for implementing service-wide policy are described in the National Park Service guideline series. The guidelines most directly pertaining to actions affecting water resources include:

Director's Order #2: Park Planning;
Director's Order #12: Conservation Planning, Environmental Impact Analysis, and Decision-making;
Director's Order #77-1: Wetland Protection;
Director's Order #77-2: Floodplain Management (under draft review);
Director's Order #83: Public Health;
NPS-75: Natural Resource Inventory and Monitoring; and
NPS-77: Natural Resources Management.

State of Michigan Statutes

The State of Michigan follows the Riparian Doctrine in allocating its water resources, and has several established programs to help protect resource values within and outside the national lakeshore's boundaries.

In 1994 the State of Michigan enacted the Natural Resources and Environmental Protection Act (Act 451) to codify, revise, consolidate and classify laws relating to the environment and natural resources of the state. Below are descriptions and limited annotations of parts of this act that pertain to water resources, directly or indirectly, and that are of importance to the national lakeshore:

- Part 31 – Water Resources Protection
  This part establishes water quality standards, establishes the State's antidegradation policy, defines and establishes Outstanding State Resource waters, toxic substance water quality-based effluent limits for point source discharges, requirements related to the implementation of the National Pollutant Discharge Elimination System, and standards for land application and recycling of biosolids originating from domestic and sanitary sewage treatment systems.
- Part 33 – Contamination of Waters
- Part 81 – General Nonpoint Source Pollution Control
- Part 87 – Groundwater and Freshwater Protection
- Part 88 – Water Pollution and Environmental Protection Act
  This part provides for grants to local government and non-profit entities to implement best management practices in approved watershed management plans, and for contracts under the Clean Water Fund to implement the environmental quality monitoring program for Michigan's surface waters, water pollution control projects, storm water treatment projects and well head protection projects.
- Part 91 – Soil Erosion and Sedimentation Control
- Part 95 – Watercraft Pollution Control
- Part 301 – Inland Lakes and Streams

- Part 303 – Wetlands Protection
- Part 305 – Natural Rivers
- Part 307 – Inland Lake Levels
- Part 309 – Inland Lake Improvements
- Part 311 – Local River Management
- Part 313 – Surplus Waters
- Part 315 – Dam Safety
- Part 321 – Great Lakes Compact Authorization
- Part 322 – Great Lakes Basin Compact
- Part 323 – Shorelands Protection and Management
- Part 325 – Great Lakes Submerged Lands
- Part 326 – Great Lakes Submerged Logs Recovery
- Part 327 – Great Lakes Preservation
- Part 329 – Great Lakes Protection
- Part 333 – Coastal Beach Erosion
- Part 337 – Flood, Drainage and Beach Erosion Control
- Part 351 – Wilderness and Natural Areas
- Part 355 – Biological Diversity Conservation
- Part 358 – Adopt-A-Shoreline Program
- Part 359 – Adopt-A-River Program
- Part 451 – Fishing From Inland Waters
- Part 453 – Fishing With Hook and Line
- Part 455 – Frogs
- Part 457 – Mussels
- Part 477 – Fish Restoration and Management Projects
- Part 487 – Sportfishing

A complete description of each of these parts is available at < http://www.michiganlegislature.org/law/getobject.asp?objName=Act-451-of-1994 >.

REGIONAL ENVIRONMENTAL SETTING

The Great Lakes are the most prominent natural feature of region. They have a combined surface area of about 94,000 mi^2 draining more than twice as much land, and are among the largest, deepest lakes in the world (Figure 2). They are the largest single aggregation of freshwater on the planet, excluding the polar ice caps, holding an estimated six quadrillion gallons of water or 18 percent of the world supply (Great Lakes Commission 1999).

Lake Michigan is 22,300 mi^2 in size but drains an area of 45,600 mi^2. The average depth of Lake Michigan is 279 ft and the maximum depth is 925 ft. The lake contains 1,170 mi^3 of water with a retention time of 99 years. It is the largest lake entirely within the US and second largest of Great Lakes. Water flows into the Lake from tributaries draining the lake basin and rain and snow falling on the Lake itself. Melting snows and basin precipitation in spring and summer add the

Figure 2. Boundary of the Great Lakes watershed. After Great Lakes Commission (1999).

most water. Thus, the highest annual water levels occur during the warm half of the year culminating in August. The highest recorded level was 581.3 feet in 1886 and the lowest was 575.5 feet in 1964. Varying water levels cause differences in the amount of beach area or erosion of shore dunes and bluffs, erosion influences harbor depths, water depths along shore, and the amount of suspended particles in the offshore waters.

Although Lake Michigan contains a large amount of surface water, ground water is an important component of the hydrologic budget of the region. Granneman et al. (2000) developed an approximate water budget for Lake Michigan that quantifies the flow of water into and out of Lake Michigan. Lake Michigan is in a topographically low setting that, under natural conditions, causes the lake to function as a sink for the ground water flow system. Of all the Great Lakes, Lake Michigan receives the largest amount of direct ground water discharge (2,700 ft^3/s) because it has more sand and gravel aquifers near the shore than any other Great Lake. Although small in comparison to the amount of water stored in Lake Michigan, ground water directly and indirectly contributes about 80 percent of the water flowing from the watershed into Lake Michigan (Holtschlag and Nicholas 1998).

Despite its large size, Lake Michigan is sensitive to the effects of a wide range of pollutants, both point and nonpoint (U.S. Environmental Protection Agency and Government of Canada 1995). Because of the lake's large surface area, it is vulnerable to atmospheric pollutant deposition onto the lake surface. In addition, the relatively high retention time for the lake's volume of water means that pollutants that enter the lake are retained in the system and become more concentrated over time.

In the late 1960s, governments began to respond to public concern about the water quality in the Great Lakes. This response took the form of control and regulation of pollutant discharges and the construction of municipal sewage treatment plants. This concern was formalized in the 1st Great Lakes Water Quality Agreement between Canada and the US in 1972.

Significant strides in the reduction of pollutant discharges were made during the decade of the 1970s. The results were visible and demonstrated that past water quality degradation could be improved. Additionally, beyond the cleanup of local pollution problems, this decade of work put things into more of an ecological perspective – that regional and ecosystem scales are important to consider in attempts to further improve water quality. For example, in order to mitigate the algal blooms caused by cultural eutrophication, a lake-wide approach was required to understand the amount of phosphorus entering and leaving each lake and the sources of this nutrient. This mass balance approach was then combined with other research and modeling to set load limits. Additionally, increased monitoring and research on toxic substances, including persistent organic chemicals and metals, found that these substances are a system-wide problem – they still exert negative impacts on the chemical, physical and biological components of the Lake Michigan ecosystem. These remaining impacts are related to legacy contamination that results in fish consumption advisories and impairment to aquatic organisms and wildlife.

The 1978 Great Lakes Water Quality Agreement formally recognized the ecosystem approach and put more emphasis on the regional problem with toxic substances. A 1987 amendment to the Agreement called for the development of remedial action plans for geographical Areas of Concern where local use impairments exist. It also called for the development of lake-wide management plans for critical pollutants of regional importance. The purpose of these plans is the identification of the key steps needed to restore and protect the lakes. The Lake-wide Management Plan for Lake Michigan was completed in 2000 (U.S. Environmental Protection Agency 2000).

LAND USE

Historical Perspective

Extensive lumbering began in the area in the late 1800's and by 1910 had depleted the forest resources -- large scale timber harvesting subsequently declined. Aquatic resources were both directly and indirectly affected by these early forestry practices. Waterways were the primary source of transportation of timber. Streams were cleared of obstructions and dammed to facilitate transportation. Following deforestation, extensive forest fires were common throughout northern Michigan. Since the 1920s much of the cleared land has been reforested and currently a large percentage of the area is covered with secondary growth northern hardwoods, aspen, and pine.

As the timber industry declined in the area, cleared lands were available for farming. In 1903, hay, corn, and potatoes were important economic crops in Benzie County (Taube 1974). However, because soils of the region are generally poor to medium quality for agriculture, farming declined to relatively low levels by the early 1920's.

Seasonal recreation and development centered primarily on and adjacent to the lakes and streams of the area, have become increasingly important to the local economy. The area was well known for sport fishing back to the 1930's. In 1928, a trout rearing station was established on the Platte River that in 1967 was replaced by the Platter River Anadromous Fish Hatchery. With the increasing recreational demands on the aquatic resources of the national lakeshore, impacts due to human activities have become a concern. The lakes and streams have traditionally been considered to be of high quality; however, as early as the 1970s changes in aquatic communities of some heavily used lakes and streams suggested that water quality was being affected by human activities (Stockwell and Gannon 1975; Grant 1979).

Past use of the lands within the national lakeshore has resulted in hundreds of dump sites, both residential and commercial, 11 gravel pits, two known gas stations, five or six areas suspected of prior use as gas stations, and over 100 underground storage tanks from commercial, farming and residential use.

Present Day

Forested lands dominate the area – about 40 percent of the land in the 17-county area from Muskegon to Emmet counties is forested. Agricultural lands, including cropland and pastureland, represent approximately 28.4 percent of land use in this same area. Timber harvesting and farming are still practiced in the area, but on much smaller scales.

In Benzie County, Christmas trees and pulpwood are the major forest products, while fruit, mainly apples and cherries, are the leading economic crops (Taube 1974). Yield and product-quality concerns for these fruit crops led to relatively high use of pesticides, which constitute an important element of nonpoint source pollution in the area as they leach into groundwater or runoff into Lake Michigan tributaries and nearshore waters.

Small villages and private landholdings are interspersed throughout the national lakeshore. A number of inland lakes in this area share shorelines and watersheds with both the national lakeshore and local villages or private landholders (including private homes with septic systems). Many of the lakes are also heavily used for recreation during the summer months.

The Platte River mouth is dredged in September to provide boat access to Lake Michigan during the fall salmon run. Above the mouth, visitors use the lower 4.5 miles for canoeing, kayaking, and fishing.

Swimming is the major activity at the mouth of the Platte River from Memorial Day weekend to Labor Day. The Platte River is popular with swimmers primarily because its waters are generally warmer than the lake.

Visitors use the lower 4.6 miles of the Platte River for canoeing and kayaking during the same time period; one canoe livery and 1 permitee operate on the Platte River. This group rarely, if ever, fishes. Their use of the river typically involves paddling down the river and stopping to rest or picnic at one or more locations. On weekends large parties travel downstream by tying canoes together as makeshift rafts.

Canoeing and kayaking are also popular activities on the Crystal River. In fact there as been approximately a 100 percent increase in these recreational pursuits on the Crystal River in recent years. Two canoe liveries and three permitees operate on the Crystal River. Tubing is also on the increase in the Crystal River.

Otter Creek is too short to encourage canoeing but some occurs. Shalda Creek is not navigable.

Fishing on the Platte River is most popular in the spring when steelhead run and in September and October when coho and king salmon run. It is the fall season that places the heaviest pressure on the Platte River mouth.

In the spring and through the summer fishing is permitted along the banks of the Platte River. ‘Smelt dipping’ is a popular spring activity during the smelt’s spawning run up the river. Bank fishing in the summer is minimal; few sport fish are available. Such fishing that occurs in the summer is typically in Loon Lake.

Salmon fishing in the fall begins in Platte Bay where anglers seek the fish before they begin their migration up the river. Most salmon fishing takes place in Platte Bay and along the Lake Michigan shoreline. After the run starts, some fishing occurs along the banks of the Platte River above the weir, but most takes place in Loon Lake, especially during windy days that preclude boat launching at the Platte River mouth.

Some salmon fishing also occurs on Shalda and Otter creeks. Turtle trapping was popular on Otter Creek, but it is now a banned activity in the national lakeshore.

The following lakes and streams are closed to use by motorized vessels: Deer Lake; Bass Lake (Benzie Co.); Otter Lake; Round Lake; Florence Lake; Hidden Lake; Lake Manitou; North Bar Lake; Tamarack Lake; Shell Lake; Narada Lake; Tucker Lake; Otter Creek; and Shalda Creek. The following lakes and streams are designated as ‘no wake’ zones for all motorized vessels: Loon Lake; Bass Lake (Leelanau Co.); School Lake; Platte River; and Crystal River.

A pig farm within the boundaries of the national lakeshore and up gradient from the Otter Creek watershed is the site of land application of sewage. A private development adjacent to the national lakeshore, the Homestead Resort, has an above ground aerial sewage disposal system that operates on national lakeshore land.

Between North and South Manitou islands and the mainland shoreline is the Manitou Passage, a high-use shipping lane. There have been documented oil spills and human waste disposal from freighters using this shipping lane. The national lakeshore is also concerned with medical waste discharged from foreign vessels and potential contamination from blood-born pathogens; medical waste has been found on lakeshore beaches. There are many shipwrecks in the passage that are now part of the Manitou Passage Underwater Preserve. Some of these shipwrecks periodically leak oil and fuel.

PARK VISITATION

For the last decade of the 20th century visitation to the national lakeshore was consistently over a million visitors per year with an average of 1,203,699. The following table lists the range in visitation from 1990 to 2000:

YEAR	TOTAL NUMBER OF VISITORS
1990	1,216,870
1991	1,246,333
1992	1,176,265
1993	1,182,843
1994	1,159,676
1995	1,151,957
1996	1,091,005
1997	1,157,616
1998	1,298,205
1999	1,364,834
2000	1,195,084

EXISTING RESOURCE CONDITIONS

GLACIAL AND POST-GLACIAL HISTORY OF THE SLEEPING BEAR DUNES AREA

Overview

The physical geography of Michigan and the Great Lakes is largely the result of the sculpturing, erosion, and deposition of materials by the advance and retreat of glaciers over the last 2 million years – the Pleistocene Epoch. These glaciers scoured the surface of the earth, leveled hills, and altered the previous ecosystem. Valleys created by the river systems of the previous era were deepened and enlarged to form the basins of the Great Lakes. Millennia later, the climate warmed causing retreat of the glaciers as they melted. Glacial retreat was followed by a relatively static interglacial period during which vegetation and wildlife returned. The cycle was repeated several times. The most important glacial advance for northwestern Michigan is the Wisconsin stage, which retreated from Michigan about 9,500 to 15,000 years ago.

As the glaciers retreated, meltwater formed along the front of the ice. Because the land was greatly depressed at this time from the weight of the glacier, large post-glacial lakes formed. These lakes were much larger than the present Great Lakes. Their legacy can still be seen in the form of beach ridges, eroded bluffs, and flat plains located hundreds of feet above present lake levels. Also, the land began to rise as the glaciers retreated. This uplift (or crustal rebound) and the shifting ice fronts caused dramatic changes in the depth, size and drainage patterns of the post-glacial lakes. Although this uplift has slowed considerably, it is still occurring in the northern portion of the Lake Michigan basin.

The land-sculpting effect of continental glaciation in northwest Michigan is clearly illustrated in the geologic features of the Sleeping Bear Dunes region (National Park Service 1961; Drexler 1974). The evidence indicates that Wisconsin ice lasted from approximately 50,000 to 10,000 years before present, with the ice having disappeared from the Sleeping Bear region about 11,800 years ago. During and following glacial retreat, the water levels of the Great Lakes fluctuated as they sought the lowest outlets, with the final adjustment as we know them today taking place about 3,000 years ago (Drexler 1974).

Immense headlands, characteristic of the Lake Michigan shoreline in the vicinity of Sleeping Bear Dunes, for the most part, resisted the force of the advancing ice and steered the ice lobes into the valleys. The ice lobes gouged debris from the valley floors and deposited it along the sides of the valleys when the ice finally melted, creating prominent moraines. Generally, these moraines and the valleys between them are oriented in a north-south direction. The formation of the Manistee moraine (Figure 3) is considered to be the climatic event of glacial

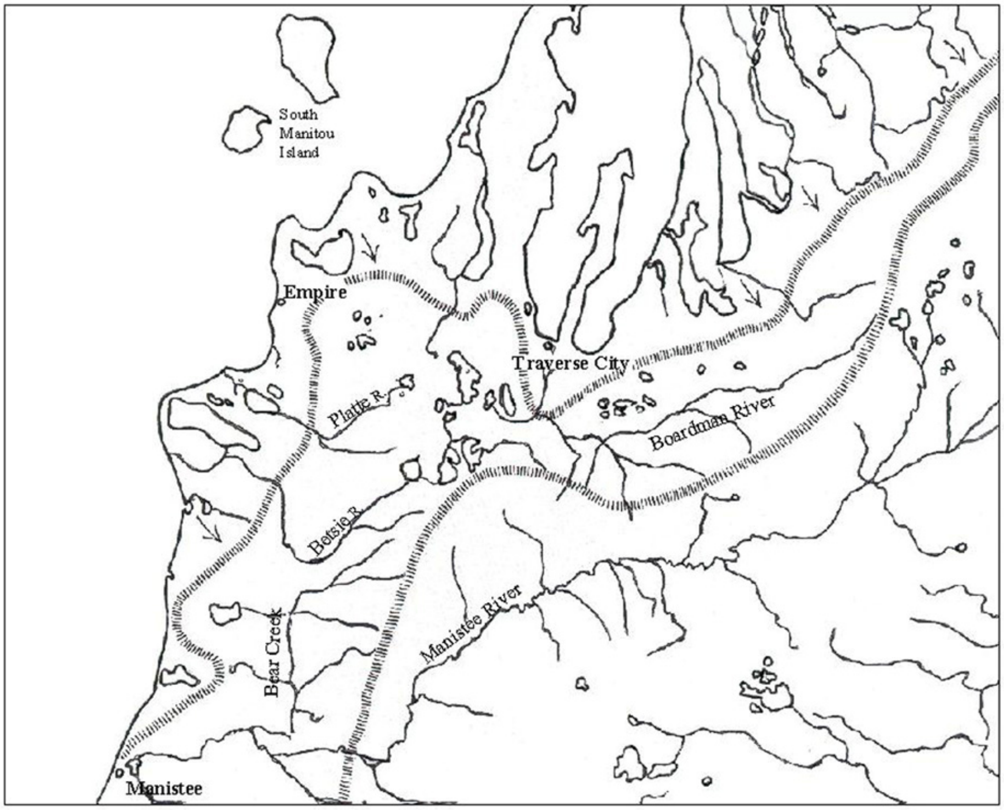


Figure 3. Relative position of Manistee Moraine. After National Park Service (1961).

processes that shaped the Sleeping Bear Dunes area (National Park Service 1961).

Meltwaters flowed southward from the glacier front and formed extensive outwash plains in southern Leelanau County and northern Benzie County. Where meltwater cut through the Manistee moraine, a drainage channel leading southward into the Platte River plain area was formed. The meltwater in several channels flowed opposite to the direction in which the streams run today; when the ice blockage disappeared, the flow was reversed and the streams began to run into the Lake Michigan basin.

As the glacial ice receded to the north, an immense volume of meltwater filled the Lake Michigan basin to form post-glacial lakes at four successive levels—Lakes Algonquin, Chippewa, Nippissing and Algoma. The elevation and extent of these lakes were dependent on the elevation of the lowest outlet available during that period. Drexler (1974) constructed figures of these successive lake stages of deglaciation in the national lakeshore. Evidence of these lakes can be seen through features such as wave-cut bluffs, beach terraces, sand bars, ridge and swale formations, and old sandy lake plains. When water receded from the lake plains, many smaller lakes were left in the embayment areas. In addition to mixed glacial materials, tremendous amounts of sand accumulated at various points throughout the region. These were later shaped by wind into the unusual variety of dunes found between Point Betsie and Good Harbor Bay, which include ancient dunes associated with the post-glacial lakes and modern dunes.

As the Wisconsin ice retreated out of the Lake Michigan and Lake Huron basins, the southern outlets of these glacial lakes were abandoned in favor of lower northern outlets (Drexler 1974). Ultimately, the water level in the Lake Michigan basin fell to an elevation of about 230 feet. This low-level lake is called Lake Chippewa. The low-water stage began about 10,000 years ago, and culminated in Lake Chippewa at about 7,500 years ago. Lake Chippewa gave way to the rising water level of the Lake Nipissing stage about 5,000 years ago when southern outlets again became functional because of continual crustal rebound in the north.

The Nipissing Lake stage ended about 3,500 years ago. From this time until 3,000 years ago the water level in the Lake Michigan basin lowered slowly in response to the continued downcutting at the northern outlet. A pause in the lowering occurred when the water level reached 595 feet – called Lake Algoma (Drexler 1974). Within the park there is little evidence for a distinct Algoma stage. Over the last 80 years the water level in the Lake Michigan basin has remained rather constant, ranging from 571 to 575 feet (< http://www.huron.lre.usace.army.mil/levels/hleumh.html >).

Formation of Hydrological Features at Sleeping Bear Dunes National Lakeshore

Seven substages of the Wisconsin stage are recognized (Hough 1958). These substages occurred successively to the north, the last being north of the Great Lakes. The fifth or Port Huron substage is the most important in the Sleeping Bear region, though the sixth or Valders substage briefly touched the area.

A highly developed morainic system from south of Manistee northward around the tip of the Lower Peninsula characterizes the Port Huron substage. This system includes a series of end moraines, ground moraines, outwash areas, glacial channels, deltas and glacial lakebeds. During the early part of the Port Huron substage most of the lower peninsula was ice-free; by the close of the substage the Lower Peninsula was completely ice-free. Therefore the characteristic topography of the Sleeping Bear region was fashioned during this time.

The northwestern corner of the Lower Peninsula is indented by a series of lakes, lowlands and bays. These features set this region apart from the area to the south. One reason for the prominence of this area is pre-glacial landscape. Though the evidence of the pre-glacial landscape is lacking, it is generally accepted that existing topography influenced the direction of ice movement (Flint

1957). In addition, following lines of least resistance, glacial ice advancing south along pre-glacial channels and along larger topographic features of the Great Lakes should be expected to show a highly lobate nature.

As the main ice lobe of the Port Huron substage advanced southward in the Lake Michigan basin, lateral lobes pushed glacial debris into the lowland valleys of tributaries. Between these tributary lobes a series of 'interlobate' moraines formed. In time these tributary lobes merged and pushed to the Port Huron maximum. In the tributary valleys the ice was thicker with more power to shape the landscape. After the thinner upland ice melted, the valley ice lobes remained, thus greatly influencing the glacial topography of the area.

As retreating ice melted, lakes formed between the ice margin and the end moraines. Water levels of these lakes rose until they cut outlets through the moraines forming outwash plains and glacial channels along the morainal front. These newly formed drainage systems were independent of the pre-glacial system. Flow in these channels depended on glacial volume and the extent of glacial melting; glacial topography largely controlled flow direction. Channels flowed between moraines formed by the Port Huron substage and those of previous substages. As the ice retreated northward, however, lower elevations were exposed and many streams abandoned the old glacial channels for these lower areas.

The final advance of the Port Huron substage formed the Manistee Moraine. During the formation of the Manistee Moraine, the ice edge maintained a nearly static position where melting equaled advance. The previous drainage pattern had been obliterated by previous glacial advance, though outwash channels formed a new drainage system, much of which is still extant today. Along the ice margin a vast river of meltwater was flowing south.

Meltwater eventually cut through three channels in the Manistee moraine; the most important was the Glen Lake Channel. This channel undercut the other ice border drainages and became the outlet for the area west of Grand Traverse Bay for a long while. A river of meltwater meandered southward from Glen Lake; skirted the ice filled Empire Embayment; flowed over the outwash plain east of Otter Lake and around the inner margin of the ice of the Platte Lobe; found its way into the ice filled Crystal Lake depression; flowed west of Benzonia and south along what is now the northward flowing Betsie River; and joined the shallow upper end of the Manistee ice border lake.

The Port Huron substage ended, when the ice re-treated farther northward and these ice border channels were vacated. Later, Valders ice flowed far to the south in the Michigan basin but the landscape/drainage systems were not visibly altered.

Following the retreat of the Valders ice, northwestern Michigan was never glaciated again. However, though the inland topography had been decided by Port Huron Ice, the shoreline underwent changes during the evolution of the glacial and post-glacial Great Lakes.

At the beginning of the Lake Algonquin stage (water elevation of 605 feet – 25 feet above present lake level), the lakeshore would have consisted of long peninsulas (interlobate moraines and islands intersperse with deep, narrow bays). At the end of this stage, the shoreline evolved to the point of truncating the moraines and sealing off at least part of the bays with bars and beaches.

The Lake Nipissing stage is also at an elevation of 605 feet. Because some crustal rebound occurred in the area of the lakeshore between the two stages, the shore features of the two lake stages are separate -- Nipissing shore features lie lower than those of the Algonquin stage.

For the national lakeshore, Calver's (1946) work in the Platte and Crystal lake depressions is the only detailed work on post-glacial shorelines. The Platte Lake Embayment forms an 8x8x6-mile triangle (Figure 4), almost equally divided by the small Platte interlobate moraine. It contains nine lakes with two separate drainages. Originally, the Platte Embayment was a Lake Algonquin bay with the Platte Moraine forming islands.

Following crustal rebound, the Platte Moraine probably formed two bays during the Nipissing stage. The Nipissing shoreline impounded a large lake including Long, Rush, Platte and Little Platte lakes and possibly the Otter Creek lakes.

Under the wave-cut bluffs east and north of the Otter Creek lakes are a series of cold flowing springs. These springs flow southwesterly towards Otter Creek, which flows north-northwest. In this area an extinct lake once existed, the bed of which is heavily underlain with marl deposits.

The springs, the primary source of Otter Creek's flow, apparently come from ground water flow in the old Glen Lake glacial drainage from about the midpoint of the Empire Meander southward. It is possible that Otter Creek once drained into the Platte Embayment, but filling of the embayment during the Lake Nipissing stage blocked this flow. Later drainage to the north may have been responsible for the extinction of the former lake.

The Bar Lake Embayment, about 3 miles long and 1.5 miles wide, is bordered to the northeast by the Sleeping Bear Moraine and to the south by the Algonquin shoreline. The Algonquin shoreline appears as a series of beach ridges that pass directly through the town of Empire to their connection with the Empire Bluffs. Behind the shoreline lay a concentric lagoon, still discernable as a low depression.

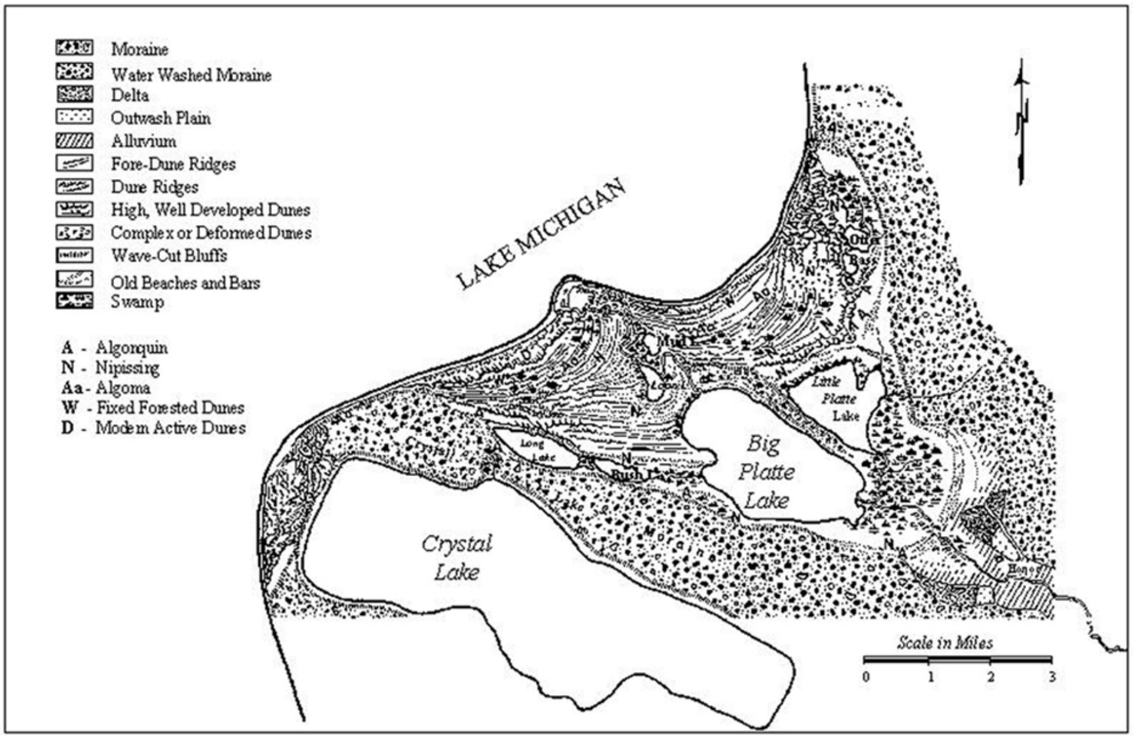


Figure 4. Platte Embayment as portrayed by Calver (1949).

During Nipissing times both the Empire and Sleeping Bear Moraines projected farther lakeward than at present. A shoreline was built spanning the embayment and creating a crescent-shaped lagoon. North and South Bar lakes were created by a series of large, barrier-beach dunes that dissected the lagoon.

The most visible shoreline feature at Glen Lake is the wave-cut north face of the Glen Lake Moraine, a prominent beach ridge along the north side of Glen Lake. Little Glen Lake once opened northwesterly to Lake Michigan between the Sleeping Bear and Glen Lake Moraines; however, this channel has long been filled by the sands of the Sleeping Bear Dunes.

At Good Harbor Bay, Bass, School and Lime lakes, all at an elevation of 620 feet, were closed off early during the Lake Algonquin stage. During the Lake Nipissing stage, a crescent-shaped belt of dunes closed off Little Traverse Lake. The Lake Algoma stage or the present shoreline, however, probably closed off Shell Lake.

CLIMATE

Warm moist air from the Pacific Ocean and the Gulf of Mexico collides with cold, dry arctic air over the Great Lakes basin. Due to their sheer size and volume, the lakes moderate the effects of both systems by acting as a heat sink or cold sink. As a result, shoreline temperatures around Lake Michigan are cooler than inland in the summer. In the winter, the warm lake waters moderate the air temperature and the shoreline is warmer than inland. In addition to modifying temperatures, the lake influences weather patterns, precipitation, and wind velocity and direction.

Extreme seasonal temperature variations and a fairly even annual distribution of precipitation are typical of the upper Great Lakes region. However, climatic conditions in the vicinity of the national lakeshore are strongly influenced by Lake Michigan, which has a stabilizing effect on air temperatures. Because of prevailing westerly winds, winters are milder and summers cooler along the shoreline than in the interior areas.

Only when southerly winds are strong enough to overcome the prevailing lake breeze does the temperature climb to the 90^{o} F level. From June through August, daily maximum temperatures range from 71^{o} to 90^{o} F. July's mean maximum is 80^{o} F. In winter, temperatures below zero are recorded on an average of only 4 days per year. January's mean minimum temperature is 18^{o} F.

Average annual precipitation is between 28 to 32 inches, and is well distributed throughout the year. September is the wettest month, and December through March the driest period. Infrequent thunderstorms produce most of the summer precipitation within the lakeshore. There are nearly 50 percent fewer days with measurable precipitation in the summer than winter months.

Snowfall totals average about 95 inches on the shoreline and increase to between 120 and 130 inches inland. Measurable snowfall occurs on an average of 15 days each month from December to March. Mean dates of the last Spring and first Fall frosts are May 25 and October 6, respectively, giving an average growing season of 134 days.

The prevailing wind direction is from the southwest, averaging 10.8 mph throughout most of the year. In the fall and early winter, the prevailing direction is northwest, and in late winter it is northeast.

AIR QUALITY

In recent years the effects of atmospheric deposition on water quality in the Great Lakes region has been the subject of increased scientific study and concern. This increased study is a direct result of 30 years of data collection showing that toxic chemicals released into the air can travel long distances and be deposited on land or water at locations far from their original sources.

A 1997 inventory update, a product of the Great Lakes Regional Air Toxic Emissions Inventory Project (< http://www.glc.org/air/air3.html >), presents a multi-jurisdictional inventory of point, area and mobile sources of toxic air emissions that have the potential to impact environmental quality in the Great Lakes region. Point, area, and mobile sources were identified for Benzie and Leelanau counties. While the absolute quantities of toxic chemical emissions differ for these counties the rankings are very similar. In descending order the most released toxic chemicals are toluene; xylene-iso; benzene; formaldehyde; trichloroethylene (TCE); xylene-m; and perchloroethylene (PERC).

The Integrated Atmospheric Deposition Network (IADN) is a joint effort of the US and Canada to measure atmospheric deposition of toxic materials to the Great Lakes. The IADN was mandated by a 1987 amendment of the Great Lakes Water Quality Agreement. The development plan for the network was approved in 1990. There is one master monitoring station on each lake that measures air, rain and particles for a suite of chemicals, including PCBs, PAHs (polyaromatic hydrocarbons), chlorinated pesticides (DDT) and trace metals including lead, arsenic and cadmium. The master station on Lake Michigan is located at Sleeping Bear Dunes National Lakeshore.

The Lake Michigan Mass Balance Study, launched in 1994, was designed to collect information about the concentration of contaminants in the environment, both in relation to their sources and to their effects in the ecosystem. It focuses on four chemicals that are persistent in the environment and/or bioaccumulate in the food chain: PCBs, trans-nonachlor (a component of chlordane), atrazine and mercury. Sleeping Bear Dunes National Lakeshore was a site where air samples were taken.

PCBs are a class of highly toxic, persistent and bioaccumulative chemical compounds that are also potentially carcinogenic. Atmospheric input of PCBs to Lake Michigan is an important pathway, accounting for over four times the loading levels coming from the water sources (Delta Institute 2000). In Lake Michigan there are significant variations in inputs of PCBs from dry deposition, ranging from 65 kg/yr to 1,100 kg/yr (Chicago urban area) (Delta Institute 2000). An IADN study concluded that PCBs in the lake water and air were approximately in equilibrium, which would allow water PCB concentrations to be tracked through air measurements (Hillery et al. 1998). Other studies have demonstrated that the atmosphere and Lake Michigan are both sources and sinks of PCBs (Offenberg and Baker 1997). Preliminary results from a recent study (Jules Blais, University of Ottawa, pers. comm.) point to a unique ‘source’ of PCBs in aquatic systems. Salmon that have spent the majority of their life cycle in the Great Lakes bioaccumulating PCBs migrate up rivers to spawn and die. This massive die-off may be actually considered a PCB load to rivers – Blais found that this PCB load was 1500 times as great as the load contributed from atmospheric deposition.

Polycyclic aromatic hydrocarbons (PAHs) are a category of semi-volatile organic compound, some of which are suspected carcinogens. They are formed during the incomplete combustion of organic matter such as wood, coal and gasoline. PAHs undergo chemical and physical changes as they are transported through the atmosphere. They can be deposited by wet and dry deposition and also move from air to water by air-water exchange. PAH concentrations in the air have been found to be generally an order of magnitude higher at urban monitoring sites than at rural or over-lake sites. Levels at some monitoring stations indicate that long-range transport was occurring (Simick et al. 1997; Keeler 1994).

Although most of the pesticides of concern in the Great Lakes are banned or use-restricted, many are still in current use in other countries (Delta Institute 2000). Therefore, long-range transport may be a significant source leading to the current levels in the Great Lakes. Volatilization is the more significant depositional process for many pesticides in the Great Lakes. For example, the net atmospheric loading for dieldrin is negative, indicating that net loses by volatilization are greater than inputs by all other depositional processes (Hillery et al. 1998).

Lindane is an organochlorine insecticide with strong potential for long-range transport. It is still widespread in use around the world, although most uses were restricted in the US in 1983. Wet and dry deposition appears to be fairly uniform across the Great Lakes (Delta Institute 2000).

Atrazine, a possible carcinogen, is one of the primary herbicides in use in the Great Lakes watershed and was the single-most used herbicide among corn and soybean crops in 1991 (Delta Institute 2000). Atrazine concentrations in precipitation concentrations have remained constant over the past 5 years, consistent with the steady sales of atrazine during that time. A study done between 1991 to 1995 found increasing atrazine concentrations in Lake Michigan waters, demonstrating a much greater persistence than had been measured on agricultural fields (Rygwelski et al. 1999). Atmospheric inputs account for 30 percent or less of the total load to Lake Michigan, where runoff and tributary loadings may be more significant.

Toxaphen, a semi-volatile organic compound considered carcinogentic, was used as an insecticide in the US and Canada until banned in 1982. Recent modeling work suggests that there were non-atmospheric sources to Lake Michigan (Pearson et al. 1997).

Mercury is an efficient bioaccumulator. Nearly all of the mercury that accumulates in fish tissue is the organic form called methylmercury (Delta Institute 2000). Inorganic mercury does not tend to bioaccumulate. Recent studies illustrate that atmospheric deposition is the major contributor of mercury to the Great Lakes (Pirrone et al. 1998). Mercury accumulation rates in sediment cores from the Great Lakes showed significant increases from pre-industrial to modern times that were larger than those reported for remote lakes in the Northeast. This indicated sources of mercury other than natural inputs to the Great Lakes area (Pirrone et al. 1998).

The results from IADN demonstrate the importance of the atmosphere both as a source and a sink (via volatilization from water and terrestrial sources) for contaminants. IADN results have demonstrated for the first time that air concentrations of PCBs and other persistent organochlorines are declining significantly in the Great Lakes region (< http://www.epa.gov/glnpo/air/iadndocs.html >). Modeling has shown the importance of source areas within the basin for metals and PAHs and more distant source areas for toxaphene and DDT.

GEOLOGY

The lakeshore is covered by recent (Holocene) alluvium and dune sand and Pleistocene glacial deposits (Handy and Stark 1984; Figure 5). Unconsolidated material, mostly sand, is the recent alluvium that forms present-day, riverine floodplains. The deposits of greatest areal extent occur along the Platte River. Two levels of sand dunes occur in the lakeshore – dunes near the current level of Lake Michigan and others on morainal plateaus 300 feet above the lake.

Glacial deposits, primarily moraines and outwash areas, in the lakeshore range from 500 to 700 feet thick (Handy and Stark 1984). Lakebeds formed after glacial retreat and during the post-glacial variations in the Lake Michigan water level. The deposits closest to the land surface and the physiography, in general are the result of glacial advance and retreat during the last glacial period, the Wisconsin. The study of the underlying bedrock has been infrequent because of the thickness of the glacial deposits.

Consolidated rock or bedrock underlies the glacial deposits. This bedrock consists of layered sedimentary units, primarily sandstone, shale and limestone (Handy and Stark 1984). Antrim Shale of Mississippian age and limestone of the Traverse Group of Devonian age underlie the bedrock. That bedrock that has been eroded is at altitudes ranging from below sea level to 200 feet.

Wallbom and Larson (1998) updated the surficial geology of the national lakeshore. They further delineated the recent and glacial deposits of Handy and Stark (1984) by recognizing 15 deposits.

The geologic history between the deposition of the Traverse-Antrim formations and the glacial deposits is unknown (Handy and Stark 1984). Apparently, either rocks were not deposited or any deposition was eroded during this time period.

SOILS

There are eight soil associations in the national lakeshore (National Park Service 1979; National Resources Conservation Service 1996). All of the soil associations are characterized by low available water capacity, primarily because

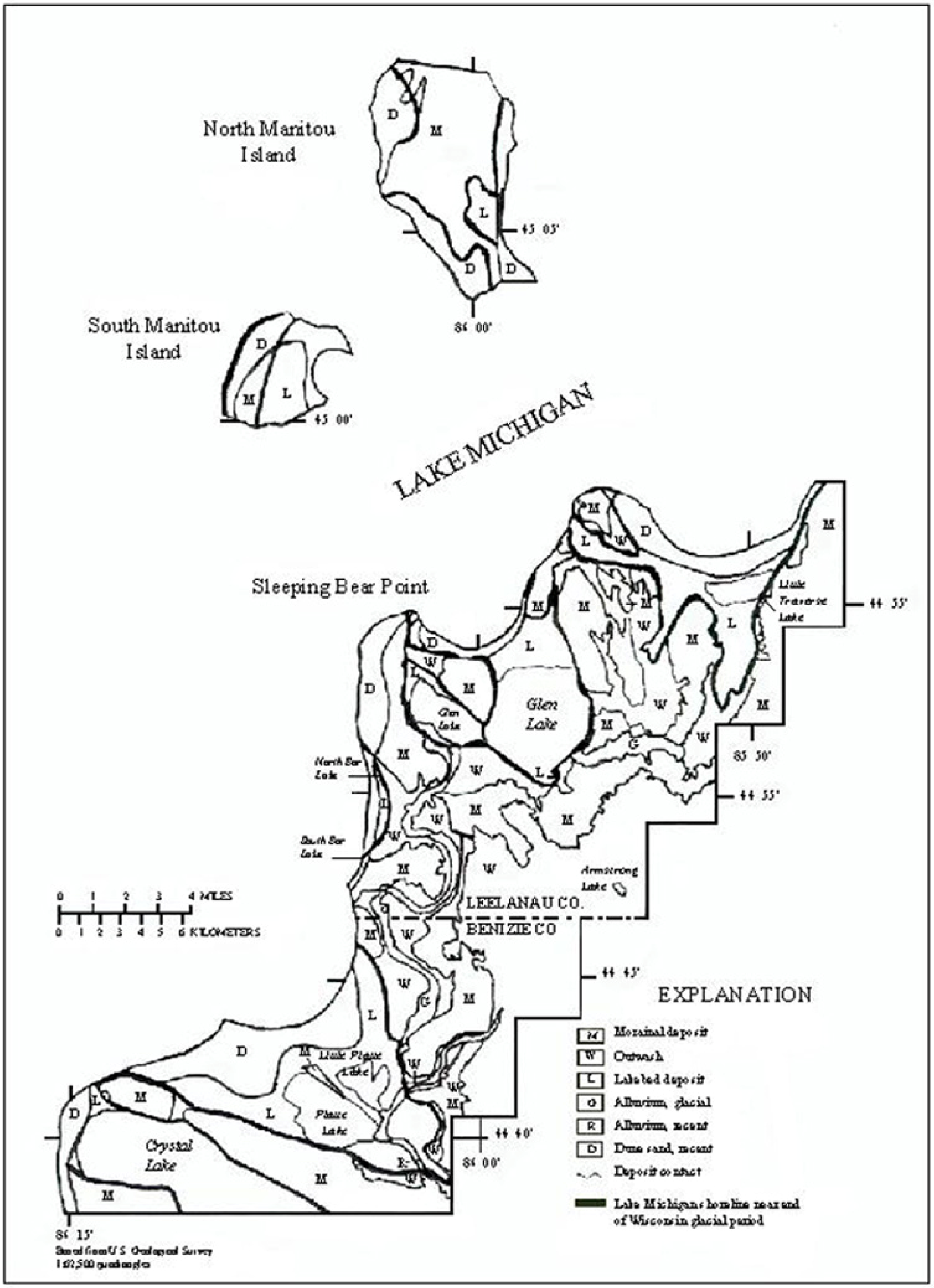


Figure 5. Distribution of recent and glacial deposits in Sleeping Bear Dunes Nationa Lakeshore. After Handy and Stark (1984).

these soils are well drained. The Kalkaska/Mancelona and Kiva/Mancelona associations are found on the glacial outwash plains. The soil of the beach ridges and lake terraces is the East Lake/Eastport/Lupton association. On wooded and active dunes the soil association is Deer Park/Dune. The remaining soil associations – Emmet/Omena, Emmet/Leelanau, Kalkaska/East Lake, and Leelanau/Mancelona – are all associated with moraines and to a lesser extent glacial till plains. As one might expect, these morainic soils are found on steeper slopes than the other soil associations.

VEGETATION

Sleeping Bear Dunes National Lakeshore is located in the Northern Central Hardwood forest of Michigan's Lower Peninsula (Omernik and Gallant1988). Before European settlement, jack pine, white pine and northern red oak dominated large areas of this region. The national lakeshore was almost entirely forested until settlers arrived in the mid-19th century. Timber cutting was the major livelihood for many years. Eventually, the land was further cleared for agriculture. Over the last 50 years, reforestation has occurred, partly with the help of tree-planting projects. Over ¾ of the land within the lakeshore is presently covered with a sub-mature second-growth forest. Hazlett (1991) provides a checklist of the vascular plants of the lakeshore.

The legacy of the moraines, outwash plains and the post-glacial effects of water and wind which formed relict beach ridges, bluffs and dunes provides a rich physiography at the lakeshore, and therefore a rich vegetation. As expected, vegetation types (and their subtypes) show a strong correlation to glacial and post-glacial geology (Hazlett 1986). The Coastal Forest type predominately occurs on the post-Nipissing dunes and relict beach ridges, while the Northern Hardwoods type is associated with moraines. The Oak-Aspen vegetation type also occurs on moraines, but these woods may be a delayed secondary succession (Hazlett 1986).

The Coastal Forest occupies much of the Platte area and also occurs along Sleeping Bear and Good Harbor bays. It is characteristic of the post-Nipissing lake plain that formed as the Lake Nipissing water level dropped to the present level of Lake Michigan.

At the lakeshore, four subtypes of the Coastal Forest are documented (Hazlett 1986). The Oak-Pine subtype, characterized by jack pine (*Pinus banksiana*), white pine (*P. strobus*), red pine (*P. resinosa*), and white oak (*Quercus alba*), occurs on the sandy ridges and some parabolic dunes of coastal areas. The Birch-Maple-Aspen subtype occurs near low moist sites and between old beach ridges in the Platte River, Crystal River and Shalda Creek areas, and along the beach ridges bordering Sleeping Bear and Good Harbor bays. In areas of repeating dune swales, the Platte River and Good Harbor Bay areas, the Coastal Forest has a mixed composition. The Birch-Maple-Aspen subtype predominates in the swales. Under wet conditions, alder thickets and open pools may be found in these swales. The dry Oak-Pine subtype may border directly on these wet areas. The Oak-Aspen vegetation type, characterized by bigtooth aspen and red oak, occurs mainly on the south facing slopes of moraines in the Good Harbor Bay area.

The Northern Hardwoods is a diverse vegetation type characterized by the dominance of beech (*Fagus grandifolia*) and sugar maple (*Acer saccharum*). Associated overstory species include basswood (*Tilia americana*), white ash (*Fraxinus americana*), black cherry (*Prunus serotina*), and red oak (*Quercus rubra*). Ironwood (*Ostrya virginiana*), white birch (*Betula papyrifera*) and hemlock (*Tsuga canadensis*) can be found less often.

Five subtypes of the Northern Hardwoods are recognized at the lakeshore (Hazlett 1986). The Beech-Maple-Ash subtype predominates on the moraines in the Glen Lakes area. The Maple-Ash-Basswood subtype occurs on the wooded dunes along the lake bluff between Empire Bluffs and Aral. The Beech-Maple-Ash-Oak subtype is most common on the moraines in the Good Harbor area. Most common in the northern Platte River area is the Maple subtype. The Beech-Maple-Birch-Hemlock subtype is generally found in coastal areas. Hazlett noted that the subtle floristic differences among these subtypes are hard to explain. The slightly different post-glaciation history for areas of the lakeshore may be the controlling factor.

Dune vegetation occurs on the coastal areas along Platte Bay, Sleeping Bear Bay, and Good Harbor Bay and on dunes at Empire Bluffs, the Sleeping Bear Plateau and Pyramid Point (Hazlett 1986). The floristic composition of the different dune areas is generally the same.

GROUND WATER HYDROLOGY AND QUALITY

There are two major aquifers represented at the lakeshore (Handy and Stark 1984; U.S. Geological Survey 2000). Material deposited during Pleistocene glacial advances comprises the surficial aquifer system. These ice sheets incorporated soil and rock fragments during advances and redistributed these materials on the eroded land surface as water- and/or ice-contact deposits during retreats. Glacial melt-water deposits are usually sorted and stratified deposits of sand or sand/gravel and include glacial outwash, lake sand, kames and eskers. These deposits are exposed at the land surface, permeable and readily receive, store, transmit, and discharge water. Kame deposits tend to be extremely permeable and commonly have collapse features that are the result of the melting of remnants of glacial ice beneath the deposits. Within the lakeshore these sorted and stratified deposits are the primary source of water for wells and are major contributors to stream base flow. Ice-contact deposits, called glacial till, are predominately the poorly sorted, unstratified deposits of ground and terminal moraines. Because of the heterogeneous nature of till, it tends to have minimal permeability and yields only small quantities of water to wells.

The surficial aquifer system is hydraulically connected to streams because of its shallow depth, ease of recharge via precipitation, and short ground water flow paths (U.S. Geological Survey 2000). However, the permeability of the aquifer deposits affects the strength of this connection. There is a direct relationship between permeability and hydraulic connection such that the connection decreases with decreasing permeability. Because the surficial aquifer system is, for the most part, highly permeable, it is vulnerable to contamination.

Underlying the surficial aquifer system is the Silurian-Devonian– primarily a dolomite/limestone that yields water from enlarged fractures and karstic features (U.S. Geological Survey 2000). The permeability of and water movement through the Silurian-Devonian aquifer are directly related to the amount of dissolution of carbonate. Large differences in transmissivity values occur between areas where this aquifer is overlain by the surficial aquifer and areas where the aquifer is confined. The availability of water in the surficial aquifer and the great depth of the glacial deposits overlying the bedrock probably will preclude the development of this aquifer in the lakeshore.

Handy and Stark (1984), in the first and only study of the lakeshore's ground water, developed a map of the potentiometric surface for the lakeshore (Figure 6). The potentiometric surface is the altitude of the water surface in wells, lakes, and streams. Handy and Stark caution that because of the geological complexity of the area and the many sources of water-level data used, the potentiometric surface for the lakeshore may reflect several flow systems.

The shape of the lakeshore's potentiometric surface is typical of such surfaces in humid areas with high relief (Handy and Stark 1984). Ground water flows from recharge areas at higher elevations to discharge areas (streams and lakes) at lower elevations. Generally, the depth to water is greater at higher elevations than lower. In the lakeshore the slope of the potentiometric surface ranges from 25 to 50 feet/mile. The slope is steepest in areas of high surface relief and low hydraulic conductivity (e.g., moraines) and is flattest in areas of low relief underlain by materials of high hydraulic conductivity (e.g., outwash plains).

Specific capacity is well discharge divided by water level drawdown in wells. High specific capacity suggests a high potential well yield. Handy and Stark (1984) used well drillers' records to determine that specific capacity of lakeshore wells ranged from 50 to less than 1 gal/min/ft. They mapped areas with high values of specific capacity in the lakeshore (Figure 7). These areas are underlain by glacial outwash or lakebed deposits (compare with Figure 5). Low values typically occur in morainal areas. Lakeshore wells in the glacial meltwater

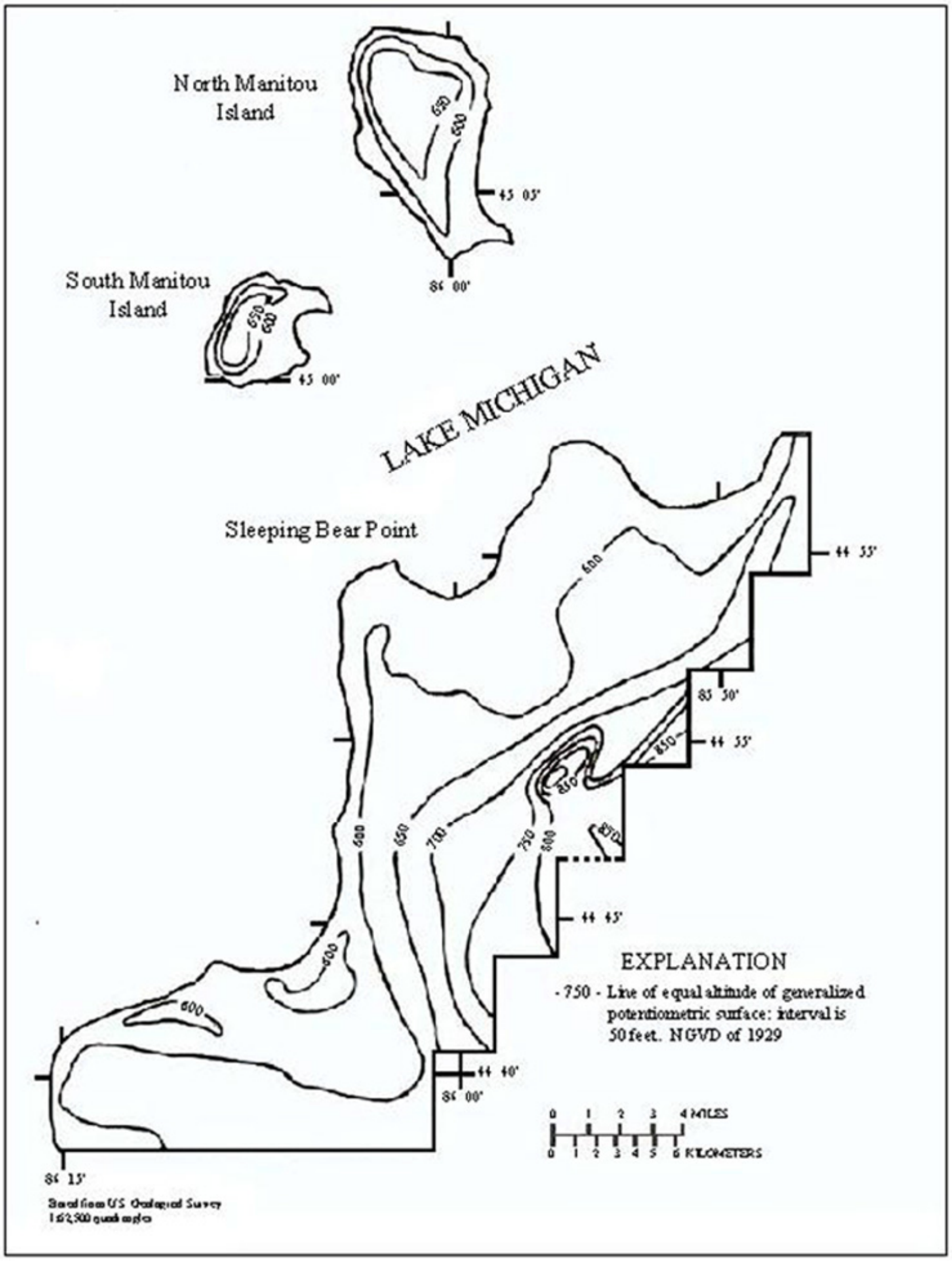


Figure 6. The potentiometric surface of Sleeping Bear Dunes National Lakeshore. After Handy and Stark (1984).

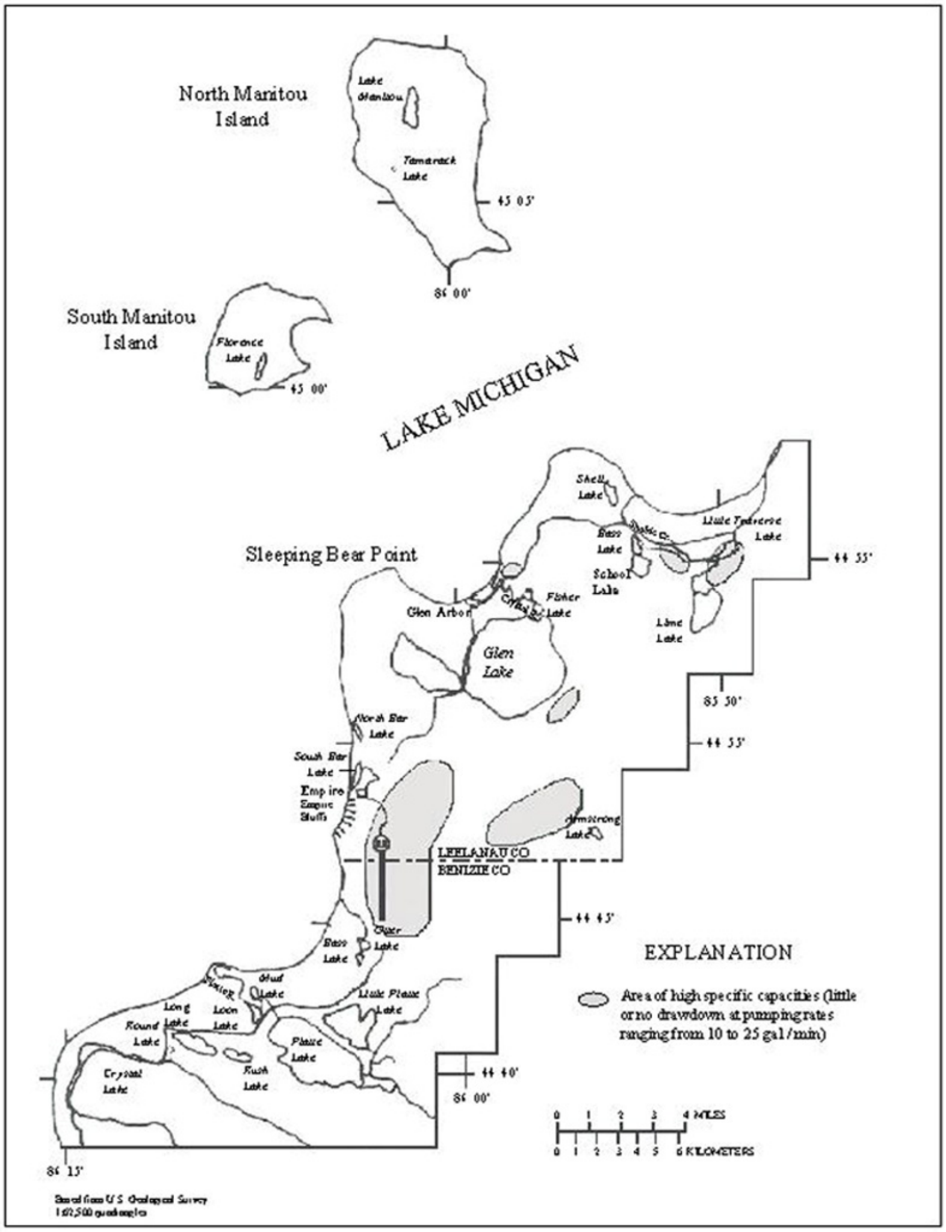


Figure 7. Areas of specific capacity of wells in glacial deposits in Sleeping Bear Dunes National Lakeshore. After Handy and Stark (1984).

deposits of the surficial aquifer yield 100 gal/min without difficulty and wells with a larger diameter can potentially produce 150 gal/min or more.

Based on a regional analysis of water quality for these two aquifers, the water in these aquifers is predominately a calcium/ magnesium bicarbonate type. That is, calcium and magnesium ions constitute more than 50 percent of the cations, and bicarbonate ions constitute more than 50 percent of the anions (U.S Geological Survey 2000). The chemical quality of natural ground water is primarily affected by the mineralogy of aquifer materials and the length of time that the water is in contact with these materials. Water deep within an aquifer has generally been in contact with aquifer materials for a long time, resulting in high concentrations of dissolved constituents. Thus, water in outcrop and recharge areas of aquifers is the least mineralized, but water in deep, confined parts of aquifers where water movement is sluggish tends to be the most mineralized.

The chemical nature of ground water is characteristically related to dissolved solids concentrations as Cummings (1980) illustrated for data from Michigan. As dissolved solids concentrations increase, the percentages of sulfate, chloride, and sodium ions increase, the percentages of calcium and bicarbonate decrease and the percentage of magnesium ions is about the same.

The Silurian-Devonian aquifer in Michigan, where it forms the bedrock surface and is overlain by the surficial aquifer system, is a mixture of various ions (Figure 8) with dissolved solids concentrations in the range of 200 to 500 mg/l.

Handy and Stark (1984) measured water quality from 10 surficial aquifer wells and two springs in the national lakeshore. The analyses suggested that water quality is unrelated to depth, and that the general relationships between dissolved solids and several constituents were as noted above. Ground water with the lowest dissolved solids concentrations occurred near School and Bass (Leelanau) lakes, the Village of Empire and Otter Creek. These locations coincide with lakebed deposits (Figure 7) and areas with a potentiometric surface close to the Lake Michigan water level, probably producing a close hydraulic connection with local surface water. Therefore, ground water from these areas would have a limited time in contact with aquifer materials. At most locations water was of a calcium/magnesium bicarbonate type, although at some places substantial amounts of chloride and sulfate occurred. Concentrations of trace metals did not exceed levels common in Michigan ground waters. Pesticides were not detected. With the exception of a high iron concentration in one well, concentrations did not exceed U.S. Environmental Protection Agency drinking water standards.

STREAM HYDROLOGY

The Platte River (Figure 1) is a 5th order stream with a watershed size of approximately 1792 mi^2. [Stream order is a measure of the position of a stream in the hierarchy of tributaries (see Hynes 1970). Headwater streams with no

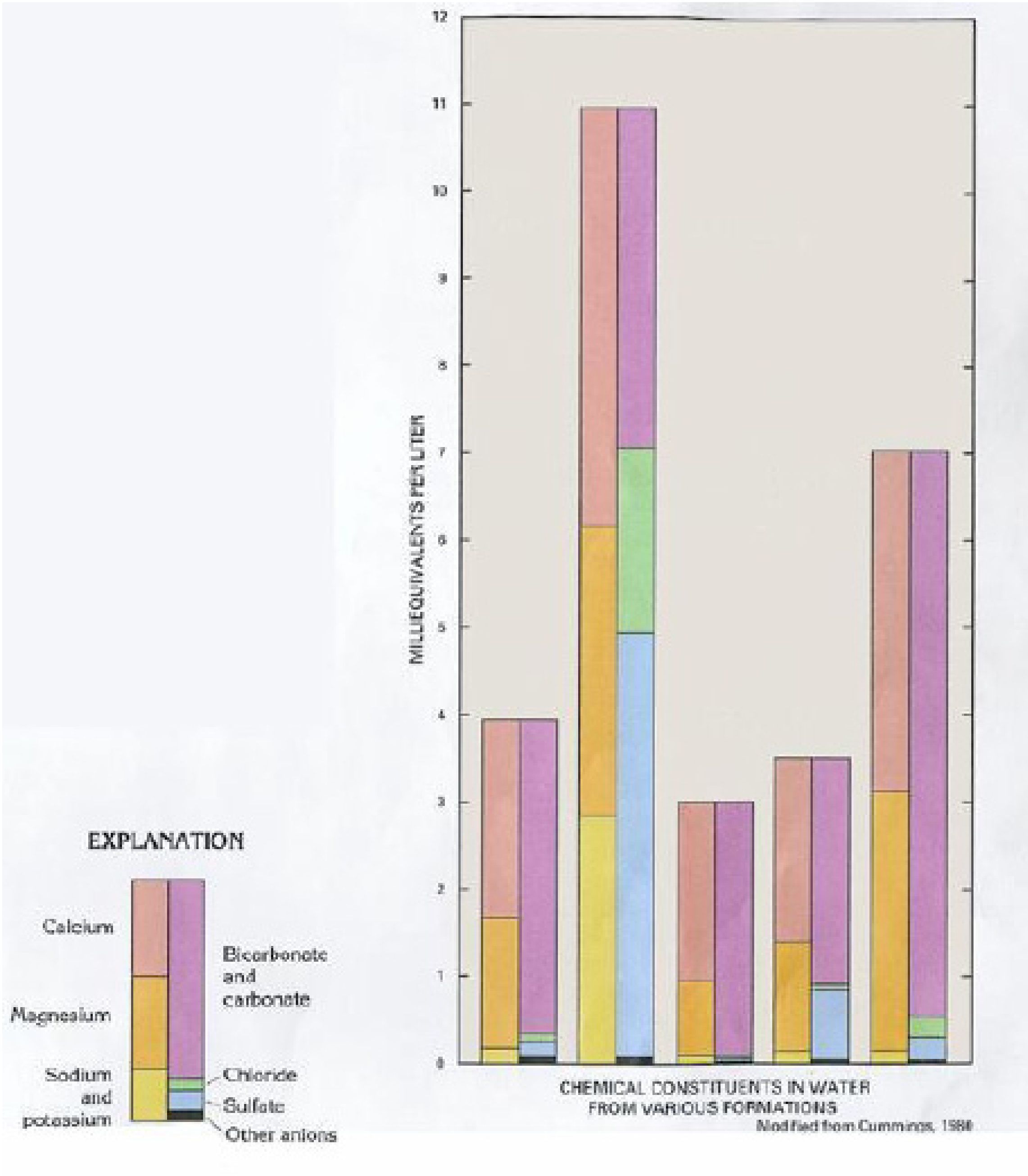


Figure 8. Chemical constituents of the Silurian-Devonian aquifer in Michigan. After U.S. Geological Survey (2000).

tributaries are 1st order streams – when two 1st order streams meet they form a 2nd order stream; the meeting of two 2nd order streams forms a 3rd order stream and so on. Any extra tributaries of a lower order than the receiving stream do not increase the order of that stream.] A small portion of the Platte River (4.6 mi of the 60 mi total length) is within the boundaries of the lakeshore. This represents only seven percent of the watershed (12.6 mi^2). Some of the headwaters of the

Platte River are located in Grand Traverse and Leelanau counties, but Benzie County contains all of the main stream and its major tributaries. The outlet of Lake Ann, west of the lakeshore, forms the main branch of the Platte River. The North Branch of the Platte River (draining Little Platte Lake), Carter Creek and Brundage Creek are the main tributaries before the Platte River flows into Platte Lake. After flowing through Platte Lake, the river enters the lakeshore boundary, flows past the Mud Lake outlet, and passes through Loon Lake before draining into Lake Michigan.

At Lake Michigan the Platte River bends sharply to the east, deflected by long-shore processes that form a sand spit along the left bank. Lakeward of the mouth of the river, the bed of Lake Michigan has shoals with as little as 10 feet of water extending for at least 1.5 miles from shore. Platte Bay itself is deep; the deepest point, northeast of the mouth is over 200 feet deep.

Linton (1987) determined the amount of each lotic zone (e.g., riffles, runs, pools) for the Platte River inside the boundaries of the national lakeshore as follows:

Zone	Feet	% of Total Length[1]
Lotic erosional - riffles	45.5	0.5
Lotic depositional		
Runs	7471.8	78.9
Loon Lake	487.5	5.1
Marsh	1462.5	15.5
Total Length	9467.3	

[1] Percentages are different from those in Linton (1987). Linton contained mathematical errors.

There is a substantial discrepancy between the total length (9467.3 feet) of the Platte River (**and Otter Creek, Crystal River, and Shalda Creek, see below**) within lakeshore boundaries as determined by Linton and the total length (23,388 feet) as determined using 1:24,000 digital line graphic (DLG) data. An accurate assessment of lotic zones is needed; however, the proportion of total length for each lotic zone as presented by Linton (1987) probably provides a relative assessment of the amount of each lotic zone by stream system in the lakeshore.

Otter Creek (Figure 1; total length = 11,801 feet using DLG data) is a 3rd order stream whose watershed is wholly contained within the lakeshore boundary with origins in Deer, Bass, and Otter lakes. The stream also passes through a series of lakes (Deer, Bass and Otter lakes), but differs from the other stream systems in passing through more marsh area along its length. The stream temperatures are generally lower than the other streams in the lakeshore, probably a result of the continued flow of springs and seeps along the stream course. For example stream temperature above the spring area was 24^{o} C but was reduced to 19.9^{o} C below (Linton 1987). Ground water inflow would appear to be the principal source water feeding the Otter Creek system.

The lotic zones of Otter Creek delineated by Linton (1987) are as follows:

Zone	Feet	% of Total Length
Lotic erosional- riffles	195	1.5
Lotic depositional		
Runs	1430	11.0
Marsh	11375	87.5
Total Length	13000	

The Crystal River (Figure 1; total length = 14,166 feet using DLG data) is a 4th order stream with is origin in Glen Lake, just outside the lakeshore boundary. The lotic zones of the Crystal River (Linton 1987) within the boundary of the lakeshore are:

Zone	Feet	% of Total Length
Lotic erosional – riffles	1023.8	4.8
Lotic depositional		
Marsh	2600	12.3
Run	17501.2	82.8
Total Length	21125	

The Crystal River has the highest incidence of riffles of the four lakeshore streams.

Shalda Creek (Figure 1; total length 15,174 feet using DLG data) is a 3rd order stream that originates at the outflow of Little Traverse Lake, just outside of the lakeshore boundary. The Shalda Creek watershed is composed of Lime Lake, Little Traverse Lake, and Shalda Creek.

The lotic zones of Shalda Creek (Linton 1987) within the lakeshore boundary are:

Zone	Feet	% of Total Length
Lotic erosional- riffles	87.8	0.7
Lotic depositional		
Sand bottom run	9662.2	74.3
Marl bottom run	3250.0	25.0
Total Length	13000.0	

There are no permanent U.S. Geological Survey gaging stations within the lakeshore boundaries. As such, basic discharge data for the four lakeshore streams has been limited to only a few, short-term studies.

Handy and Stark (1984) measured discharge on all four streams from May 1979 to May 1981 (eight total measurements per location; six locations). This discharge data is summarized below:

Location	Range (cfs)	Mean (cfs)
Platte River at M-22	194 to 283	177.3
Platte River at Loon Lake	122 to 307	185.4
Otter Creek at Otter Lake	1.9 to 6.8	4.4
Otter Creek at Aral Road	13.6 to 21.6	17.1
Crystal R. near G. Arbor	23.1 to 92.0	55.8
Shalda C. near G. Arbor	17.1 to 54.9	28.5

Handy and Stark (1984) noted that the flow of Otter Creek during low-flow conditions seemed to be due largely to ground water inflow -- seepage along the stream bank was evident and several springs were found. Platte and Crystal rivers are also in an area characterized by seeps and springs. Groundwater inflow seemed to be a significant component of stream flow throughout the year.

Boyle and Hoefs (1993) measured discharge for all four streams in the lakeshore from 1990 to 1992. They found that the hydrograph for these streams revealed a pattern that was less variable than one would expect from an overland runoff stream hydrograph, indicating strong ground water influence. As with the study of Handy and Stark (1984), the Platte River had the greatest flow of the four streams. The discharge in the lower reach was greater than the upper reach. Given that there are no tributary inputs in the lower reach, the increased flow is probably due to ground water additions; they also found a similar situation in Otter Creek and Shalda Creek. However, for the Crystal River the 1991 flows on the upstream reach were greater than the downstream flows. In 1992 this difference was smaller and infrequently flipped to larger discharges in the upstream reach. Because the water level in Glen Lake at that time was regulated by a dam with an adjustable stop log, the discharge may be a function of both lake level and the height of the dam. Today, a dam with a manually adjusted gate regulates the Glen Lake water level.

At Honor, MI a US Geological Survey gaging station became operational in March, 1990, as part of the court case involving the Platte Lake Improvement Association and the State of Michigan. The purpose of the gaging station is to supply river flow data for modeling and load calculations. This is the only extant gaging station close to the lakeshore on the Platte River. The hydrograph for this station (Figures 9 and 10) shows a fairly uniform flow regime, with an average range from 120 to 180 cfs. Peak flows occur typically in the spring with low flows occurring in the late summer/early fall. The hydrograph also shows the effect of the drought years of the late 1990s – more uniform flow across the year and the range of flows reduced to 100 to 130 cfs on average. Given the limited discharge data on the other lakeshore streams, this Platte River hydrograph should be considered representative of the hydrographs for these streams.

Poff (1996) derived a classification of US streams based on ecologically relevant hydrological characteristics. This classification was an outcome of the view that hydrological variation is an important element of the habitat template that influences population and community dynamics in streams. Because the apparent contribution of ground water is high, the four streams of the lakeshore,

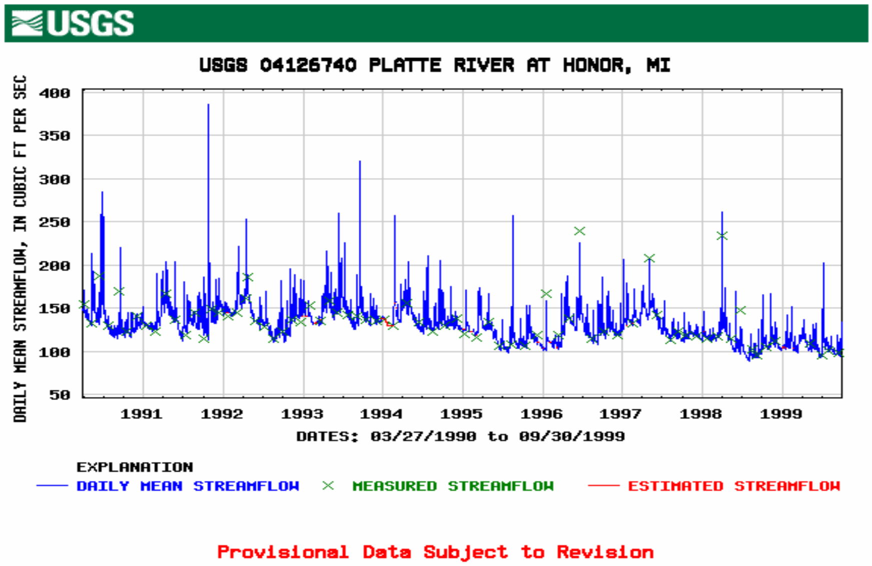


Figure 9. Daily flow hydrograph for the Platte River at Honor, Mi.
Available at: < http://waterdata.usgs.gov/nwis-w/MI >.

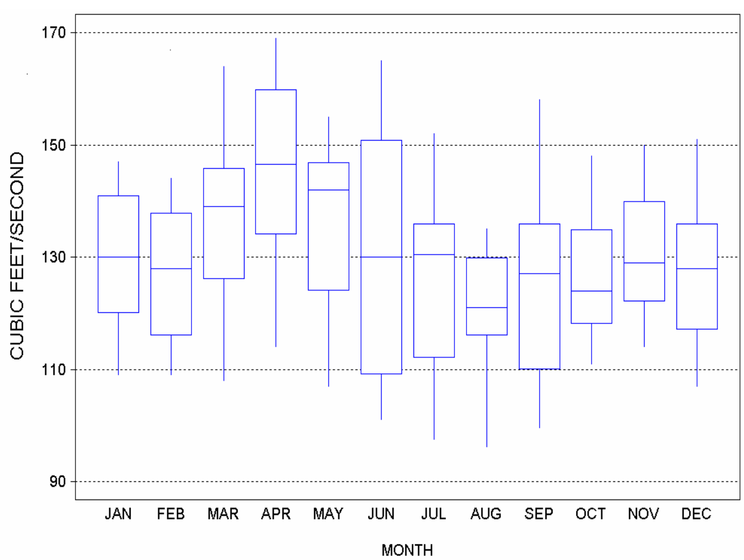


Figure 10. Annual hydrograph for the Platte River at Honor, MI. Box represents middle half of data; horizontal line through box represents median; and, vertical lines extending from top and bottom of box represent the range. Based on data from < http://waterdata.usgs.gov/nwis-w/monthly/site_no=04126740 >.

Platte River, Crystal River, Otter Creek and Shalda Creek, appear to have high flow stability and a low susceptibility to drying. In addition, it appears (based only on the Platte River at Honor U.S. Geological Survey station) that these streams also have low flow variability (i.e., low coefficient of variation of daily flows). Based on these conditions, Poff would classify national lakeshore streams as either Stable Groundwater or Superstable Groundwater. The difference between the two types is in the degree of flow stability, and susceptibility to drying, seasonal predictability of flooding, and the seasonal predictability of low flows. Without more quantitative flow data for these streams it is difficult to firmly classify these streams. However, based on Figure 9 and the study of Boyle and Hoefs (1993), all four streams would be classified as Superstable Groundwater. In either case, the high flow stability of the lakeshore's streams would translate into biological communities that are less likely physically controlled through environmental variability – biological control, through competition, predation, etc., is probably more important in these streams.

Stream Ecology

The following text is excerpted from a book by Doppelt et al. (1993) entitled "Entering the Watershed, A New Approach to Save America's River Ecosystems." It is intended as a brief primer on the importance of a holistic, watershed context to understanding the structure and function stream ecosystems and the responses of stream ecosystems to perturbations. Combined with what is currently known of the lakeshore's stream ecosystems, it sets the stage for future stream management in the national lakeshore.

In the past 15 years many scientific studies and reports have documented that riverine systems are intimately coupled with and created by the characteristics of their catchment basins or watersheds. Watersheds involve four-dimensional processes that connect the longitudinal (upstream-downstream), lateral (floodplains-upland), and vertical (hyporheic or ground water zone-stream channel) dimensions, each differing temporally.

Watersheds are ecosystems composed of a mosaic of different land or terrestrial patches that are connected by a network of streams. In turn the flowing water environment is composed of a mosaic of habitats in which organisms, materials and energy move in complex, yet highly integrated, systems. Physical and chemical processes and complex food webs depend on these movements. Given the dynamic connectedness of a watershed, management activities can fragment and disconnect the habitat patches if they are not planned and implemented from an ecosystem and watershed perspective.

Processes that occur within the watershed, therefore, largely determine in-stream conditions, and they cannot be isolated from or manipulated independently of this context. A riverine system is an open ecosystem because a large proportion of the materials and energy in the system are derived from the surrounding terrestrial system, yet flow outward. Disturbances in a watershed propagate downstream from headwater sources. The protection of sensitive headwater areas in watersheds is therefore critical to maintaining and restoring riverine habitat and ecosystems for considerable distances downstream.

Flowing freshwater systems are directly linked with the terrestrial environment – the land base – for shade and input of nutrients and organic materials. The riparian area is the area where that interface occurs. The riparian area is linked with the flowing water ecosystem to such an extent that the former is the essential part of the latter. Thus, the term riverine-riparian ecosystem more accurately describes the entire area (National Research Council 1992).

When described alone, the riparian area means an ecotone (transition region) between flowing water and terrestrial ecosystems, which serves as the area of continuous exchange of nutrients and woody debris between land and water (Skovlin 1984). Riparian vegetation is an especially critical component of the watershed because it provides an estimated 90 percent of the in-stream nutrients in the aquatic food web (Platts 1981). Although riparian areas constitute a relatively small proportion of the nation's land area, they are of vital importance to the ecological and biological health of watershed ecosystems.

Riparian vegetation provides shade, helping to maintain water temperatures at the levels to which native riverine-riparian biodiversity are best adapted. Leaves and woody debris from the riparian area feed the water with nutrients for growth of aquatic plants and provide food and habitat for the insects upon which fish feed. This debris also contributes to the physical structure of the system by slowing water velocity and deflecting its course. As the water is slowed and deflected, it pushes against the banks and into the soils underlying the adjacent floodplain, thereby contributing to the local water table. Riparian areas are a vital source of important structural components of the entire riverine system.

Healthy riverine systems are dynamic, changing systems that tend to meander. Their movement contributes to the health of the ecosystem because it slows water velocity in flood stages, burying and storing organic materials upon which certain species depend while releasing the degraded materials that are crucial to the survival of other species. It creates a complete mosaic of seasonal habitats for riverine-riparian biodiversity. The dynamic nature of the systems is an important consideration in any restoration approach – the system's ability to move and change must be protected.

Riverine-riparian ecosystems play an important role in producing habitats for both terrestrial and riverine biodiversity. Riverine habitats support the greatest biodiversity of any aquatic habitat types, including lakes and springs. Riverine-riparian ecosystems provide life-supporting habitat for multitudes of non-fish vertebrate and invertebrate species – key links in the aquatic food chain. They are also natural highways for migratory birds and other forms of biodiversity. The biological diversity supported by riverine-riparian ecosystems is a critical link in the entire natural food chain of which human beings are a part.

Human activities continue to degrade America's riverine systems and biodiversity in a variety of ways. The cumulative result of the many impacts has been called ecosystem simplification: huge reductions in the life-supporting complexity and diversity of riverine ecosystems. As complexity is reduced, the system's ability to repair itself after natural and human-caused disturbances erodes, leaving many systems and species seriously harmed or extinct, and with reduced ability to perform ecological functions. The most damaging impacts usually result from changes to the basic structure and function of riverine-riparian ecosystems and habitats.

Riverine ecosystem simplification is caused by a number of factors including: 1) changes in water quantity or flow; 2) modification of channel and riparian ecosystem morphology through dams, channelization, and drainage and filling of wetlands; 3) damaging land use practices; 4) degrading water quality through addition of point- and nonpoint-source contaminants; 5) the decline of native fish and other species from overharvest and intentional or accidental poisoning; and 6) the introduction of exotic species (Karr 1991). These activities may occur anywhere within the watershed, along the riparian or floodplain areas, or in river channels.

Ecosystem simplification is the cumulative result of these impacts. It is the dramatic reduction of the complexity and diversity of structure, function and biological factors of riverine systems (Allen and Flecker 1993). This leaves the ecosystems, habitats and species unable to withstand disturbances, both natural and human-induced, and ultimately unable to perform ecological functions or to repair themselves.

LIMNOLOGY

Basic limnological features for lakes within or adjacent to the national lakeshore are portrayed in Table 1.

The lakes of the national lakeshore experience a range of stratification regimes (Table 1; Boyle and Hoefs 1993; Last et al. 1995; Whitman 2001 draft). Glen, Loon, Platte and Narada are dimictic lakes that maintain stratification between spring and fall overturns (mid-April to mid-October; Whitman 2001 draft). Hypolimnetic oxygen depletion usually occurs in all four lakes. Other dimictic lakes include North Bar, Manitou, Bow Lakes (north), Deer and Bass (Benzie) (Boyle and Hoefs 1993).

All remaining lakes are polymictic, circulating frequently during the summer, but may stratify beneath winter ice (Paul Murphy, Sleeping Bear Dunes National Lakeshore, person. comm., Whitman 2001 draft). Shallow water depth prevented any stratification in some lakes (Shell and Tucker lakes) whereas Otter Lake stratifies periodically, but does not maintain stratification throughout the summer. A degree of hypolimnetic oxygen depletion is present at times in Otter Lake (Whitman 2001 draft).

Whitman (2001 draft) noted that all lakes under 23 ft maximum depth were unstratified, and those with smaller surface-to-volume ratios tended to be more strongly stratified. Deer and Otter lakes, for example, while having similar depths, had quite different temperature profiles -- due to its smaller surface area, Deer was more strongly stratified than Otter. Narada Lake, a strongly stratified lake, is quite deep in comparison with its surface area.

Narada Lake (See Figure 11)

Narada is a small lake with moderate depth (Table 1). A small stream flows out through a cedar swamp on the eastside and connects the lake to Shalda Creek. Flooding caused by a beaver dam killed off many trees along the shoreline. Recent work in the lakeshore by Heuschele (2000) identifies this lake as having the highest species richness for sponges.

School Lake (Figure 11)

School Lake is a small to mid-size, shallow lake (Table 1). The maximum depth is in a small cove in the southwest corner. The rest of the lake is 3 feet deep with mud sediments. A small inlet enters the southeast corner of the lake through a black ash swamp. Another small stream connects to Bass Lake. There is no surface water connection to Shalda Creek.

Shell Lake (Figure 11)

Shell Lake is also a small, shallow lake (Table 1). Maximum depth in the main part of the lake is 13 feet. There is no apparent surface inlet or outlet; therefore, there is no connection to Shalda Creek.

Bass Lake (Leelanau) (Figure 11)

Bass Lake is a small to moderately sized lake with a relatively shallow depth (Table 1). A narrow bank along the east side of the lake separates it from School Lake. Three private cottages and a private boat launch line the north shore – this is also the deepest part of the lake. This lake sustains moderate to heavy fishing pressure. A recent survey of mussels in the lake (Nichols 2000) found a significant number of shells but no live mussels. The health of this lake may be now in question.

Bass Lake (Benzie) (Figure 11)

Bass Lake is the second lake in the chain of lakes in the Otter Creek watershed. It is a small, yet relatively deep lake for its size (Table 1). It is spring fed, but also receives water from an inlet that is the outlet for Deer Lake. Beaver have recently dammed this channel. The outlet of Bass Lake flows into Otter Lake, and beaver have also dammed this channel, although the national lakeshore

Table 1. Limnological features of lakes within or adjacent to Sleeping Bear Dunes National Lakeshore. 'X' means presence.

Lake	Lake Area (acres)	Maximum Depth (ft)	Lake Type [1]	Inlet	Within Park	Outlet
Florence	78	26	2	-	Yes	-
Manitou	256	45	1	-	Yes	X
Bow Lakes (total of three)	13	-	1	-	Yes	-
Tamarack	9	9	2	X	Yes	-
School	176	13	2	X	Yes	X
Bass (Leelanau Co.)	93	24	1	X	Yes	-
Narada	31	39	1	X	Yes	X
Shell	102	13	2	-	Yes	X
Hidden	1.5	0.6	2	-	Yes	-
Fisher	58	14	1	X	No	X
Tucker	17	9	2	X	Yes	X
Long	326	20	2	-	partially	-
Rush	121	3	2	-	No	-
Little Glen	1,419	14	2	-	partially	X
Glen	4,890	130	1	X	partially	X
Taylor	3.3	-	2	-	Yes	-
North Bar	30	31	1	X	Yes	X
Deer		22	1	X	Yes	X
Bass (Benzie Co.)	27	26	1	X	Yes	X
Otter	64	21	2	X	Yes	X
Loon	92	64	1	X	Yes	X
Day Mill Pond	6	?	?	-	Yes	X
Mud	53	0.6	2	X	Yes	X
Round	15	26	2	-	Yes	X
Big Platte	2,522	90	1	X	No	X

[1] Type of thermal stratification: 1 = dimictic; 2 = polymictic

manages this dam to keep the water level on the lake from encroaching upon the only residence. Zebra mussels are present in this lake.

Deer Lake (Figure 11)

Deer Lake is the first lake in the chain of lakes in the Otter Creek watershed. It is very small, but like Bass Lake (Benzie) its relatively deep for its size (Table 1).

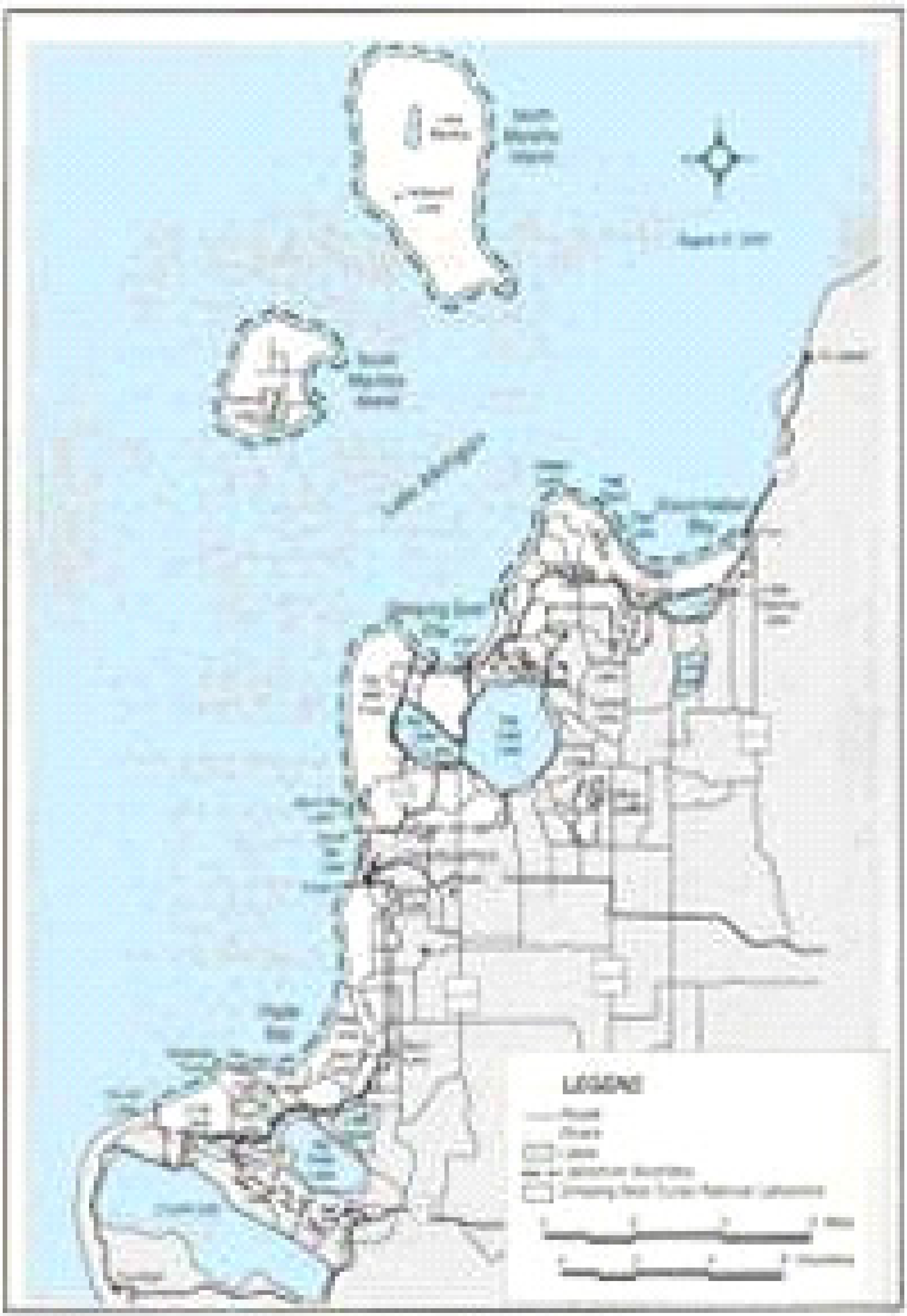


Figure 11. Lakes of Sleeping Bear Dunes National Lakeshore

This lake is spring fed. It is surrounded by hardwood forest with a small wetland at its south end. Beaver are present.

Fisher Lake (Figure 11)

Fischer Lake is a small to moderately sized lake that is relatively shallow (Table 1). It has a large inlet that also is the outlet of Glen Lake. Its outlet represents the headwaters of the Crystal River. Large and small homes and cottages surround it. Boat traffic is substantial; a small marina exists in the headwaters of the Crystal River.

Long Lake (Figure 11)

Long Lake is large and relatively shallow (Table 1). Its mean depth is approximately 3 – 4 feet depth, but there is reportedly a deep hole in the east end of the lake. The national lakeshore lands occur on the west end of the lake. There is a boat launch for motorboats and most traffic is on weekends. There are several residences surrounding the lake.

Rush Lake (Table 1; Figure 11)

Rush Lake may be considered a fairly large interdunal pond. Wetlands and forest surround the lake. There are two residences on the lake.

Day Mill Pond (Table 1; Figure 11)

Day Mill Pond was originally much larger and connected to Little Glen Lake by a channel. Past improvements to M109 resulted in portions of the pond and channel to be filled in. A culvert now exists between the pond and lake; however, it is plugged and no connection exists between pond and lake. It appears that the past road improvements caused the demise of what extant residents called a good northern pike fishery.

Hidden Lake (Figure 11)

This 'lake' is very small and quite shallow (Table 1). The lake is surrounded by thick vegetation. Access is difficult and visitor use is therefore negligible. The west side of the lake is bordered by a sand dune called Pyramid Point. The 'lake' is probably best classified as a ridge and swale wetland.

Lake Tamarack (Figure 11)

Lake Tamarack is a small, relatively shallow lake on the south end of North Manitou Island (Table 1). It is surrounded by wetlands. Limited water samples suggest that this is a soft water lake.

Lake Manitou (Figure 11)

Lake Manitou, located on North Manitou Island, is one of the largest and deepest lakes in the national lakeshore (Table 1). This lake is surrounded by hardwood forest and is an important fishing spot for campers. It is in a designated wilderness area.

Glen Lake (Figure 11)

Glen Lake is a large, deep lake in the Crystal River watershed (Table 1). Only small portions of the shoreline along the south side of the lake are within the park. Many summer homes, cottages and rental units exist along the shoreline. It has two marinas. Glen is thus a popular recreational lake for sailing, jet skies, water skiing and fishing. Hatlam Creek flows into the south end of the lake. The outflow enters Fisher Lake, which flows into the Crystal River. The lake water level, and hence the flow of the Crystal River are controlled by a dam operated by the Glen Lake Association.

Little Glen Lake (Figure 11)

This lake is essentially an extension of Glen Lake. It is a large but shallow lake (Table 1). The national lakeshore owns a large area of shoreline along the north and northwest corner of the lake. Many summer homes, cottages and rental units surround the rest of the lake. The national lakeshore has a picnic area with changing room and pit toilets. This area is visited frequently by geese and other waterfowl, and the shoreline water has experienced high bacteria levels in the past prompting a human health concern. However, recent bacteria levels have dropped, perhaps because the national lakeshore developed a greenbelt to mitigate runoff contaminated with waterfowl feces.

Tucker Lake (Figure 11)

Tucker Lake is a small, shallow lake (Table 1). Lake level is controlled by a beaver dam across the outlet. The outlet flows south to Fisher Lake. A swampy area is located west of the lake. Glen Arbor residents used a 5 to 6 acre area adjacent to Tucker Lake as a ‘town dump’ from the early 1900s to the late 1960s (Enviroscience 1995). After a thorough environmental site assessment by the national lakeshore, this dump area appears to be successfully remediated.

North Bar Lake (Table 1; Figure 11)

North Bar is a small, moderately deep lake that was once an embayment of Lake Michigan and is still periodically connected by a narrow channel through the sand dune between the two lakes. Presently, increased sand transport from the dunes and/or from Lake Michigan longshore currents have filled the channel and closed off the lake from Lake Michigan. Open sand dominates the shorelines on the north end of the lake. Northern hardwood forest rims the lake to the West. A black ash swamp north of the access road and a cedar swamp south of the access road border the east side. Heavy foot traffic has removed natural vegetation and destabilized the dunes; however, attempts are being made to stabilize the dune complex.

Otter Lake (Figure 11)

Otter Lake is the largest lake in the Otter Creek watershed. It is a small shallow lake (Table 1). An inlet flowing from Bass Lake is located on the south side and Otter Creek leaves from the north side of the lake. Ground water flow is the principal water source to Otter Lake.

Loon Lake (Figure 11)

Loon is a small to moderately sized lake with a moderate depth (Table 1). A dense shrub zone borders the west and north sides of the lake, and an extensive tamarack bog border the western shore. A small stream enters the lake on the southwest side, and the Platte River flows through the lake from the east to north.

Stockwell and Gannon (1975) made a rough calculation of the flushing rate (the amount of time it takes to flush out the existing volume of lake water and replace it with in-flowing water). Loon Lake has a flushing rate of 12 days – a relatively rapid flushing rate. This rapid flushing rate may be important factor in maintaining good water quality in spite of nutrient loading from upstream areas. The flushing rate for Platte Lake was also relatively rapid at 302 days. For comparison, Lakes Erie and Michigan have estimated flushing rates of 20 and 100 years, respectively.

Mud Lake (Figure 11)

Mud Lake is located between Platte and Loon Lakes. It drains into the Platte River (1/2 mile above Loon Lake) by way of a small, sluggish stream known as Mud Creek. It is small and quite shallow (Table 1).

Round Lake (Figure 11)

Round Lake is a small, shallow lake (Table 1). There is a large floating sedge (*Carex* spp.) mat on the south side of the lake. An outlet flows through this mat to Crystal Lake. It is the only waterbody in the lakeshore that is part of the Betsie River watershed. *Phragmites* is strongly established on the south and east sides of the lake.

Florence Lake (Table 1; Figure 11)

Florence is a soft-water lake (Stockwell and Gannon 1975). With no surface inlet, ground water seepage provides the major source of water. Since the lake lies so close to Lake Michigan and its basin extends below the level of the Great Lake, subsurface seepage of Lake Michigan water into Florence Lake would normally occur. However, Florence contains substantially softer water than Lake Michigan. This suggests that some factor, perhaps a sub-surface clay layer, inhibits this seepage.

Because it is a soft-water lake, Florence may be particularly susceptible to anthropogenic phosphorus inputs. Soft-water lakes cannot withstand phosphorus loading as well as hard-water lakes. In hard water lakes phosphorus co-precipitates into the sediments as marl (calcium carbonate) and becomes unavailable to stimulate plant growth, but soft-water lakes do not have this limiting factor since they are low in calcium. Also since this is a seepage lake, complete water replacement takes an extremely long time and pollution inputs would remain for an extended period of time before cycled out.

Bow Lakes (total of three lakes) (Table 1; Figure 11)

In a long narrow valley nestled between two high wooded bluffs are a number of kettle lakes, surrounded by bogs, fens, wet meadows, and marshes. Bow Lake and its two sister lakes are open marl lakes lying in the valley.

This area was formed by a mass of stagnant ice left over from the retreating ice sheet. Bow Lake and the other small lakes and bogs occupy the deepest areas of the depression, probably the sites of individual ice blocks that remained in the area while the extensive meltwater plain southeast and southwest of here was being formed.

There is no public access to the Bow Lakes area.

Lake Ecology

The following text is excerpted from a paper by Carpenter and Cottingham (1997) entitled “Resilience and Restoration of Lakes.” It is intended as a brief primer on the structure and function lake ecosystems and the responses of lake ecosystems to perturbations. Combined with what is currently known of the lakeshore’s lake ecosystems, it sets the context for future lake management activities.

Limnologists recognize that lakes must be understood in the landscape context of their catchments (Wetzel 1990). Airborne pollutants connect lakes to perturbations of the global environment (Schindler et al. 1996). Changes in agriculture, riparian land use, forestry, and demand for ecosystem services link lakes to much larger social and economic systems (Postel and Carpenter 1997).

In the normal dynamics of lakes, ecological processes are maintained despite moderate and continuous disturbances originating in the lake, its watershed, and its airshed. This resilience involves different ecological systems in a watershed context.

Riparian forests delay or prevent nutrient transport from uplands to streams and lakes (Osborne and Kovacic 1993). Riparian forests are a source of fallen trees that can provide important fish habitat for decades (Maser and Sedell 1994).

Wetlands function as vast sponges that delay the transport of water to downstream ecosystems and thereby, reduce the risk of flooding. Wetlands also modulate nutrient transport from uplands to streams and lakes. Wetlands are a major source of humic substances for lakes (Wetzel 1992). This complex of organic compounds stains lake water and affects ecosystem metabolism through several mechanisms (Wetzel 1992).

Submerged macrophytes of the littoral zone provide crucial habitat for attached algae, invertebrates and fishes (Heck and Crowder 1991). They also modify inputs to lakes from riparian or upstream ecosystems, store substantial amounts of nutrients, and are a source of dissolved organic compounds (Wetzel 1992). Oxygen production by macrophytes and attached algae can decrease the rate of phosphorus release from sediments, and high denitrification rates in littoral vegetation can decrease nitrogen availability (Wetzel 1992).

Low or moderate rates of phosphorus input promote low rates of phosphorus recycling, through effects on the oxygen content of the water. Conditions of low to moderate productivity constrain respiration by bacteria, so that oxygen is not depleted from deeper waters during the summer (Cornett and Rigler 1979). Oxygenated conditions decrease the rate of phosphorus recycling from sediments in many lakes. If production of the overlying water increases, deep waters can be deoxygenated and phosphorus recycling can increase, thereby further increasing production. Oxygenation of bottom waters prevents this positive feedback and confers resilience in moderately productive and unproductive lakes.

Degradation of lakes is a syndrome that involves breakdown of several resilience mechanisms and formation of several new ones. Eutrophication is probably the best-understood type of lake degradation. Agriculture and urban development increase phosphorus transport to lakes. Losses of riparian areas and wetlands increase phosphorus flows. Humic inputs decline and humic constraints on phytoplankton become less effective. At the same time, game fish abundance is often reduced by overfishing, so planktivorous forage fishes and bottom-feeding fishes become more abundant. The large zooplanktonic grazers are reduced, and incoming phorphorus accumulates in phytoplankton biomass, especially blue-green algae. Macrophyte beds decline because of reductions in water clarity and disturbance by bottom-feeding fishes. Loss of crucial habitat (macrophytes, wetlands, fallen trees) leads to further breakdown of the food web. The result is a lake with few piscivorous game fishes, abundant plankton- and bottom-feeding fishes, few large, herbivorous zooplankton, few macrophytes, dense algal blooms, and risks of anoxia and algal toxins. Toxic pollutants, species invasions, and species extinctions may interact with effects of phosphorus enrichment, habitat loss, and overfishing to exacerbate the degradation of lakes.

Airborne pollutants and exotic species have become global controls of lake dynamics. Mercury, for example, is a widespread toxic pollutant derived from fossil fuels and other sources. Under certain conditions, mercury is methylated and bioaccumulates through food chains (Driscoll et al. 1994). Organochlorine compounds are persistent toxic pollutants that affect many lakes. Although the more pernicious organochlorine compounds are no longer manufactured in the US, significant amounts of some compounds still cycle within lakes and enter lakes from the atmosphere (Stow et al. 1995).

Lakes, like islands, can be changed dramatically by species invasions. The one spectacular example is the Great Lakes, where invading sea lamprey (and overfishing) extirpated piscivorous lake trout, thereby allowing populations of another exotic species, the planktivorous alewife, to explode (Christie 1974). Some, but by no means all, invading species have powerful impacts on lakes, but our abilities to predict the effects of an invader in advance of the invasion are limited (Lodge 1993). Like the chemical changes in lakes, these biotic changes are driven by regional and global alterations of human activity and enterprise.

The role of species diversity in lake resilience is illustrated by experiments in which lakes were manipulated to various levels of toxic chemical stress or nutrient input. At low levels of toxic stress changes in species composition are substantial, but changes in ecosystem process rates are negligible (Schindler 1990). Structural changes at the species level stabilize ecosystem process rates, called functional compensation by Frost et al. (1995). [However, functional compensation is not the universal expectation for all systems – in oligotrophic and species-poor ecosystems functional compensation is probably less important because there are too few “redundant” species combinations in such systems.] At more extreme levels of toxic chemical stress, functional compensation is not possible because too many species have been lost; consequently, ecosystem process rates change. Nutrient enrichment, in contrast, simultaneously changes both species composition and ecosystem process rates (Cottingham 1996). In this case, functional compensation allows ecosystem process rates to rapidly track shifts in availability of the limiting nutrient. Phytoplankton species turnover rates are high at all enrichment levels. Studies of both toxic stress and nutrient enrichment show that we cannot predict which species will account for functional compensation or other responses to manipulation (Frost et al. 1995). Ecosystem response to a given perturbation depends on only a fraction of the species pool, but the critical species are situation specific and can rarely be anticipated. It should also be noted that functional compensation appears to be less important in oligotrophic and species-poor ecosystems because there are often too few species with the ability to functionally compensate. In summary, biodiversity confers resilience through compensatory shifts among species capable of performing key control processes. However, species number is not necessarily a good predictor of resilience.

SURFACE WATER QUALITY

All water resources within the designated boundaries of Sleeping Bear Dunes National Lakeshore are considered high quality waters that are designated as outstanding state resource waters (OSRW) by the State of Michigan. This designation provides that the level of water quality necessary to protect existing uses shall be maintained and protected. Furthermore, where designated uses of a water body are not attained, there shall be no lowering of the water quality with respect to the pollutant or pollutants that are causing the nonattainment. This designation also calls for controls on pollutant sources to OSRW waters so that the water quality is not lowered in the OSRW. The OSRW designation falls under the antidegradation rule of the State of Michigan’s water quality standards promulgated pursuant to Part 31 of Michigan’s Natural Resources and Environmental Protection Act of 1994.

Retrospective Analysis of Past Water Quality Studies

The National Park Service (1997) conducted surface water quality retrievals for Sleeping Bear Dunes National Lakeshore from six of the U.S. Environmental Protection Agency’s national databases, including STORET the national water quality database. The results of these retrievals for the study area (limits include 3 miles upstream and 1 mile downstream of park boundary) covered the years 1962 to 1996 and included 149 water quality monitoring stations (Figure 12), three industrial/municipal discharge sites (only two of which are in the watersheds represented in the national lakeshore), 12 water impoundments (only one of importance to national lakeshore), and four active or inactive U.S. Geological Survey gaging stations. Of the 149 stations, 10 stations were established but contained no data. Seventy-six stations were located within the national lakeshore boundary. Twenty stations are located in Lake Michigan waters; however, 17 stations have data older than 1985 and three show no data. Presently, there are no active stations on the Lake Michigan waters of the lakeshore to determine existing water quality and water quality trends.

Most of the remaining monitoring stations represent either one-time or intensive single-year sampling efforts by collection entities or discontinued stations. Sixty-two stations represent data collected before January 1985 and are of little use in an assessment of current water quality of the park. Forty-seven national lakeshore stations show data collected from 1985 to 1996; 23 of these stations each represent less than 10 total water quality observations over this period and are of little use in determining water quality trends; however, parameter values indicate no water quality impairment. Of the remaining 24 stations in the national lakeshore, all represent data collected no later than 1995 and represent not monitoring stations *per se* but several multi-year assessments (e.g., Boyle and Hoefs 1993; Last et al. 1995). The data from these stations are important in establishing the water quality baseline for many of the lakeshore water resources. These data are summarized in Tables 2 and 3. Of the national lakeshore's lakes only 12 were consistently sampled over a 5-year time frame (1990-1995); however, only 10 remained common between 1991 to 1992 and 1993 to 1995 (Last and Whitman 1996). For all the lakes, the values for the measured parameters are consistent with hard-water lakes and show no obvious indications of impaired water quality. The national lakeshore's streams show that at least one station on each stream was sampled consistently over a 5-year time frame (1990-1995). As with the lakes, no streams show any obvious water quality impairments.

A trophic status index (TSI) of lakes can be determined by the analysis of several variables: 1) estimation of the transparency of the water as measured by Secchi disk depth; 2) the concentration of the limiting nutrients such as phosphorous or nitrogen; and, 3) the density of the phytoplankton community as measured by chlorophyll *a* (Carlson 1977; Kratzer and Brezonik 1981). The TSI can be used with a number of variables to calculate a value that can be used to compare among years the trophic status of a particular lake. Table 4 represents a comparison of those national lakeshore lakes where Boyle and Hoefs (1993) and Whitman et al. (2002) calculated TSI values. The TSI based on the Secchi disk compares favorably; only Narada and Tucker lakes showed changes in trophic status. The TSIs based on total phosphorus and chlorophyll *a* for 1999 are consistently higher than those for 1992. In fact, the 1999 values reflect major changes in trophic state for all lakes – the tendency is for ever-increasing eutrophy. It is unclear without further study just what is driving this discrepancy. The higher chlorophyll *a* values for 1999 would indicate that algal blooms were occurring over the summer (possibly stimulated by the high total phosphorus concentrations); however, these blooms did not reduce the Secchi depths as evidenced by the TSI values for Secchi depth (Table 4).

A common misconception is that the term trophic state is synonymous with the concept of water quality. Although the concepts are related they should not be used interchangeably. Trophic state is an absolute scale that describes the biological condition of a waterbody. Water quality is a term used to describe the condition of a waterbody in relation to human needs or values. Quality is not an absolute term; the terms good and poor water quality only have meaning relative to the use of the water and the attitude of the user. An oligotrophic lake might have good water quality for swimming but is considered poor water quality for fishing. Confusion may ensue when the term 'trophic state' is used to infer quality.

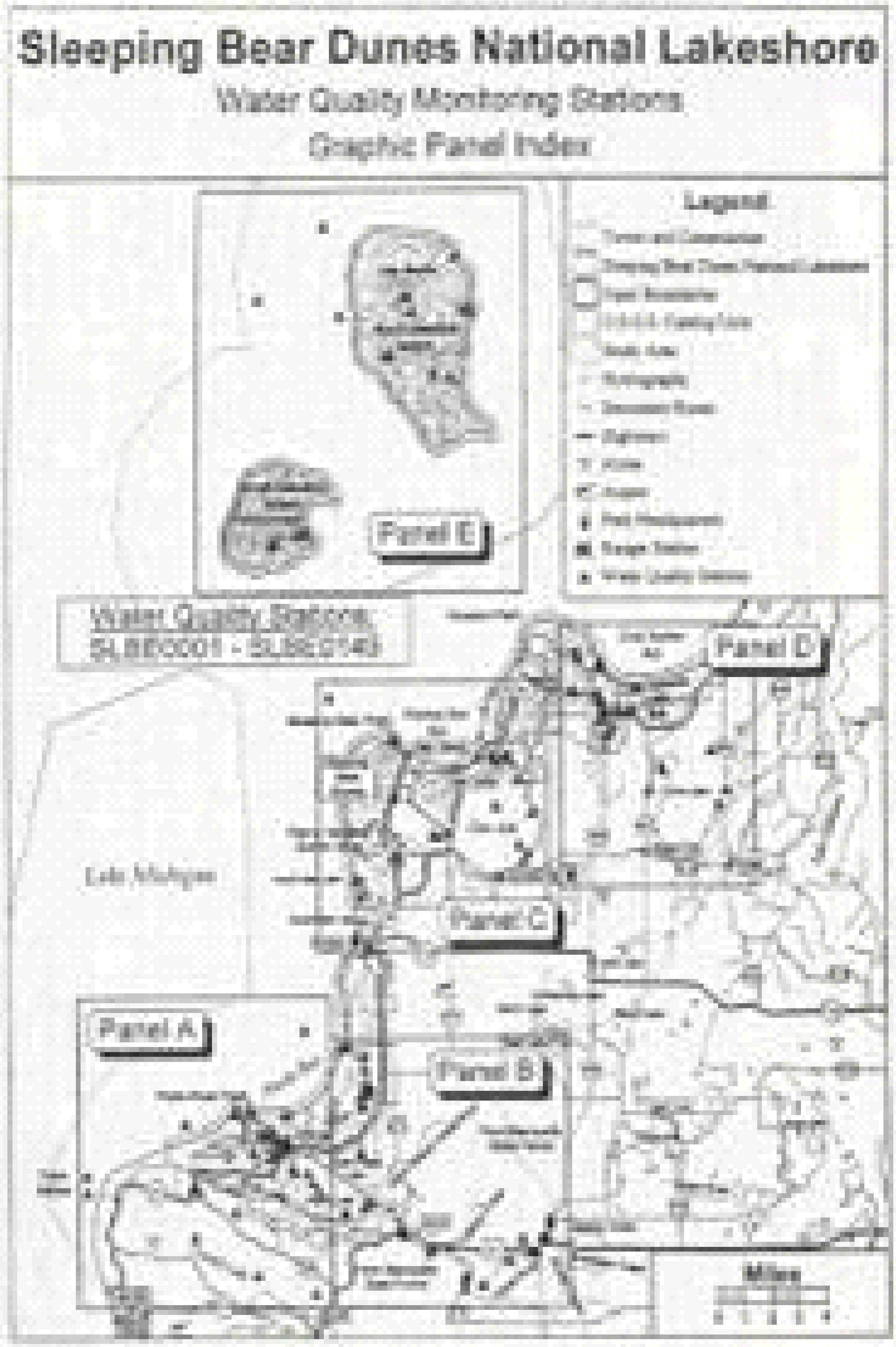


Figure 13. Locations of water quality monitoring stations in and adjacent to Sleeping Bear Dunes National Lakeshore. After National Park Service (1997).

Table 2. A summary of water quality data from important lake water quality monitoring stations in Sleeping Bear Dunes National Lakeshore, 1990-1995. Based on data from National Park Service (1997).

Lake	Time Frame	Secchi Depth (ft) Mean[range] # of obs.	pH Mean[range] # of obs.	Total Alkalinity (mg/l) Mean[range] # of obs.	Total Kjeldahl Nitrogen (mg/l) Mean[range] # of obs.	Total Phosphorus (mg/l) Mean[range] # of obs.	Chlorophyll a (ug/l) Mean[range] # of obs.	Specific Conductance (umhos/cm) Mean[range] # of obs.	Turbidity (NTU) Mean[range] # of obs.
Round	1990-92	14.4[11.4-17.2] 3	8.5[8.3-8.8] 3	129.7[120-138] 6	0.473[0.22-0.7] 6	0.007[6.012-0.002] 6	2.85[1.7-4.0] 2	NA	0.68[0.3-1.0] 6
Loon	1990-95	12.5[8.1-17.6] 6	8.3[7.7-9.2] 11	149.7[130-172] 6	0.49[0.2-1.1] 6	0.014[0.002-0.05] 8	1.5[0.6-2.9] 7	248[211-285] 2	2.6[0.9-5.5] 6
Mud	1990-92	0.3 1	8.7[8.6-8.8] 3	120[100-132] 3	0.65[0.29-1.0] 3	0.02[0.005-0.042] 3	1.4[1.0-1.7] 2	NA	1.1[0.7-1.6] 3
Deer	1990-95	12.5[10.7-15.0] 6	8.1[7.5-8.5] 10	158.5[141-170] 6	0.26[0.2-0.4] 6	0.02[0.002-0.1] 8	2.85[1.4-3.3] 11	256.5[224-289] 2	1.08[0.6-1.7] 6
Bass (L)	1990-95	11.6[9.4-14.0] 6	8.7[8.5-9.2] 10	102[94-108] 5	0.54[0.32-0.7] 4	0.007[0.004-0.012] 7	3.2[2.2-5.9] 6	205[170-240] 2	1.04[0.6-1.4] 5
Bass (B)	1990-95	12.4[8.5-14.6] 6	8.44[8.2-8.7] 10	144.3[136-162] 6	0.28[0.085-0.5] 6	0.015[0.002-0.05] 8	2.79[0.9-4.1] 9	258[218-298] 2	0.93[0.7-1.1] 6
Otter	1990-95	10.2[8.8-12.0] 6	8.44[7.9-8.8] 10	137.7[132-142] 6	0.33[0.29-0.51] 6	0.009[0.001-0.05] 8	2.52[1.0-3.5] 11	249.5[210-289] 2	1.23[0.9-1.5] 6
N. Bar	1990-95	7.8[5.9-11.4] 7	8.35[8.0-8.7] 11	143.3[140-146] 6	0.37[0.29-0.44] 5	0.013[0.001-0.04] 7	2.8[1.4-7.7] 7	272[238-304] 2	2.08[1.4-2.9] 6
Bow (South)	1990	13.3 1	8.6 1	152 1	0.7 1	0.005 1	0.6 1	NA	0.5 1
Bow (North)	1990	23.7 1	8.5[8.1-8.9] 2	172[156-188] 2	0.5[0.3-0.7] 2	0.005[0.005] 2	1.1[0.5-1.7] 2	NA	0.9[0.6-1.2] 2
Big Glen	1990-95	11.7[6.2-15.9] 3	8.2[7.6-8.7] 43	128.7[124-134] 3	0.1[0.1] 3	0.005[0.002-0.01] 5	0.63[0.3-1.2] 4	240[230-260] 42	0.7[0.5-0.9] 3
Little Glen	1990-95	8.6[6.8-10.1] 3	8.4[8.2-8.8] 12	116[108-124] 2	0.3[0.3] 2	0.016[0.004-0.05] 4	1.4[0.8-2.3] 4	213.3[199-254] 10	0.5[0.1-0.9] 2
Tucker	1990-95	8.3[6.5-10.8] 6	8.5[8.1-8.7] 7	121.3[118-126] 3	0.68[0.24-1.1] 3	0.011[0.005-0.021] 5	3.85[2.2-7.3] 4	266[232-300] 2	1.1[0.9-1.5] 3
School	1990-95	5.3[4.9-6.5] 8	8.99[8.7-9.3] 10	85.7[77-98] 3	0.69[0.47-0.8] 3	0.022[0.01-0.06] 7	1.85[0.9-3.9] 4	161[137-185] 2	1.4[0.9-1.8] 3
Narada	1990-95	12.9[8.1-16.3] 6	8.3[7.2-8.9] 11	148.3[124-178] 6	0.45[0.3-0.6] 7	0.02[0.004-0.08] 8	5.6[1.1-16.2] 11	216.5[180-253] 2	1.3[0.8-2.0] 6
Shell	1990-95	10.0[8.1-11.4] 6	8.8[8.2-9.2] 9	99[92-112] 4	0.59[0.42-0.8] 4	0.013[0.004-0.04] 6	1.23[1.0-1.4] 4	193.5[154-233] 2	1.05[0.9-1.3] 4
Tamarack	1982	NA	7.5 1	NA	NA	0.03 1	NA	63 1	NA
Manitou	1990	4.6 1	8.95[8.9-9.0] 2	121[120-122] 2	0.9[0.7-1.1] 2	0.005[0.005] 2	2.35[2.3-2.4] 2	NA	5.4[4.3-6.5] 2
Florence	1990	11.7 1	8.4[8.3-8.5] 2	48[48] 2	0.55[0.5-0.6] 2	0.005[0.005] 2	2.25[1.7-2.8] 2	NA	0.7[0.5-0.9] 2

Table 3. A summary of water quality data from important stream water quality monitoring stations in Sleeping Bear Dunes National Lakeshore, 1990-1995. Based on data from National Park Service (1997).

Stream	Time Frame	pH Mean[range] # of obs.	Total Alkalinity (mg/l) Mean[range] # of obs.	Total Nitrogen (mg/l) Mean[range] # of obs.	Total Phosphorus (mg/l) Mean[range] # of obs.	Dissolved O_2 (mg/l) Mean[range] # of obs.	Specific Conductance (umhos/cm) Mean[range] # of obs.	Chlorophyll a (ug/l) Mean[range] # of obs.	Turbidity (NTU) Mean[range] # of obs.
Platte below M-22 bridge	1990-95	8.3[6.8-8.9] 31	139.8[128-150] 24	0.27[0.15-0.6] 27	0.019[0.001-0.11] 27	9.0[6.2-15] 27	309.5[233-375] 28	1.7[0.7-3.1] 24	1.7[0.9-4.7] 22
Platte before enters L. Mich.	1990-93	8.4[8.0-8.9] 29	139.7[104-160] 24	0.31[0.05-0.9] 27	0.019[0.001-0.21] 27	9.3[7.2-15.0] 26	315.6[275-350] 25	2.0[1.2-3.0] 6	1.4[0.7-5.0] 22
Otter upstream	1990-95	8.2[7.3-8.6] 31	142.3[134-154] 24	0.48[0.05-1.1] 27	0.006[0.002-0.03] 27	8.7[7.6-10.4] 27	304.7[222-350] 28	1.1[0.4-1.8] 24	1.2[0.4-2.5] 22
Otter downstream	1990-95	8.1[7.0-8.8] 28	167.0[150-178] 23	1.0[0.15-1.5] 27	0.008[0.002-0.03] 27	10.8[8.0-14.2] 25	331.4[253-375] 26	0.98[0.0-1.9] 6	0.962[0.4-1.8] 21
Crystal upstream	1990-95	8.4[7.6-8.9] 31	124.3[116-136] 24	0.26[0.15-0.5] 14	0.008[0.005-0.02] 14	9.7[7.8-14.0] 27	281.3[230-425] 26	0.75[0.3-1.8] 17	0.65[0.2-1.2] 23
Crystal downstream	1990-93	8.3[7.4-8.8] 29	124.6[114-136] 24	0.21[0.05-0.6] 27	0.006[0.003-0.02] 27	9.2[7.6-12.5] 26	276.0[200-350] 24	0.7[0.3-1.8] 14	0.6[0.3-1.2] 23
Shalda upstream	1990-95	8.3[7.7-8.7] 30	145.5[136-152] 23	0.5[0.15-1.4] 27	0.01[0.002-0.07] 27	8.0[0.8-11.5] 26	339.5[267-375] 26	1.1[0.7-2.3] 25	1.36[0.7-2.1] 23
Shalda downstream	1990-93	8.0[7.4-8.7] 29	152.6[144-176] 29	0.43[0.15-0.9] 27	0.009[0.004-0.03] 27	8.4[7.0-11.6] 25	326.5[200-375] 24	1.07[0.8-1.7] 6	1.15[0.5-2.4] 22

Table 4. Carlson's TSI values and associated trophic status as calculated from Secchi disk transparency (1992 and 1999), chlorophyll *a* concentration (1992 and 1999), and total phosphorus (1992 only) for selected lakes in Sleeping Bear Dunes National Lakeshore [based on Boyle and Hoefs (1993) and Whitman et al. (2002)]. Data from Boyle and Hoefs (1993) based on one sample collected in the summer of 1992; whereas, data from Whitman et al. (2002) represents the mean of all samples taken in 1999. Multiple values for trophic status indicate differences in the trophic status assessments for the different years. Abbrevations are: TS=trophic status; P=phosphorus; o=oligotrophic, m=mesotrophic, e=eutrophic, h=hypereutrophic, SH=Shell Lake, L=Loon Lake, O=Otter Lake, NB=North Bar Lake, R=Round Lake, T=Tucker Lake, N=Narada Lake, SC=School Lake.

Lake	Secchi (92)	Secchi (99)	TS (Secchi)	Total P (92)	Total P (99)	TS (P)	Chl *a* (92)	Chl *a* (99)	TS (Chl *a*)
SH	43	43	o-m	100	56	h,e	30	50	o,m
L	46	47	m	40	54	o,e	34	54	o,e
O	45	47	m	30	60	o,e	31	58	o,e
NB	47	46	m	37	50	o,m	32	58	o,e
R	44	44	o-m	44	54	o,e	35	58	o,e
T	46	50	m	38	54	o,e	37	59	o,e
N	40	46	o,m	43	60	o,m	34	60	o,e
SC	50	52	m,m-e	100	62	h,e	30	69	o,e-h

Whitman et al. (2002) also sampled specific conductance, total alkalinity, hardness, pH, sulfate, nitrate, and ammonia. This study provides the most recent assessment of water quality for the lakes studied. Values for these parameters compare favorably with past studies (Table 2). Slightly higher nitrate concentrations (compared with the other study lakes) were found in Otter and North Bar lakes, with levels of 0.12 and 0.18 mg/l, respectively.

Additional water quality monitoring being conducted by other entities includes the volunteer monitoring on Platte and Glen lakes by the Michigan's Citizen Volunteer Lakes Monitoring Program (Michigan Cooperative Lakes Monitoring Program 1999). In 1999 the Secchi disk transparency was measured 18 times in Platte Lake resulting in a mean depth of 12.4 ft from a range of 8.0 to 21.0 ft. This equated to an overall Trophic State Index for Secchi disk depth of 41, essentially the low end of mesotrophy. Glen Lake had a mean Secchi depth of 15.9 ft with a range of 11.0 to 21.0 ft and a Trophic State Index of 37 or an oligo-mesotrophic condition. Total phosphorus concentration and chlorophyll *a* are measured by volunteers on some Michigan lakes, but Platte and Big Glen lakes were not assessed for these parameters.

As part of State's Surface Water Quality Division's watershed surveillance activities, Flower and Walker (1999) conducted a qualitative biological survey of the Crystal River according to GLEAS Procedure 51. The objectives of this study were to document the existing habitat and aquatic macroinvertebrate communities of the river and evaluate compliance with water quality standards. Habitat and macroinvertebrate ratings were obtained at one station within the lakeshore boundaries. The other two stations were rated for only habitat, were downstream of the national lakeshore station and outside the boundary of the lakeshore. The aquatic macroinvertebrate community was rated as acceptable at the lakeshore station and therefore attaining Michigan water quality standards. The habitat was rated as good (slightly impaired).

General habitat observations were made for the first 150 yds of the river upstream of County Road 675 within the lakeshore. Approximately 100 yd upstream of the road crossing, a slug of sand approximately 50 yd long filled the central channel. This slug of sand reduced the average depth to approximately 10 inches and redirected the current to the lateral portions of the channel. Flower and Walker (1999) suggest that the road culvert may be undersized and causing a damming affect that slows water velocity and allows deposition of suspended sediment.

Of all the lakes of concern to the national lakeshore only Glen Lake is <u>individually</u> identified on the State of Michigan's 303(d) list – for PCBs, chlordane, and mercury. This designation says that Glen Lake (includes Big and Little) will not attain applicable water quality standards with technology-based controls, that is, it is an impaired waterbody. For such waterbodies the State needs to develop and implement either total maximum daily loads (TMDLs) or other suitable corrective actions to achieve water quality standards. Although not individually identified (for ease of presentation), all of Michigan's inland lakes (including the rest of the national lakeshore's lakes) are considered to be included on this list due to the generic statewide mercury fish consumption advisory. Michigan waters of the Great Lakes are also considered to be included on the 303(d) list due to fish consumption advisories.

The Evolution of Water Quality Monitoring Program at Sleeping Bear Dunes National Lakeshore

<u>1990 to 1998</u>

The national lakeshore initiated a 3–year project in 1990 to provide a comprehensive aquatic natural resource inventory (Boyle and Hoefs 1993a) and a program for long-term aquatic resource monitoring (Boyle and Hoefs 1993b). Although the developed program by Boyle and Hoefs was detailed and ecologically sound, it was not sustainable because it was ill suited to the needs of the national lakeshore – the lakeshore lacked the resources to conduct such a program and it had no aquatic expertise. Additionally, the comprehensive inventory did not provide enough interpretation of the vast amount of data that was collected, nor was a voucher collection of biological specimens deposited with the national lakeshore.

Last and Whitman (1996) briefly summarized the water quality monitoring that followed at the national lakeshore from 1993 to 1995. Following this initial effort, the monitoring program became the responsibility of the park. In 1993, a bachelor's degree-level biologist (temporary position) without specific training and unfamiliar with the work of Boyle and Hoefs (1993 a and b) conducted water quality monitoring. Samples were collected by park staff and analyzed by an outside laboratory. The national lakeshore received only data sheets and lab results with no interpretation or analysis.

In 1994 the NPS Lake Michigan Ecological Station sampled and collected field data with the help of park interns. Macroinvertebrate and water quality data were analyzed and interpreted. The station performed the water quality analysis and provided the park with a report (Last et al. 1995). In 1995 the station returned and again analyzed water quality, but had inadequate resources for the macroinvertebrate analysis.

From 1990 to 1995, 21 lakes were monitored in 1990 and 12 lakes were monitored each year thereafter. Parameters measured for all years included temperature and dissolved oxygen vertical profiles; Secchi disk transparency; surface pH; chlorophyll *a*, nitrate-nitrogen, and total phosphorus. Specific conductance and ammonia-nitrogen were additional parameters measured from 1994 to 1995. Except for 1993, 10 sites on four streams -- Platte, Otter, Crystal and Shalda – were monitored every year. Parameters included temperature, dissolved oxygen, pH, benthic macroinvertebrate community composition for all years plus specific conductance from 1994 to 1995.

In 1996 the Lake Michigan Ecological Station conducted minimal sampling of a few lakes within the national lakeshore. Monitoring in 1997 and 1998 was basically that conducted by Whitman et al. (2000) and Whitman et al. (2002). Whitman et al. (2000) concentrated only on three lakes (Round, Loon, N. Bar) because the study was a multi-year and multi-park effort. Whitman et al. (2002) primarily conducted a multi-lake zooplankton study that concurrently collected water quality data. For 1998 the water quality program included 18 lakes (11 lakes systematically and seven lakes randomly; no streams were monitored) measuring the following parameters: temperature, pH, total dissolved solids, dissolved oxygen, sulfate, nitrate, ammonia nitrogen, alkalinity, hardness, total hardness and chloride. Water quality samples in 1998 were limited to the epilimnion of lakes; analysis occurred in the national lakeshore's new water quality laboratory. In addition, the national lakeshore installed three staff gages – on the Crystal River (1999), and Loon (1999) and North Bar (1998) lakes.

Recreational monitoring for *E. coli* at the national lakeshore began in 1997 (May through September timeframe) with three monitoring sites on Little Glen Lake and 11 other sites ranging from river outlets and beaches to lakes. All *E. coli* analyses were conducted in the park's water quality laboratory.

1999

The monitoring program was the same as that for 1998 with the following exceptions: 1) both the epilimnion and hypolimnion of lakes were sampled; 2) the recreational monitoring program for *E. coli* deleted one site and added another. National lakeshore staff continued analyzing most water quality parameters and *E. coli* at its water quality laboratory. Phosphorus samples were analyzed by the Michigan Water Resources Center, Central Michigan University.

2000

A total of 13 lakes was monitored twice-monthly from June through September for the following parameters: dissolved oxygen, temperature, depth, total dissolved solids, pH, conductivity, chlorophyll *a*, total phosphorus, sulfate, ammonia-nitrogen, nitrate, alkalinity, hardness, and total hardness. This same suite of parameters was analyzed on a monthly basis at five sites on the Platte River, two sites each for the Crystal River, Shalda Creek and Otter Creek, and 12 springs in the Otter Creek drainage. Recreational monitoring of *E. coli* became a major part of water quality monitoring at the national lakeshore. Monitoring for *E. coli* occurred at 20 sites – nine on national lakeshore streams, nine on Lake Michigan, and two on inland lakes. Sampling occurred weekly from the end of May to the middle of September; the analytical method was the standard membrane filtration technique. National lakeshore staff continued to analyze the same parameters as in 1999.

2001

For this year the same parameters, sites and frequencies as in 2000 were monitored, except the Shalda Creek site was deleted; a site on the Platte River was added; phosphorus samples were collected only in the epilimnion; chlorophyll *a* was an added parameter; six *E. coli* sites were added; and a macroinvertebrate-based rapid bioassessment study on the Crystal River was initiated.

Lake Michigan Waters in Sleeping Bear Dunes National Lakeshore

The nearshore waters largely occupy a band of varying width around the perimeter of Lake Michigan between the land and the deeper offshore waters of the lake. Nearshore waters begin at the shoreline or the lakeward edge of coastal wetlands and extend offshore to the deepest lakebed contour where the thermocline typically intersects with the lakebed in late summer or early fall (Edsall and Charlton 1996).

The nearshore waters of the national lakeshore are virtually unstudied. The reasons for this paucity of information are primarily two-fold: (1) a perception that environmental quality in the Lake Michigan basin is best in the north and deteriorates to the south; and (2) a concentration and proliferation of studies in Areas of Concern (most degraded) over the last decade or so. As such, any discussion of national lakeshore nearshore waters is data-dependent and relies on general summarization or studies of other nearshore waters.

Generally speaking, the open waters of Lake Michigan have good water quality except for a few nearshore waters influenced by large, densely populated and heavily industrialized urban areas (Michigan Department of Environmental Quality 2002). All Michigan waters of the Great Lakes fully support secondary contact (non-swimming) recreational, agricultural, industrial and navigational uses. However, the aquatic life use, based on fish consumption advisories is not being met in Lake Michigan. Therefore, no Michigan waters of Lake Michigan are considered to be fully supporting designated uses.

Water quality in the open waters of Lake Michigan has substantially improved over the last three decades. Since the 1970s, phosphorus loadings and chlorophyll concentrations have decreased significantly due to improved point source controls (e.g., municipal sewage treatment) and laws requiring the reduction or elimination of phosphorus in soaps and detergents. However, recent, preliminary sampling results indicate that phosphorus levels in the open waters of the lake may be increasing. Presently, Lake Michigan has a trophic status characterized by moderate nutrient levels (oligo/mesotrophic). In contrast chloride concentrations continue to increase and the rate of increase is accelerating. The primary source of chloride seems to be municipal wastewater discharges and salt from road deicing.

Lake Michigan continues to exhibit problems associated with very persistent, bioaccumulative, toxic organic substances, such as PCBs, chlordane, and dioxin. Based on the amount of PCB in Lake Michigan's fish, Michigan's water quality standards are not being met for PCBs. Since the 1970s, when the use of many persistent bioaccumulative toxins were banned, levels of these parameters concentrated in Lake Michigan fish tissues have declined. However, the rate of this decrease has apparently slowed and levels have stabilized at concentrations in some fish species that still require fish consumption advisories. Currently, the source of persistent bioaccumulative, toxic substances appears to come primarily form tributary loadings, atmospheric deposition, and the dynamic exchange and cycling between air, water, and sediments within the Lake Michigan basin.

Sediment input to the nearshore waters has occurred since the lakes were formed (Edsall and Charlton 1996). Inputs occur from shoreline erosion and tributaries. Tributary inputs increased in the 19^{th} century when the forest cover was removed for lumber or to permit farming. Agricultural activities continue to facilitate soil erosion and cause accelerated sediment input to the nearshore waters. Sediment inputs are of concern because they decrease water clarity and light penetration into the water, thereby limiting the growth of the aquatic plants that form the base of the food chain. The total annual load of suspended solids is about 22.5 million metric tons in Lake Michigan; for perspective, the total annual load is 2.8 million metric tons in Lake Huron.

Monitoring-based estimates of loading rates of pesticides into the Great Lakes are virtually absent from the published literature (Edsall and Charlton 1996). Knowledge of these loads is needed for developing and refining lakewide management plans, predicting equilibrium concentrations of herbicides in the Great Lakes and interpreting their effects on human and ecosystem health, and providing a basis for assessing the status of agricultural pollution on regional and national scales.

Changes to plankton communities may be occurring as a result of exotic species such as the spiny water flea (*Bythotrephes cederstroemi*) and the zebra mussel (*Dreissena polymorpha*). Many species of non-indigenous algae have also been introduced into Lake Michigan and studies indicate that increased salinity and other environmental changes are enabling introduced algae to adapt more readily to the environment of the Great Lakes (U.S. Environmental Protection Agency 2000). It may be argued that stresses associated with biological factors have in fact caused more severe degradation than physical and chemical stresses.

Population dynamics over the last 100 years include observations that would indicate that zooplankton community structure and abundance have changed markedly in Lake Michigan, especially during the mid-20th century when phosphorus loadings were higher and water quality more degraded (U.S. Environmental Protection Agency 2000). Research conducted in the past 15 years also indicates that zooplanton populations may be experiencing changes induced by the spiny water flea. Dramatic declines in local *Daphnia* spp*.* populations have coincided with increases in populations of the spiny water flea. Preliminary studies indicate that between 10 and 20 percent of zooplanton production can be consumed by the spiny water flea. The spiny water flea is not a preferred prey for many fish -- at best this species represents an extra trophic level between algae and fish, resulting in inefficient energy transfer. At worst, the spiny water flea is an energy sink from the standpoint of fish production.

Although portions of the lake appear to support high quality benthic communities, the overall documentation of the character and quality of invertebrate biota is still scanty. The lake's biotic communities also have not been systematically described or ranked from a biodiversity standpoint. However, many communities would presumably rank as globally rare or imperiled due to restricted distribution, level of threat, ecological fragility, widespread damage and because they are part of the single largest source of fresh water in the world.

Further studies suggest that zebra mussels are having a significant effect on benthic community structure and plankton abundance (U.S. Environmental Protection Agency 2000). Zebra mussels have reached densities higher than

$16{,}000/m^2$ in southern Lake Michigan. The mussels divert energy away from the pelagic food web by filtering out a significant portion of the plankton. Negative impacts include increased competition for plankton at the expense of fish fry from nearshore species, increased biomagnification of contaminants in piscivores feeding on benthic specialists, and possible zebra mussel-induced *Mycrocystis* and *Cladophora* blooms.

Despite healthy recruitment in recent years, lake whitefish (*Coregonus clupeaformis*) populations in northern Lake Michigan are showing signs of stress, including lower body mass possibly due to an explosion of the zebra mussel population in the area. There is evidence that the normal whitefish diet of *Diporeia spp.* (amphipods) and other benthic invertebrates is disappearing possibly due to ecosystem perturbations caused by zebra mussels.

The Great Lakes Water Quality Agreement (GLWQA) calls for the development of lakewide management plans (LaMP). The LaMP for Lake Michigan (U.S. Environmental Protection Agency 2000) focuses on the restoration and protection of the ecological health of the lake through the reduction of pollutant discharges. However, pollutants in Lake Michigan are not the only cause of existing or potential impairments. Habitat loss and shifts in species composition are also important factors contributing to the degradation of ecosystem quality. Despite reductions in ambient levels of toxic pollutants during the past 20 years, data indicate that toxic pollutants still exert negative impacts on the physical and biological components of the Lake Michigan ecosystem.

GLWQA mandates that the Lake Michigan LaMP address the following 14 warning signs of an impaired ecosystem, called beneficial-use impairments:

- Restriction on fish and wildlife consumption;
- Tainting of fish and wildlife flavor;
- Degradation of fish and wildlife populations;
- Fish tumors or other deformities;
- Bird or animal deformities or reproduction problems;
- Degradation of the benthos;
- Restriction of dredging activities;
- Eutrophication or undesirable algae;
- Restriction on drinking water consumption, or taste and odor problems;
- Beach closings;
- Degradation of aesthetics;
- Added costs to agriculture or industry;
- Degradation of phytoplankton populations; and
- Loss of fish and wildlife habitat.

The LaMP pollutants are categorized into three levels based on degree of association with use impairments and spatial distribution or frequency of occurrence:

Pollutants: Lake Michigan LaMP

Level 1 Critical Pollutants	Level 2 Pollutants of Concern	Level 3 Emerging Pollutants
Total PCBs	Hexachlorobenzene	Atrazine
Chlordane	Toxaphene	PCB substitute compounds
Dioxins	Cadmium	selenium
Mercury	Copper	
Dieldrin	Arsenic	
DDT/DDD/DDE	PAHs	
Furans	Chromium	
	Zinc	
	cyanide	

Critical pollutants are substances that exist at levels that impair beneficial uses due to their presence in open lake waters, their ability to cause or contribute to a failure to meet Agreement objectives, or their ability to bioaccumulate. For the purposes of the LaMP, critical pollutants are substances that violate the most stringent federal or state water quality standards or criteria in nearshore and/or open Lake Michigan waters; exceed a Food and Drug Administration action level in lake fish; or contribute to use impairments on a lakewide basis. Pollutants of concern are pollutants that cause or contribute to use impairments on a local or regional basis or for which there is evidence that loadings to, or ambient concentrations in, the Lake Michigan watershed are increasing. Emerging pollutants are those toxic substances that, while not presently known to contribute to impairments or show increasing loadings or concentrations, have characteristics indicating a potential to impact the physical or biological integrity of Lake Michigan.

Because (1) the Lake Michigan shoreline and watersheds of Benzie and Lelanau counties have remained largely free of urbanization, (2) a large coordinated effort (federal, state and local agencies) is being expended through the continuing development of the Lake Michigan LaMP, and (3) the national lakeshore's water resources management program is presently limited by staff and dollars, the national lakeshore should concentrate its water resources management program on inland (both mainland and island) water resources. However, the lakeshore should continue with recreational monitoring of appropriate Lake Michigan swimming beaches. Additionally, the national lakeshore staff should remain vigilant of any problems as they arise in the Lake Michigan waters of the lakeshore. These problems should then be brought to the attention of the general public and those regulatory agencies (local, state and/or federal) with purview over such problems.

WETLANDS

The National Wetland Inventory of the U.S. Fish and Wildlife Service identified, classified (according to Cowardin et al. 1979), and mapped wetlands of the lakeshore. A total number of wetlands in excess of 300 (several wetland types were too numerous to count), representing 32 wetland types, was identified. Sleeping Bear Dunes National Lakeshore is dominated by palustrine wetlands (approximately 80 percent of the total number of wetlands). Palustrine wetlands include all nontidal wetlands dominated by trees, shrubs, persistent emergent vegetation and emergent mosses or lichens. This broad classification was developed to group the vegetated wetlands traditionally called by such names as marsh, swamp, bog, fen, and prairie. It also includes small, shallow, permanent or intermittent water bodies often called ponds. Palustrine wetlands may be situated shoreward of lakes; river channels; on river floodplains; in isolated catchments; or on slopes. They may also occur as islands in lakes or rivers. Wind and water as agents of major change (via erosion) are of minor importance except during severe floods.

There are primarily three classes of palustrine wetlands in the national lakeshore: emergent; forested; and scrub-shrub. Emergent wetlands are characterized by erect, rooted hydrophytic vegetation that is present most of the growing season. Herbaceous, perennial plants usually dominate these wetlands. Forested wetlands are characterized by tall (> 20 feet), woody vegetation. Normally, they contain an overstory of trees, an understory of young trees or shrubs, and a herbaceous layer. Scrub-shrub wetlands include areas dominated by woody vegetation (< 20 feet), including young trees, tree shrubs, and trees and shrubs that are small or stunted because of environmental conditions. Scrub-shrub wetlands are often a successional stage leading to forested wetlands.

For the national lakeshore it is difficult to determine the predominance among these wetland classes because each class has its own wetland type that was 'too numerous to count'. Based on professional judgement, forested and scrub-shrub wetlands are co-dominant with persistent, emergent wetlands not far behind. Within the three palustrine classes, persistent saturated emergent, saturated/semi-permanent/seasonal forested, and saturated/semi-permanent/ seasonal scrub-shrub wetlands were the dominant wetland types. Persistent emergent wetlands are dominated by species that typically remain standing at least until the beginning of the next growing season. Saturated refers to a water regime that has the substrate saturated to the surface for extended periods of time during the growing season, but surface water is seldom present. The catch-all category saturated/semi-permanent/ seasonal is used when it is unclear from photographic interpretation whether a wetland is saturated, semi-permanently flooded (surface water present throughout the growing season in most years), or seasonally flooded (surface water present for extended periods early in the growing season).

Open water wetland types of both the lacustrine and palustrine classes, as well as the unconsolidated bottom type of the palustrine class represent the lakes of the lakeshore. Rivers fall under the riverine, lower perennial class and both unconsolidated bottom and open water wetland types. Either the open water or beach/bar wetland types of the lacustrine/littoral class represent the shoreline of Lake Michigan within the park boundary.

Hazlett (1988) determined the presence/absence of wetland species for 18 lakes and three stream systems in the lakeshore. His study provides a catalog of aquatic vascular plant species (true aquatic, wetland, riparian) for the lakeshore. This catalog is also included in Hazlett's seminal work on the flora of Sleeping Bear Dunes National Lakeshore (Hazlett 1991).

Albert (1992) determined the presence/absence of wetland flora for all 4 major watersheds in the lakeshore and four lakes. This study also determined coverage class for each plant species, total plant coverage class, water depth, substrate, and depth of organic material. Therefore, this study provides the only quantitative, albeit a semi-quantitative, look at wetland species in the lakeshore. His study added to the past work of Hazlett (1988; 1991).

Hazlett (1991) provided good descriptions of 'traditional' wetland types within the national lakeshore. These descriptions, augmented by information presented in Thompson (1967), Hazlett (1986) and Albert (1992), are discussed below.

Bogs usually form in low basins that have no drainage inlets or outlets, and that are less influenced by ground water inflows. The water has a low pH and sphagnum moss (*Sphagnum spp.*) is abundant. Leatherleaf (*Chamadaphne calyculata*) is a common shrub. Larch (*Larix laricina*) and black spruce (*Picea mariana*) are common trees. The Bow Lakes area includes a good example of a bog as well as three other bogs: one observed from M-22 east of Westman Road, Round Lake, and one northeast of the intersection of Port Oneida and Kelderhouse roads.

The most extensive cedar swamp system borders Otter Creek. Smaller areas occur along the Crystal River and Shalda Creek. White cedar (*Thuja occidentalis*) is the dominant species with white pine (*Pinus strobus*), white birch (*Betula papyrifera*), and balsam fir (*Abies balsamea*) as associates.

Black ash (*Fraxinus nigra*) swamps occur in low, poorly drained sites bordering lakes and are found near Tucker, Shell, Narada, School, North Bar and Glen lakes. Black ash is common in the overstory with cedar, hemlock (*Tsuga canadensis*), white birch, and red maple (*Acer rubrum*). These swamps tend to be more open than cedar swamps and allow for a more diverse understory.

Alder (*Alnus rugosa*) thickets are quite wet, with alders and willows (*Salix spp.*) forming a very dense shrub zone.

Marshes are wetlands with a predominately herbaceous cover. Such areas are most common along the Platte River (e.g., Boekeloo Pond in the ridge and swale area of the river), near the mouth of Otter Creek, by Round Lake and Day Mill Pond. Sedges (Carex spp.), rushes (Juncus spp.) and grasses (*Leersia sp.*; *Calamagrostis sp.*) dominate these wetlands.

The wooded dune and swale is a complex of wetland swales (also called interdunal swales or wetlands) and upland beach ridges (dunes) that are found in embayments and on large sand spits along the shoreline of all the Great Lakes. Five subtypes of the dune and swale complex have been identified in Michigan (Michigan Natural Features Inventory No Date). The Northern Lake Huron/Lake Michigan-High Dune subtype occurs in the national lakeshore, and is common in Benzie and Leelanau counties. High, often irregular dune ridges formed by prevailing westerly winds distinguish this subtype. Clear distinctions can be made between the upland vegetation of the high dune ridges and the wetland vegetation of the swales. Wetland plant communities include emergent marsh, intermittent wetland, bog, northern wet meadow, alder swamp and cedar swamp.

Albert (1992) noted that the Platte River and Shalda Creek are the two wooded dune and swale complexes in the lakeshore. His work demonstrated that the hydrology of the swales is not determined by the present Lake Michigan water level, but instead by local substrate and drainage conditions in the swales or influenced by adjacent uplands. He found no sign of any seepage into the swales within the lakeshore. The vegetation of the wet swales gradually changes from aquatic macrophytes characteristic of wet meadows and emergent marshes near the present Lake Michigan shoreline, to shrub swamp and treed swamp vegetation on thick organic soils farther from the present shoreline – a pattern that is seen throughout the state. The wooded dune and swale complex may support many endangered or threatened species. Due to the natural fragility of interdunal wetlands and the loss of shoreline habitat due to development along the Great Lakes shoreline, this habitat is threatened.

One of the most variable wetland habitats on an annual basis within the national lakeshore is the coastal pool/dune panne (Hazlett 1988). These small wetlands usually occur on coastal dunes. Coastal pools (areas of open water) and dune pannes (low, moist sites) exist on the open dunes of Platte Bay, along Good Harbor Bay NE of County Road 651, and on South Manitou Island at Sandy Point. The water level of Lake Michigan largely determines the surface area of pools and pannes. The vegetation of dune pools and pannes is predominately herbaceous with sedges (*Carex* spp. and *Eleocharis* spp.) and rushes (*Juncus* spp.).

One predicted outcome of climate change is an increase in temperature, likely affecting Great Lakes wetlands through its effect on lake levels and ground water systems feeding the lakes. Lake level is a factor ultimately determining the status of Great Lakes coastal wetlands, but the mechanisms of this control and its long-term dynamics are still poorly understood.

A 4-year, U.S. Geological Survey study begun in 1999 (< http://www.nrel.colostate.edu/brd_global_change/proj_31_great_lakes.html >) will provide sedimentological and paleoecological data on the responses of wetlands at three different latitudes in the Lake Michigan basin to warming and cooling events over the past 4000 years. One of the study sites is in the Platte River area of the national lakeshore. This area contains a series of fossil beach ridges laid down in response to the Lake Michigan water-level fluctuations over the past several thousand years. As each ridge formed, a wetland developed in the swale behind it. The ridge/swale complexes comprise a time sequence that recorded changes in lake level over time and wetland response to those changes.

RIPARIAN AREAS

Natural riparian zones are some of the most diverse, dynamic, and complex biophysical habitats in the terrestrial environment (Naiman et al. 1993). The riparian zone encompasses that stream channel between low and high watermarks and that portion of the terrestrial landscape from the high watermark toward the uplands where vegetation may be influenced by elevated water tables or flooding and by the ability of the soils to hold water (Naiman and Decamps 1997). The riparian zone may be small in numerous headwater streams. In mid-sized streams, the riparian zone is larger, being represented by a distinct band of vegetation whose width is determined by long-term (>50 years) channel dynamics and the annual discharge regime. Riparian zones of large streams are characterized by well developed but physically complex floodplains, with long periods of seasonal flooding, lateral channel migration, old channel oxbow lakes and a diverse vegetative community (Malanson 1993). These attributes suggest that riparian zones are key systems for regulating aquatic-terrestrial linkages (Ward 1989) and that they may provide early indications of environmental change (Decamps 1993).

Physically, riparian zones control mass movements of materials and channel morphology (Naiman and Decamps 1997). Material supplied to streams comes from erosion of stream banks, a process influenced by root strength and resilience, as well as from the uplands. Stream banks largely devoid of riparian vegetation are often highly unstable and subject to mass wasting that can widen channels by several tens of feet annually. Major bank erosion is 30 times more prevalent on nonvegetated banks exposed to currents as on vegetated banks (Beeson and Doyle 1995).

In addition, riparian zones provide woody debris. Woody debris piles dissipate energy, trap moving materials, and create habitat (Naiman and Decamps 1997). Depending upon size, position in the channel and geometry, woody debris can resist and redirect water currents, causing a mosaic of erosional and depositional patches in the riparian corridor (Montgomery et al. 1995).

Riparian forests exert strong controls on the microclimate of streams (Naiman and Decamps 1997). Stream water temperatures are highly correlated with riparian soil temperatures, and strong microclimatic gradients appear in air, soil, and surface temperatures, and in relative humidity.

Ecologically, riparian zones: 1) provide sources of nourishment—allochthonous inputs to rivers and herbivory; 2) control nonpoint sources of pollution, in particular, sediment and nutrients in agricultural watersheds; and 3) create a complex of shifting habitats with different spatio-temporal scales, through variations in flood duration and frequency and concomitant changes in water table depth and plant succession (Naiman and Decamps 1997).

Other than a cursory understanding of the presence of riparian plant species (Hazlett 1986; Albert 1992), the riparian areas of the national lakeshore are unstudied. More importantly, it is not known how healthy these areas are and if they are functioning properly, thus providing maximum ecological protection to the lakeshore's water resources.

Hazlett (1988) noted that the development of riparian vegetation near the mouth of the Platte River was not as extensive in 1986 as it had been. In 1922 (Waterman 1922) the open water was narrower than in 1988 and was bordered by "grass meadows", densely developed mats of grasses and sedges. These grass meadows may be similar to vegetation now found south of Round Lake or upstream from the Otter Creek bridge. In 1986 many of the areas appearing as grass meadows in earlier studies are flooded. Increased river traffic (recreational) may have had some influence in preventing the development of grass meadows and other vegetation along the river, but a more important factor may be river water level. Waterman (1922) suggested that grass meadows along the Platte River formed rapidly and would grow as river level (dependent on Lake Michigan levels) dropped. Hazlett provides further evidence that riparian vegetation growth along the Platte River is dependent upon a drop in lake level. Whether this same correlation holds for the other streams in the national lakeshore remains to be seen.

AQUATIC MACROPHYTES

Prior to 1988, information on the composition, distribution and ecology of aquatic macrophytes [emergent, floating-leaved, submersed, and free-floating (Wetzel 1975)] within the lakeshore was primarily limited to qualitative or anecdotal comments in a few studies (Coulter 1904; Waterman 1922; Thompson 1967; Stockwell and Gannon 1975; Linton 1987). However, the focused studies of

Hazlett (1988; 1991) and Albert (1992) greatly added to the knowledge of aquatic macrophytes within the lakeshore.

Hazlett (1988) described aquatic macrophytes from 18 lakes and three watersheds in the lakeshore based on intensive, yet qualitative, sampling of aquatic vegetation in the summers of 1986 (an exceptionally wet year in which flooding occurred in previously dry areas) and 1987. Albert (1992) conducted quantitative transect sampling in 1991 and provided a list of aquatic macrophytes for all four watersheds in the lakeshore, four lakes, and the dune swales near the Platte River and Shalda Creek.

The floristic composition and productivity of a given lake or stream is influenced by factors such as its depth, area, isolation, substrate composition, pH and dissolved ionic composition. The result is extremes in heterogeneity in both distribution and productivity, spatially and temporally (Wetzel 1975). Table 5 combines the results of Hazlett (1988) and Albert (1992) to provide the only known distribution of aquatic macrophyte species in the lakeshore. For the purposes of this table, only floating-leaved, submersed, or free-floating aquatic macrophyte species are included. Emergent macrophytes (e.g. *Scirpus* sp., *Typha* sp. and *Carex* sp.) are more often classified as ‘wetland’ or ‘riparian’ species. Wetland and riparian vegetation are discussed in other sections of the document.

Based on Table 5, a total of 42 species of aquatic macrophytes is found in or adjacent to the national lakeshore. Species richness ranged from a low of one species (Tamarack Lake) to a high of 23 species (Platte River). Waterbodies of high species richness, besides the Platte River, included Otter Lake (20 species); Bass Lake (Benzie; 19); Otter Creek (18); and Tucker Lake, School Lake and the Crystal River (all with 15 species). Waterbodies of low species richness included the Hidden Lake (4); Florence Lake (4); the Bow Lakes (5); Mud Lake (6); and Loon Lake (6). Among the four, lakeshore watersheds, Shalda Creek had the lowest species richness (7).

Widely distributed species (= presence in > 50 percent of waterbodies) included the naiad, pond-lily, water-lily and three species of pondweed (*Potamogeton gramineus*, *P. illinoensis*, and *P. pectinatus*). Several species had limited distributions (= presence in < 10 percent of waterbodies) within the national lakeshore. These included greater duckweed (Day Mill Pond); star duckweed (Day Mill Pond); mare’s-tail (Otter Creek); lady’s thumb (the Bow Lakes); the pondweed, *P. oakesianus* (Platte River); *P. strictifolius* (North Bar Lake); water star-grass (Deer and Bass (Benzie) lakes); whitewater crowfoot (Otter Creek and Lake Manitou); hooked crowfoot (the Bow Lakes and Shalda Creek); *P. hilli*

Table 5. Aquatic macrophyte distribution within Sleeping Bear Dunes National Lakeshore. After Hazlett (1988) and Albert (1992). 'X' denotes presence. ^{E} denotes exotic species.

SPECIES	N. Bar Lake	Day Mill Pond	Glen and Little Glen lakes	Tucker Lake	School Lake	Bass Lake (Leelanau)	Narada Lake
Myriophyllum heterophyllum (water-milfoil)	X			X			X
M. exalbescens (water-milfoil)		X		X	X	X	
M. spicatum^{E} (water-milfoil)	X						
Elodea canadensis (Elodea)	X	X	X				
Najas flexilis (naiad)	X	X	X	X	X	X	
Nuphar variegata (pond-lily)	X			X	X		X
Nymphaea odorata (water-lily)	X			X	X		X
Potamogeton amplifolius (pondweed)	X			X	X	X	
P. crispus^{E} (pondweed)	X				X		
P. foliosus (pondweed)	X			X		X	
P. gramineus (pondweed)	X		X	X	X	X	
P. illinoensis (pondweed)	X	X		X		X	
P. pectinatus (pondweed)	X	X		X	X	X	
P. richardsonii (pondweed)	X	X	X				
P. natans (pondweed)		X		X	X	X	X
P. zosteriformis (pondweed)		X	X		X	X	
P. filiformis (pondweed)			X				
P. friesii (pondweed)					X		
P. praelongus (pondweed)							X
P. berchtoldii (pondweed)							X

Table 5. Continued.

SPECIES	N. Bar Lake	Day Mill Pond	Glen and Little Glen lakes	Tucker Lake	School Lake	Bass Lake (Leelanau)	Narada Lake
Utricularia spp. (bladderwort)	X			X			X
U. vulgaris (bladderwort)		X		X			
Lemna minor (duckweed)		X		X	X		X
L. trisulca (star duckweed)		X					
Spirodela polyrhiza (greater duckweed)		X					
Wolffia punctata (water-meal)							X
Ceratophyllum demersum (coontail)		X					X
Sagittaria latifolia (duck-potato)			X		X	X	
Vallisneria americana (tape-grass)			X	X	X	X	
Chara globularis (a macroalgal species)					X	X	

Table 5. Continued

SPECIES	Shell Lake	Hidden Lake	Bow Lakes	Rand Lake	Mud Lake	Loon Lake	Deer Lake
Myriophyllum Heterophyllum (water-milfoil)							X
M. exalbescens (water-milfoil)				X			
M. spicatum[E] (water-milfoil)						X	
Elodea canadensis (Elodea)							X
Najas flexilis (naiad)	X			X			
Nuphar variegata (pond-lily)	X	X		X	X	X	X
Nymphaea odorata (water-lily)	X			X	X		X
Potamogeton amplifolius (pondweed)		X		X			X
P. crispus[E] (pondweed)						X	
P. gramineus (pondweed)	X				X		
P. illinoensis (pondweed)	X			X			
P. friesii (pondweed)				X			
P. pectinatus (pondweed)	X			X	X	X	X
P. richardsonii (pondweed)							X
P. natans (pondweed)	X	X				X	X
P. zosteriformis (pondweed)							X
P. friesii ***(pondweed)***				X			
Utricularia spp. (bladderwort)	X						
U. vulgaris (bladderwort)							X
U. minor (bladderwort)				X	X		
U. geminiscapa (bladderwort)			X				
Lemna minor (duckweed)	X		X				X

Table 5. Continued.

SPECIES	Shell Lake	Hidden Lake	Bow Lakes	Rand Lake	Mud Lake	Loon Lake	Deer Lake
Wolffia punctata (water-meal)							X
Ceratophyllum demersum (coontail)						X	
Sagittaria latifolia (duck-potato)					X		
Polygonum amphibium (water smartweed)	X	X	X				
Polygonum persicaria (lady's thumb)			X				
Ranunculus recurvatus (hooked crowfoot)			X				
Heteranthera dubia (water star-grass)							X

Table 5. Continued.

SPECIES	Bass Lake (Benzie)	Otter Lake	Lake Florence	Tamarack Lake	Lake Manitou	Crystal River	Shalda Creek
Myriophyllum heterophyllum (water-milfoil)	X	X					
M. exalbescens (water-milfoil)					X	X	X
Elodea canadensis (Elodea)	X					X	
Najas flexilis (naiad)	X	X			X	X	
Nuphar variegata (pond-lily)	X	X		X	X		X
Nymphaea odorata (water-lily)	X	X				X	
Potamogeton amplifolius (pondweed)	X	X	X				
P. crispus[E] (pondweed)						X	
P. foliosus (pondweed)	X				X		
P. gramineus (pondweed)	X	X	X		X		
P. illinoensis (pondweed)	X	X			X	X	X
P. pectinatus (pondweed)	X	X				X	
P. richardsonii (pondweed)	X	X			X	X	
P. natans (pondweed)		X			X		
P. zosteriformis (pondweed)	X	X				X	
P. filiformis (pondweed)					X		
P. praelongus (pondweed)					X		
P. friesii (pondweed)		X					
P. hilli (pondweed)		X					
P. strictifolius (pondweed)	X						
P. robbinsii (pondweed)		X					
P. berchtoldii (pondweed)	X	X	X				
Polygonum amphibium (water smartweed)	X						

Table 5. Continued.

SPECIES	Bass Lake (Benzie)	Otter Lake	Lake Florence	Tamarack Lake	Lake Manitou	Crystal River	Shalda Creek
Ranunculus longirostris (white water crowfoot)					X		
Ranunculus recurvatus (hooked crowfoot)							X
Heteranthera dubia (water stargrass)	X						
Nasturtium offininale[E] (watercress)							X
Chara globularis (a macroalgal species)	X	X					X
Chara vulgaris (a macroalgal species)						X	
Utricularia spp. (bladderwort)						X	
U. vulgaris (bladderwort)			X				
Lemna minor (duckweed)						X	
Ceratophyllum demersum (coontail)	X					X	
Sagittaria latifolia (duck-potato)		X				X	X
Vallisneria americana (tape-grass)	X	X				X	

Table 5. Continued.

SPECIES	Platte River	Otter Creek
Myriophyllum heterophyllum *(water-milfoil)*		X
M. exalbescens (water-milfoil)	X	
M. spicatum [E] (water-milfoil)	X	
Elodea canadensis (Elodea)	X	
Najas flexilis (naiad)	X	
Nuphar variegata (pond-lily)	X	X
Nymphaea odorata (water-lily)	X	
P. gramineus (pondweed)	X	
P. illinoensis (pondweed)	X	X
P. pectinatus (pondweed)	X	X
P. richardsonii (pondweed)	X	X
P. natans (pondweed)	X	X
P. zosteriformis (pondweed)	X	X
P. friesii (pondweed)	X	X
P. robinsii (pondweed)	X	
P. hilli (pondweed)		X
P. perfoliatus (pondweed)	X	
P. obtusifolius (pondweed)	X	X
P. oakesianus (pondweed)	X	
Lemna minor (duckweed)	X	X
Ceratophyllum demersum (coontail)	X	X
Polygonum amphibium (water smartweed)	X	
Polygonum punctatum (smartweed)		X

Table 5. continued

SPECIES	Platte River	Otter Creek
Heteranthera dubia (water stargrass)		X
Hippuris vulgaris (mare's-tail)		X
Ranunculus longirostris (white water crowfoot)		X
Utricularia spp. (bladderwort	X	
U. vulgaris (bladderwort)		X
U. minor (bladderwort)		X
Sagittaria latifolia (duck-potato)		X
Vallisneria americana (tape-grass)	X	
Chara globularis (a macroalgal species)	X	X

(Otter Lake and Otter Creek); *P. robbinsii* (Otter Lake and Platte River); and, *P. filiformis* (Glen Lake, Litter Glen Lake and Lake Manitou).

White (1987) noted that aquatic macrophyte beds were extensive at the outflows of lakes in the national lakeshore. He noted that the taxa present in the lakes are among those known to remove nutrients and inorganic carbon (carbonates and bicarbonates) directly from the water column (e.g., *Potamogeton*, *Chara*, *Myriophyllum*, *Elodea*). Macrophyte production and accompanying environmental changes generate significant marl deposition at the lake outflows and for some distance downstream.

Day Mill Pond, a shallow 6-acre extension of Little Glen Lake separated from Glen Lake by M-109, was once used in the operation of a lumber mill. It is noteworthy because it contains four relatively rare species within the lakeshore – star duckweed, greater duckweed, *P. robbinsii* and *P. hilli* (Hazlett (1991).

Otter Creek is the only place where mare's-tail has been found in the lakeshore and the only locality for white water crowfoot on the mainland portion of the lakeshore (Hazlett 1991).

The Marl springs area of Otter Creek is noteworthy for the abundance of water-parsnip in the cold, calcareous waters of the springs (Hazlett 1991) – it is a state threatened species. Hazlett (1988) also sampled the Port Oneida Bog NE of the intersection of Port Oneida and Kelderhouse roads. A noteworthy species was the presence of *P. oakesianus*, a rare pondweed found in only one other area in the lakeshore.

Albert (1992) also listed the aquatic macrophytes found in the dune and swale complexes of the Platter River and Shalda Creek. Those species (not including emergent species) were: *Chara globularis*; duckweed; water-lily; water smart-weed; *P. gramineus*; *P. natans*; and four bladderworts -- *U. intermedia*, *U. minor*, *U. cornuta* and *U. vulgaris*.

FISH AND FISHERIES

A total of 153 species (64 genera and 25 families) comprises the native fish fauna of the Great Lakes basin (Bailey and Smith 1981). Ninety-one species occur in Lake Michigan and 135 species in the Lake Michigan watershed. Lake Michigan ranks 3rd in fish species richness compared to other Great Lakes and 1st in fish species richness of the watershed.

Kelly and Price (1979) systematically surveyed the waters of the lakeshore for fish species presence/absence. Prior to this study, no comprehensive survey had been made for fish in the lakeshore. Fish were collected from 40 sampling stations representing all aquatic habitats in the lakeshore, including most inland lakes and the Lake Michigan shoreline. To develop their species distribution lists, Kelly and Price combined their sampling results with the results of other entities (e.g., U.S. Fish and Wildlife Service and University of Michigan Museum of Zoology) that had previously sampled fish within the lakeshore.

A total of 76 species occurs in the national lakeshore. The Platte River watershed had the highest species richness with 53 total species (Table 6), followed by Shalda Creek watershed (45 species; Table 7), Crystal River watershed (35; Table 8), and the Otter Creek watershed (27; Table 9). Not associated with these main watersheds are several, relatively small lakes. The total fish species richness for these lakes was 22 (Table 10). Generally speaking fish species richness per watershed was directly related to watershed size. The underlying factor for this relationship in typical watersheds without flow-through lakes is habitat diversity, i.e. larger watersheds have more habitat diversity. This factor is still at play for the lakeshore's watershed(s), but habitat diversity is largely expressed as variability in the number, size, and types of flow-through lakes within each watershed.

The total fish species richness for lakes within or adjacent to the lakeshore was as follows: Big Glen Lake (18 species); Little Glen Lake (11); Bass Lake (Benzie -10); Fisher Lake (10); Mud Lake (9); Narada Lake (9); Round Lake (9); School Lake (9); Shell Lake (9); Otter Lake (9); North Bar (7); Lake Manitou (7); Tucker Lake (6); Bass Lake (Leelanau – 6); Florence Lake (4); Loon Lake (3); Deer Lake (3); and Hidden Lake (3) (Tables 7-11). As expected there is a general tendency for fish species richness to relate directly with lake area (Figure 13) – more area equates to more habitat types for more species.

The Lake Michigan shoreline of the national lakeshore yielded a total of 34 fish species (Table 11).

Based on historical distribution maps (Lee et al. 1980 - *et seq*), the following fish species may be found in the national lakeshore: gizzard shad (*Alosa pseudoharengus*); brassy minnow (*Hybognathus hankinsoni*); pugnose shiner (*Notropis anogenus*); finescale dace *(Phoxinus neogaeus);* bloater *(Coregonus hoyi);* and shortjaw cisco *(Coregonus zenithicus).* This would bring the possible fish fauna of the national lakeshore to 82 species.

Arctic grayling (*Thymallus arcticus*), once an inhabitant of northern Michigan streams and a popular game species, became extinct in the Platte River before 1895 (Taube 1974).

Kelly and Price (1979) determined that eight, nonnative species and one hybrid inhabit the waters of national lakeshore: sea lamprey (*Petromyzon marinus*); alewife (*Alosa pseudoharengus*); carp (*Cyprinus carpio*); rainbow smelt (*Osmerus modax*); coho salmon (*Onchorhynchus kisutch*); chinook salmon (*O. tshawytscha*); rainbow trout (*O. mykiss*); brown trout (*Salmo trutta*); and splake [a

Table 6. Fishes of the Platte River watershed in Sleeping Bear Dunes National Lakeshore. After Kelly and Price (1979).

Species	Lower Platte River	Loon Lake	Mud Lake	Platte Lake & Platte River
Sea Lamprey[1] *Petromyzon marinus*				X
American Brook Lamprey *Lampetra appendix*				X
Chestnut Lamprey *Ichthyomyzon castaneus*	X			X
Northern Brook Lamprey *Ichthyomyzon fossor*				X
Silver Lamprey *Ichthyomyzon unicuspis*				X
Longnose Gar *Lepisosteus osseus*				X
Bowfin *Amia calva*				X
Brook Trout *Salvelinus fontinalis*				X
Lake Trout *Salvelinus namaycush*				X
Brown Trout[1] *Salmo trutta*				X
Rainbow Trout[1] *Oncorhynchus mykiss*				X
Coho Salmon[1] *Oncorhynchus kisutch*				X
Chinook Salmon[1] *Oncorhynchus tshawytscha*				X
Lake Herring *Coregonus artedi*				X
Rainbow Smelt[1] *Osmerus mordax*				X
Alewife *Alosa pseudoharengus*				X
Central Mudminnow *Umbra limi*				X
Common Carp[1] *Cyprinus carpio*				X
Blacknose Dace *Rhinichthys atratulus*				X
Hornyhead Chub *Nocomis biguttatus*	X			X
Bluntnose Minnow *Pimephales notatus*	X		X	X
Creek Chub *Semotilus atromaculatus*				X
Common Shiner *Luxilus cornutus*				X

Table 6. Continued.

Species	Lower Platte River	Loon Lake	Mud Lake	Platte Lake & Platte River
Rosyface Shiner *Notropis rubellus*				X
Sand Shiner *Notropis stramineus*	X		X	X
Blacknose Shiner *Notropis heterolepis*				X
Spottail Shiner *Notropis hudsonius*	X			X
Mimic Shiner *Notropis volucellus*				X
Lake Chub *Couesius plumbeus*				X
White Sucker *Catostomus commersoni*				X
Longnose Sucker *Catostomus catostomus*				X
Shorthead Redhorse *Moxostoma macrolepidotum*		X		X
Silver Redhorse *Moxostoma anisurum*	X			X
Northern Pike *Esox lucius*			X	X
Muskellunge *Esox masquinongy*				X
Brown Bullhead *Ameiurus nebulosus*				X
Yellow Bullhead *Ameiurus natalis*				X
Banded Killifish *Fundulus diaphanus*			X	
Brook Stickleback *Culaea inconstans*				X
Bluegill *Lepomis macrochirus*			X	X
Pumpkinseed *Lepomis gibbosus*		X		X
Longear Sunfish *Lepomis megalotis*				X
Black Crappie *Pomoxis nigromaculatus*				
Rock Bass *Ambloplites rupestris*	X	X	X	X
Largemouth Bass *Micropterus salmoides*			X	X
Smallmouth Bass *Micropterus dolomieu*	X		X	X
Yellow Perch *Perca flavescens*				X

Table 6. Continued.

Species	Lower Platte River	Loon Lake	Mud Lake	Platte Lake & Platte River
Walleye *Stizostedion vitreum*				X
Log Perch *Percina caprodes*	X			X
Johnny Darter *Etheostoma nigrum*	X		X	X
Iowa Darter *Etheostoma exile*				X
Mottled Sculpin *Cottus bairdi*				X
Slimy Sculpin *Cottus cognatus*				X

[1] Non-native species.

Table 7. Fishes of the Shalda Creek watershed in Sleeping Bear Dunes National Lakeshore. After Kelly and Price (1979).
[1] denotes non-native species.

Species	Shalda Creek Mouth	Shalda Creek Source	Little Traverse Lake	Shetland Creek	Lime Lake	Narada Lake	Narada Pond	Narada Creek	School Lake	Bass Lake	Shell Lake
Sea Lamprey[1] *Petromyzon marinus*	X										
Lamprey *Ichthyomyzon sp.*	X										
American Brook Lamprey *Lampetra appendix*	X										
Brook Trout *Salvelinus fontinalis*	X										
Brown Trout[1] *Salmo trutta*	X				X						
Rainbow Trout[1] *Oncorhynchus mykiss*	X				X	X					
Coho Salmon[1] *Oncorhynchus kisutch*	X										
Chinook Salmon[1] *Oncorhynchus tshawytscha*	X										
Lake Herring *Coregonus artedi*			X		X						
Rainbow Smelt[1] *Osmerus mordax*	X										
Alewife[1] *Alosa pseudoharengus*	X		X		X	X					
Central Mudminnow *Umbra limi*	X	X									
Northern Redbelly Dace *Phoxinus eos*	X										
Blacknose Dace *Rhinichthys atratulus*	X										
Longnose Dace *Rhinichthys cataractae*	X										

Table 7. Continued.

Species	Shalda Creek Mouth	Shalda Creek Source	Little Traverse Lake	Shetland Creek	Lime Lake	Narada Lake	Narada Pond	Narada Creek	School Lake	Bass Lake	Shell Lake
Bluntnose Minnow *Pimephales notatus*	X	X		X	X				X		X
Creek Chub *Semotilus atromaculatus*	X			X				X			
Golden Shiner *Notemigonus crysoleucas*						X	X				
Common Shiner Luxilus cornutus	X			X	X						
Sand Shiner *Notropis stramineus*	X				X						
Blacknose Shiner *Nottrpis heterolepis*	X			X							
Blackchin Shiner *Notropis heterodon*				X							
Spottail Shiner *Notropis hudsonius*	X			X	X						
Emerald Shiner *Notropis atherinoides*	X										
Mimic Shiner *Notropis volucellus*	X										
White Sucker *Catostomus commersoni*	X	X	X	X	X	X			X	X	X
Northern Pike *Esox lucius*	X		X		X				X	X	
Yellow Bullhead *Ameiurus natalis*									X	X	
Brown Bullhead *Ameiurus nebulosus*			X		X				X	X	

Table 7 Continued.

Species	Shalda Creek Mouth	Shalda Creek Source	Little Traverse Lake	Shetland Creek	Lime Lake	Narada Lake	Narada Pond	Narada Creek	School Lake	Bass Lake	Shell Lake
Banded Killifish *Fundulus diahanus*	X	X			X						X
Brook Stickleback *Culaea inconstans*						X	X				
Ninespine Stickleback *Pungitius pungitius*	X										
Bluegill *Lepomis macrochirus*	X		X		X	X			X	X	X
Pumpkinseed *Lepomis gibbosus*			X			X			X		X
Black Crappie *Pomoxis nigromaculatus*			X								
Rock Bass *Ambloplites rupestris*	X		X	X	X				X	X	
Largemouth Bass *Micropterus salmoides*	X		X		X	X			X		X
Smallmouth Bass *Micropterus dolomieu*	X		X		X						X
Yellow Perch *Perca flavescens*			X		X	X					X
Walleye *Stizostedion vitreum*					X						
Logperch *Percina caprodes*	X			X							
Johnny Darter *Etheostoma nigrum*	X	X		X	X						X
Fantailed Darter *Etheostoma flabellare*	X			X							
Slimy Sculpin *Cottus cognatus*	X										
Mottled Sculpin *Cottus bairdi*	X										

Table 8. Fishes of the Crystal River watershed in Sleeping Bear Dunes National Lakeshore. After Kelly and Price (1979).
[1] denotes non-native species.

Species	Crystal River	Tucker Lake	Tucker Creek	Fisher Lake	Big Glen Lake	Little Glen Lake	Hatland Creek	Day Mill Pond
Northern Brook Lamprey *Icthyomyzon fossor*	X							
Sea Lamprey[1] *Petromyzon marinus*	X							
Brook Trout *Salvelinus fontinalis*	X				X			
Lake Trout *Salvelinus namaycush*					X			
Splake *S, fontinalis* X *S. namaycush*					X			
Rainbow Trout[1] *Oncorhynchus mykiss*	X				X	X	X	
Brown Trout[1] *Salmo trutta*	X				X			
Coho Salmon[1] *Oncorhynchus kisutch*	X				X		X	
Chinook Salmon[1] *Oncorhynchus tshawytscha*	X				X		X	
Lake Herring *Coregonus artedi*					X	X		
White Sucker *Catostomus commersoni*	X				X	X	X	
Alewife[1] *Alosa pseudoharengus*	X							
Hornyhead Chub *Nocomis biguttatus*				X				
Creek Chub *Semotilus atromaculatus*								

Table 8. Continued.

Species	Crystal River	Tucker Lake	Tucker Creek	Fisher Lake	Big Glen Lake	Little Glen Lake	Hatland Creek	Day Mill Pond
Bluntnose Minnow *Pimephales notatus*	X			X		X	X	
Blacknose Dace *Rhinichthys atratulus*	X							
Common Shiner *Luxilus cornutus*	X						X	
Spottail Shiner *Notropis hudsonius*				X				
Sand Shiner *Notropis stramineus*					X	X		
Emerald Shiner *Notropis atherinoides*			X		X			
Rock Bass *Morone chrysops*	X	X		X	X	X	X	
Largemouth Bass *Micropterus salmoides*	X	X		X	X	X	X	
Smallmouth Bass *Micropterus dolomieu*	X			X	X			
Bluegill *Lepomis macrochirus*	X	X			X			
Pumpkinseed *Lepomis gibbosus*		X	X					
Black Crappie *Pomoxis nigromaculatus*	X							
Yellow Perch *Perca flavescens*	X	X		X	X	X	X	
Blackside Darter *Percina maculata*	X							

Table 8. Continued.

	Crystal River	Tucker Lake	Tucker Creek	Fisher Lake	Big Glen Lake	Little Glen Lake	Hatland Creek	Day Mill Pond
Iowa Darter *Etheostoma exile*	X			X				
Johnny Darter *Etheostoma nigrum*	X			X	X	X		
Northern Pike *Esox lucius*	X	X		X				X
Yellow Bullhead *Ameiurus natalis*	X							
Brown Bullhead *Ameiurus nebulosus*						X		
Central Mudminnow *Umbra limi*	X		X				X	
Brook Stickleback *Culaea inconstans*	X							
Mottled Sculpin *Cottus bairdi*							X	

Table 9. Fishes of the Otter Creek watershed in Sleeping Bear Dunes National Lakeshore. After Kelly and Price (1979). [1] denotes non-native species.

Species	Otter Creek Mouth	Otter Pond	Otter Lake	Upper Otter Creek	Bass Lake	Deer Lake
Brook Trout *Salvelinus fontinalis*	X			X		
Bluntnose Minnow *Pimephales notatus*	X		X		X	
Creek Chub *Semotilus atromaculatus*	X		X	X		
Hornyhead Chub *Nocomis biguttatus*	X					
Blacknose Dace *Rhinichthys atratulus*	X					
Sand Shiner *Notropis stramineus*	X		X			
Common Shiner *Luxilus cornutus*	X		X	X		
Blacknose Shiner *Notropis heterolepis*	X					
Spottail Shiner *Notropis hydsonius*	X					
Coho Salmon[1] *Oncorhynchus kisutch*				X		
Black Bullhead *Ameiurus melas*				X		
Banded Killifish *Fundulus diaphanus*	X					
Central Mudminnow *Umbra limi*	X	X		X		
Yellow Perch *Perca flavescens*	X		X		X	
Johnny Darter *Etheostoma nigrum*			X	X	X	
Iowa Darter *Ethestoma exile*					X	X
Northern Pike *Esox lucius*						X
Smallmouth Bass *Micropterus dolomieu*	X					
Largemouth Bass *Micropterus salmoides*			X	X	X	X
Black Crappie *Pomoxix nigromaculatus*			X			
Rock Bass *Ambloplites rupestris*				X	X	
Bluegill *Lepomis macrochirus*					X	
Pumpkinseed *Lepomis gibbosus*				X	X	
Longear Sunfish *Lepomis megalotis*					X	

Table 9. Continued.

Species	Otter Creek Mouth	Otter Pond	Otter Lake	Upper Otter Creek	Bass Lake	Deer Lake
White Sucker *Catostomus commersoni*	X		X			
Brook Stickleback *Culaea inconstans*	X					
Sculpin *Cottus sp.*	X					

Table 10. Fishes of small watersheds in Sleeping Bear Dunes National Lakeshore. After Kelly and Price (1979).

Species	Hidden Lake	North Bar Lake	South Bar Lake	Round Lake	Rush Lake	Florence Lake	Lake Manitou
Brown Trout[1] *Salmo trutta*							X
Alewife[1] *Alosa pseudoharengus*		X					
Northern Redbelly Dace *Phoxinus eos*	X						
Bluntnose Minnow *Pimephales notatus*			X	X			
Fathead Minnow *Pimephales promelas*	X						
Golden Shiner *Notemigonus crysoleucas*				X	X		
Blacknose Shiner *Notropis heterolepis*				X			
Sand Shiner *Notropis stramineus*		X		X			
Spottail Shiner *Notropis hudsonius*		X					
White Sucker *Catostomus commersoni*				X			X
Northern Pike *Esox lucius*	X				X	X	
Banded Killifish *Fundulus diahanus*				X			
Brook Stickleback *Culaea inconstans*	X						
Largemouth Bass *Micropterus salmoides*			X	X			
Smallmouth Bass *Micropterus dolomieu*		X	X			X	X

Table 10. Continued.

Species	Hidden Lake	North Bar Lake	South Bar Lake	Round Lake	Rush Lake	Florence Lake	Lake Manitou
Green Sunfish *Lepomis cyanellus*							X
Bluegill *Lepomis macrochirus*					X		
Pumpkinseed *Lepomis gibbosus*					X		
Yellow Perch *Perca flavescens*		X	X	X		X	X
Johnny Darter *Etheostoma nigrum*		X	X	X			
Iowa Darter *Etheostoma exile*			X		X	X	X
Mottled Sculpin *Cottus bairdi*							X

[1]Non-native species.

Table 11. Fishes of the Lake Michigan shoreline in Sleeping Bear Dunes National Lakeshore. After Kelly and Price (1979).

Sea Lamprey[1] *(Petromyzon marinus)*
Lake Sturgeon *(Acipenser fulvescens)*
Lake Herring *(Coregonus artedi)*
Lake Whitefish *(Coregonus clupeaformis)*
Bloater *(Coregonus hoyi)*
Round Whitefish *(Prosopium cylindraceum)*
Rainbow Smelt[1] *(Osmerus mordax)*
Coho Salmon[1] *(Oncorhynchus kisutch)*
Chinook Salmon[1] *(Oncorhynchus tshawytscha)*
Atlantic Salmon *(Salmo salar)*
Rainbow Trout[1] (Steelhead) *(Oncorhynchus mykiss)*
Brown Trout[1] *(Salmo trutta)*
Brook Trout *(Salvelinus fontinalis)*
Lake Trout *(Salvelinus namaycush)*
Alewife[1] *(Alosa pseudoharengus)*
Common Carp[1] *(Cyprinus carpio)*
Longnose Dace *(Rhinichthys cataractae)*
Lake Chub *(Couesius plumbeus)*
Emerald Shiner *(Notropis atherinoides)*
Spottail Shiner *(Couesius plumbeus)*
Bluntnose Minnow *(Pimephales notatus)*
White Sucker *(Catostomus commersoni)*
Longnose Sucker *(Catostomus commersoni)*
Golden Redhorse *(Moxostoma erythrurum)*
Trout-perch *(Percopsis omiscomaycus)*
Burbot *(lota lota)*
Ninespine Stickleback *(Pungitius pungitius)*
Yellow Perch *(Perca flavescens)*
Walleye *(Stizostedion vitreum)*
ChannelCatfish *(Ictalurus punctatus)*
Deepwater Sculpin *(Myoxocephalus thompsoni)*
Spoonhead Sculpin *(Cottus ricei)*
Slimy Sculpin *(Cottus cognatus)*

[1] Non-native species.

hybrid between brook trout (*Salvelinus fontinalis*) and lake trout (*S. namaycush*)]. Most of the important game fish are nonnative.

Cyclical die-off of alewives occurs, polluting the water and beaches along Lake Michigan. To increase productivity in the Great Lakes and to curb alewife population fluctuations, the Michigan Department of Natural Resources introduced coho and chinook salmon in the Platte River in 1966 and 1971, respectively (Taube 1974). These salmon species spend several summers in Lake Michigan waters before returning to spawn in the streams where they were released. The large size (5 to 30 lb) of the spawning adults has attracted anglers to the national lakeshore, especially in the Platte River area.

An anadromous fish hatchery and weir were constructed on the Platte River by the state of Michigan. The hatchery, a 1969 reconstruction of a 1928 trout rearing facility, is located approximately 8.7 miles upstream of the river mouth and thus outside of the lakeshore's boundary. The weir was constructed in 1968 and is situated about 2 miles upstream of the river mouth within the lakeshore's boundaries. Its purposes are to harvest salmon during spawning migration and to control escapement into the stretch of river between this point and the hatchery.

Largemouth and smallmouth bass (*Micropterus salmoides*; *M. dolomieui)*, trout and salmon (*Onchorhynchus* spp.), lake trout, yellow perch (*Perca flavescens*); bluegill (*Lepomis macrochirus*); rock bass (*Ambloplites rupestris*); and northern pike (*Esox lucius*) are the popular game fish of Lake Michigan, the inland lakes and area streams. Rainbow smelt ascend streams to spawn in spring – many are taken by dip net. Sea lamprey predation on lake trout populations has been drastically reduced through the use of a chemical, TFM, which selectively kills lamprey larvae. The U.S. Fish and Wildlife Service last applied TFM to the Platte River and Shalda Creek in 2001; application usually follows a 2 to 3 year cycle.

AMPHIBIANS AND REPTILES

The amphibians and reptiles of the Great Lakes are an interesting and diverse group that includes 83 species – 51 in Michigan (11 salamanders; 2 toads; 10 frogs; 1 lizard; 9 turtles; and 18 snakes) (< http://biology.usgs.gov/ >). The National Park Service (1979) stated that past studies in the Sleeping Bear Dunes area listed 32 species of herptiles – 17 amphibian and 15 reptiles. A systematic survey of herptiles has yet to be accomplished for the lakeshore; however, distribution records from the University of Michigan's Museum of Zoology (< http://www.ummz.lsa.umich.edu/herps/miherps>) show that a total of 23 herptiles inhabit the lakeshore -- 11 species of frogs and toads; 4 species of salamanders; 1 lizard; 5 snakes; and 2 turtles.

Since 1989, the national lakeshore has been conducting frog surveys as part of the Frog and Toad Survey of Michigan's Natural Heritage Program. Ten sampling sites (all in Leelanau County; sampling in Benzie County to begin in

2001), ranging from vernal pools to wooded swamps, are sampled three times a year. Sampling consists of identification of frog and toad calls. The following species have been identified over the last 3 years of the survey: wood frog (*Rana sylvatica*), spring peeper (*Pseudacris crucifer*) American toad (Bufo *americanus*), eastern gray tree *frog (Hyla versicolor*), green frog (*Rana clamitans*), northern leopard frog (*Rana pipiens*), pickerel frog (*Rana palustris*), and chorus frog (*Pseudacris triseriata triseriata*).

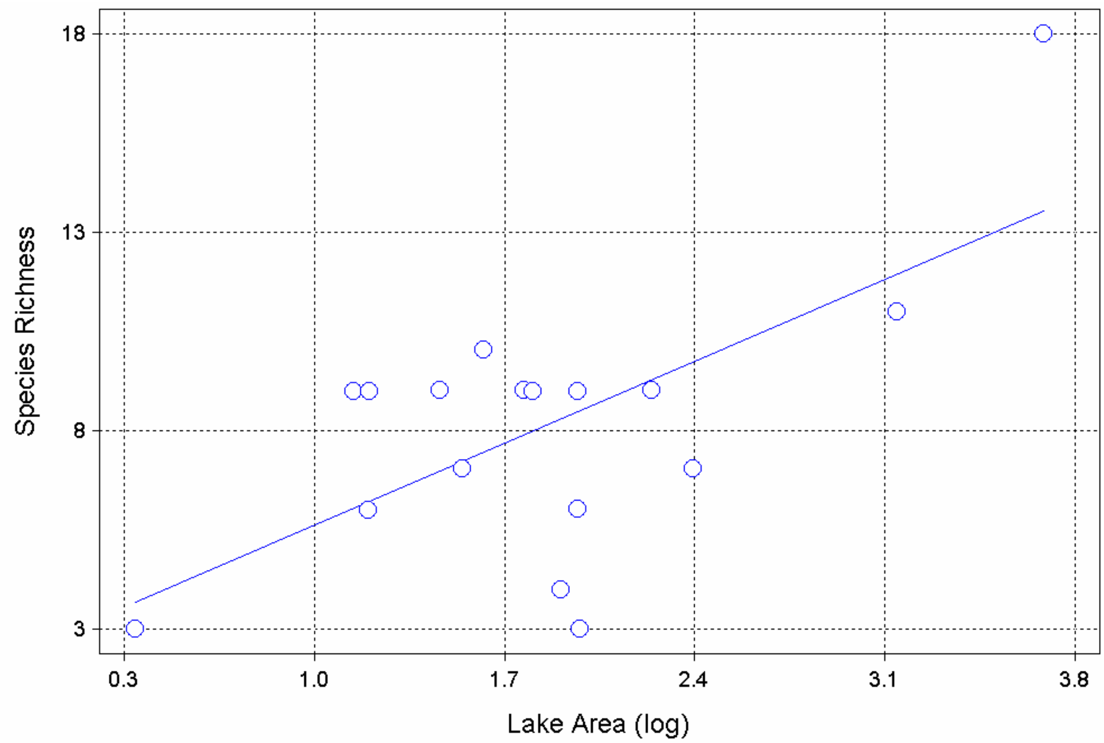


Figure 13. Plot of lake area (log) versus fish species richness for 17 lakes of Sleeping Bear Dunes National Lakeshore. Data are from Kelly and Price (1979). The line represents the least squares regression line (r^2 =0.42, p=0.005).

AQUATIC MACROINVERTEBRATES

Hildebrand (1971) sampled quantitatively the macroinvertebrates of the Platte River upstream of Platte Lake from 1967 to 1968. His primary objective was to determine the effects of a salmon spawning run on the benthos. Although outside of the lakeshore boundary, this study is important because it was quantitatively based and provides good baseline data for the Platte River system.

Curry (1977) studied the midge (Diptera: Chironomidae) communities of the Crystal River drainage basin in 1972. He sampled 11 sites including the Crystal

River and Little Glen and Big Glen lakes. Lentic midge species outnumbered lotic midge species 53 to 46. Stream midge communities had more biomass per sample; however, lake midge communities had higher species diversity, on average. Both communities had similar species richness per sample; lakes were composed of 9 to 28 species and streams were composed of 9 to 26 species.

White (1987) sampled 19 sites on all four lakeshore streams. He identified 50 taxa from over 2500 individuals and identified the trophic position for each taxon. The structure and function of aquatic invertebrate communities of these lakeshore streams were on par with other streams of the region. All the invertebrates found in this study were typical of and widespread in warmwater streams in Michigan. Typical coldwater taxa (e.g. stoneflies, Ephemerellidae, *Brachycentrus*) that denote northern Michigan trout streams were absent. He hypothesized that these streams appear to be autotrophic (relying on production from within the water system rather than input from outside, i.e. leaf fall). To date, this hypothesis has not been evaluated.

Boyle and Hoefs (1993) provided a comprehensive, quantitative baseline of stream macroinvertebrates for all lakeshore streams. They even assessed functional groups and their changes from upstream to downstream. However, the utility of this study is compromised by a lack of interpretation of results and by the fact that no voucher specimens were ever deposited with the lakeshore.

Boyle and Hoefs (1993) sampled over three seasons (1990-92) and found the highest density of macroinvertebrates in Otter Creek, relatively high densities in the Crystal River and Shalda Creek, and the lowest densities in the Platte River. The Crystal River and Shalda Creek also had relatively high mean densities of benthic fauna, while the Platte River exhibited medium to low mean densities. Although not specifically noted by Boyle and Hoefs, it is possible that the low densities found in the Platte River were the result of lampricide application during the study period.

Taxa richness of the benthic macroinvertebrates was not as variable as that for macroinvertebrate densities. The Platte River tended to have the higher species richness. All four streams had comparable species richness and demonstrated a pattern of higher species richness at downstream sites versus upstream sites. The downstream site on Shalda Creek had the highest species richness of all sampling sites.

Interestingly, Boyle and Hoefs (1993) used four sampling protocols: 1) a quantitative direct substrate sampler (Surber); 2) a quantitative artificial substrate sampler (Hester-Dendy plate); 3) a combined quantitative and qualitative method (Surber combined with a kick net sample of other microhabitats); and 4) a qualitative sampling of prevailing microhabitats following the protocol of Lenat (1988). Species richness, both total and for sensitive, indicator taxa (i.e., mayflies, stoneflies, and caddisflies) was highest in the qualitative samples using the Lenat method. This should have importance to the lakeshore in assessing methods of biological assessment as part of any overall water quality monitoring program.

In an ongoing study Heuschele (2000) is surveying the aquatic macroinvertebrate fauna of the Aral Springs area (Otter Creek drainage). Preliminary results from December samples indicate that the primary macroinvertebrate groups, in decreasing order of abundance are amphipods; snails; caddisflies; chironomids; mayflies; and isopods.

Stockwell and Gannon (1975) collected benthic macroinvertebrate samples from Florence Lake. This is the only known systematically designed, lake sampling of benthic macroinvertebrates in the lakeshore. Benthic macroinvertebrates were identified only to genus – mayflies (Ephemeroptera); Odonata (dragon and damsel files); Trichoptera (caddisflies); beetles (Coleoptera) and Hemiptera (bugs) were predominant among rooted vegetation. Bottom sediments produced oligochaete worms, amphipods, mollusks, and dipterans.

Heuschele (1999) surveyed lentic habitats of the lakeshore for sponges. Sponges were not found in School, Glen, North Bar, Shell and Bass (Leelanau Co.) lakes. Abundant sponge populations were found in Narada, Bass (Benzie Co.), and Deer lakes. Narada had the most abundant sponge populations. Taxonomic identification of these sponge populates is ongoing. Heuschele regards the recent invasions of Otter and Bass (Benzie Co.) lakes by zebra mussels as a cause for concern for their sponge populations. This is because zebra mussels are filter feeders like sponges and zebra mussels will probably out-compete sponges for crucial habitat.

There are about 50 species of freshwater mussels in the US portion of Great Lakes region (Cummings and Mayer 1992). As a group, freshwater mussels are one of the most endangered groups of animals in North America. Nichols (2000) is conducting a 3-year study (2000-2002) of the native clams/mussels (Unionidae) of the lakeshore. Preliminary results yielded the following species: *Elliptio dilatata*, *Lasmigona costata*, *Lasmigona compressa*, *Lampsilis fasciolaris*, *Lampsilis radiata luteola*, *Lampsilis radiata radiata*, *Lampsilis ventricosa*, *Pyganodon cataracta*, *Pyganodon grandis*, *Ptychobranchus fasciolaris*, *Strophitus undulatus*, and *Venusticoncla* spp. Several lakes have lost their entire unionid fauna as indicated by no live animals and abundant dead shells. The unionid fauna of a number of lakes and streams is at risk, especially from zebra mussel invasions.

Lake Plankton

The only known work on phytoplankton in the national lakeshore is that by Gannon and Stockwell (1978) for Florence Lake. They identified 132 phytoplankton taxa – 69 species of diatoms (Bacillariophyceae); 30 of green algae (Chlorophyta); 7 species of yellow-green algae (Chryosphyta); 23 of blue-green algae (Cyanophyta); one euglenoid (Euglenophyta); and 3 yellow-brown algae (Pyrrhophyta). Seven species of Chlorophyta and seven species of Cyanophyta were most common taxa.

Gannon and Stockwell (1978) also sampled the zooplankton community of Florence Lake. This community consisted of 36 rotifer species and 30 micro-crustaceans (copepods and cladocerans), with two rotifers, three copepods and two cladocerans the most common taxa.

The Gannon and Stockwell (1978) study represents the only aquatic biological study for Florence Lake. As such it will be useful as a reference for any future work on this lake.

Whitman et al. (2002) studied the application of limnetic zooplankton communities as a bioassessment tool for the lakes within the lakeshore. This study represents the most comprehensive, spatiotemporal look at the structure of zooplankton communities in the lakeshore. They took biweekly, zooplankton samples from late April to early October 1999 from Narada, School, Shell, Big Glen, Tucker, North Bar, Otter, Loon, and Round lakes.

Whitman et al. (2002) identified 85 total zooplankton taxa. Only 32 of these taxa comprised one percent or greater of the average abundance for any lake. Copepod nauplii and copepodids (particularly Cyclopoid copepodids) were quite common in most lakes. The cladoceran, *Bosmina longirostris*, was relatively common in all lakes, ranging from 2 to 13 percent of the average number of zooplankton in a lake. The only other taxon found in at least 1-percent abundance in all lakes was the rotifer genus, *Kellicottia*, though *Keratella* was relatively abundant in most lakes.

The total number of genera was relatively similar among the lakes, generally falling between 30 and 40; however, total zooplankton density varied greatly among the lakes (Table 12). The highest average zooplankton abundance (in School Lake) was over 100X the average abundance in the most sparsely populated lake (Glen Lake).

Figure 14 shows the numerical contribution by the three major zooplankton groups (Branchiopoda, Copepoda, Rotifera) for each lake. With the exception of Glen Lake, the Rotifera are the dominant zooplankton group, followed by Copepoda. Branchiopoda are never dominant and are only relatively abundant in South Bar, Tucker, and School lakes.

Table 12. Zooplankton genera richness and total individuals for each lake averaged over all sampling dates [Modified from Whitman et al. (2002)].

Lake	Genera Richness	Total Individuals
Glen	28	7
Shell	40	37
Loon	34	62
Otter	33	65
Round	29	114
North Bar	34	140
Narada	35	193
Tucker	37	496
School	33	792

One of the more important aspects of this study is the graphical display of major zooplankton group abundance over time (Figure 15). This provides an excellent baseline to compare with future zooplankton samples. In particular, changes in the abundance peaks (primary and secondary) and valleys point to structural changes in the zooplankton community that may be linked to a natural phenomenon or an environmental perturbation.

AQUATIC NUISANCE SPECIES (EXOTIC SPECIES)

Biological impoverishment is the antithesis of ecological integrity – the maintenance of the physical, chemical, and biological systems necessary for sustaining an acceptable quality of life. Causes of biological impoverishment are many; however, one of particular concern to the Great Lakes is the spread of aquatic nuisance species, commonly referred to as exotic species (or nonnative species).

Since the 1800s some 139 nonindigenous aquatic organisms have become established in the Great Lakes (Mills et al. 1993; < http://www.g.c.org/ans/modelsmp.htm >). The bulk of these species include plants (59), fish (25), algae (24), mollusks (14) and oligochaetes (7). Most of these have come from Europe (55 percent), Asia (14 percent), and the Atlantic Coast (13 percent), and the rate of introduction has increased as the rate of human activity increased. In 1989 more than 1/3 of the organisms had been introduced in the prior 30 years, coincident with the opening of the St. Lawrence Seaway in 1959 (Mills et al. 1991). Although the obvious impacts of some of the most abundant species are being

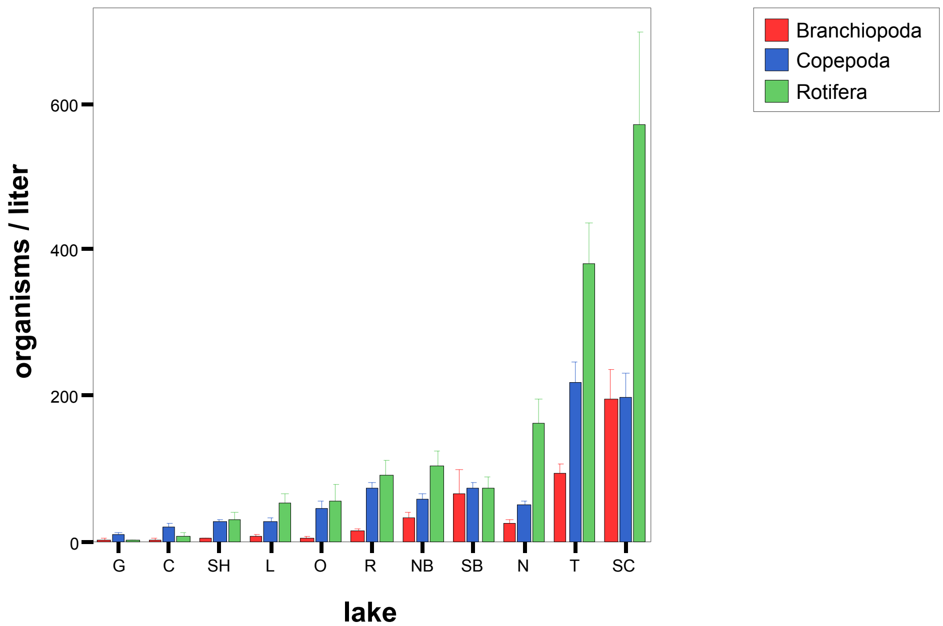


Figure 14. Mean abundance of major zooplankton groups for each study lake. Error bars = 1 standard error of the mean. After Whitman et al. (2002). Abbreviations are as follows: G=Glen Lake; C=Crystal Lake; SH=Shell Lake; L=Loon Lake; O=Otter Lake; R=Round Lake; NB=North Bar Lake; SB=South Bar Lake; N=Narada Lake; T=Tucker Lake; and SC=School Lake.

determined, most of the aquatic nuisance species and their direct and indirect impacts are not known.

A newly introduced species, if it successfully reproduces, can significantly disrupt the natural ecosystem balance by altering the composition, density and co-evolved interactions of native species. The effects of this disruption may cause changes in the structure and function of ecosystems, such as alterations to foodwebs, nutrient dynamics and biodiversity. New introductions also can cause costly socio-economic impacts even if effective prevention and control mechanisms are established. For example, the sea lamprey invasion in the 1940s resulted in substantial economic losses to recreational and commercial fisheries, and has required annual expenditures of millions of dollars to financecontrol programs. This species devastated populations of whitefish and lake trout. This predation permitted populations of commercially less valuable fish to proliferate. In 1992, annual sea lamprey control costs and research to reduce its predation were approximately at $10 million annually; the total value of the lost fishing opportunities (plus indirect economic impacts) potentially exceeded $500 million annually (< http://www.g.c.org/ans/modelsmp.html >).

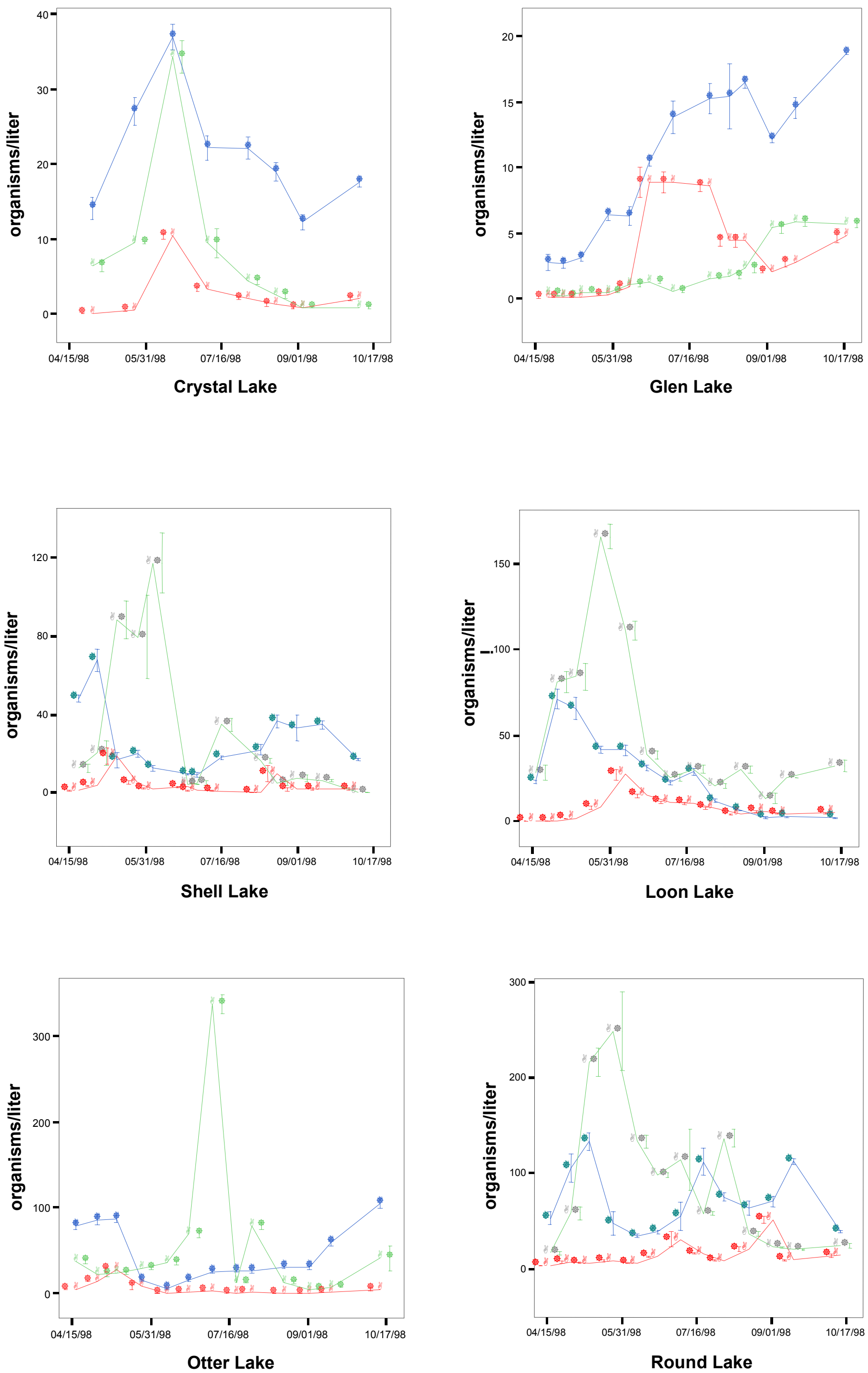


Figure 15. Mean abundance of major zooplankton groups by sample date for several lakes (after Whitman et al. 2002). Red=branchiopods, Blue=copepods, Green=rotifers. Error bars = 1 standard error of the mean.

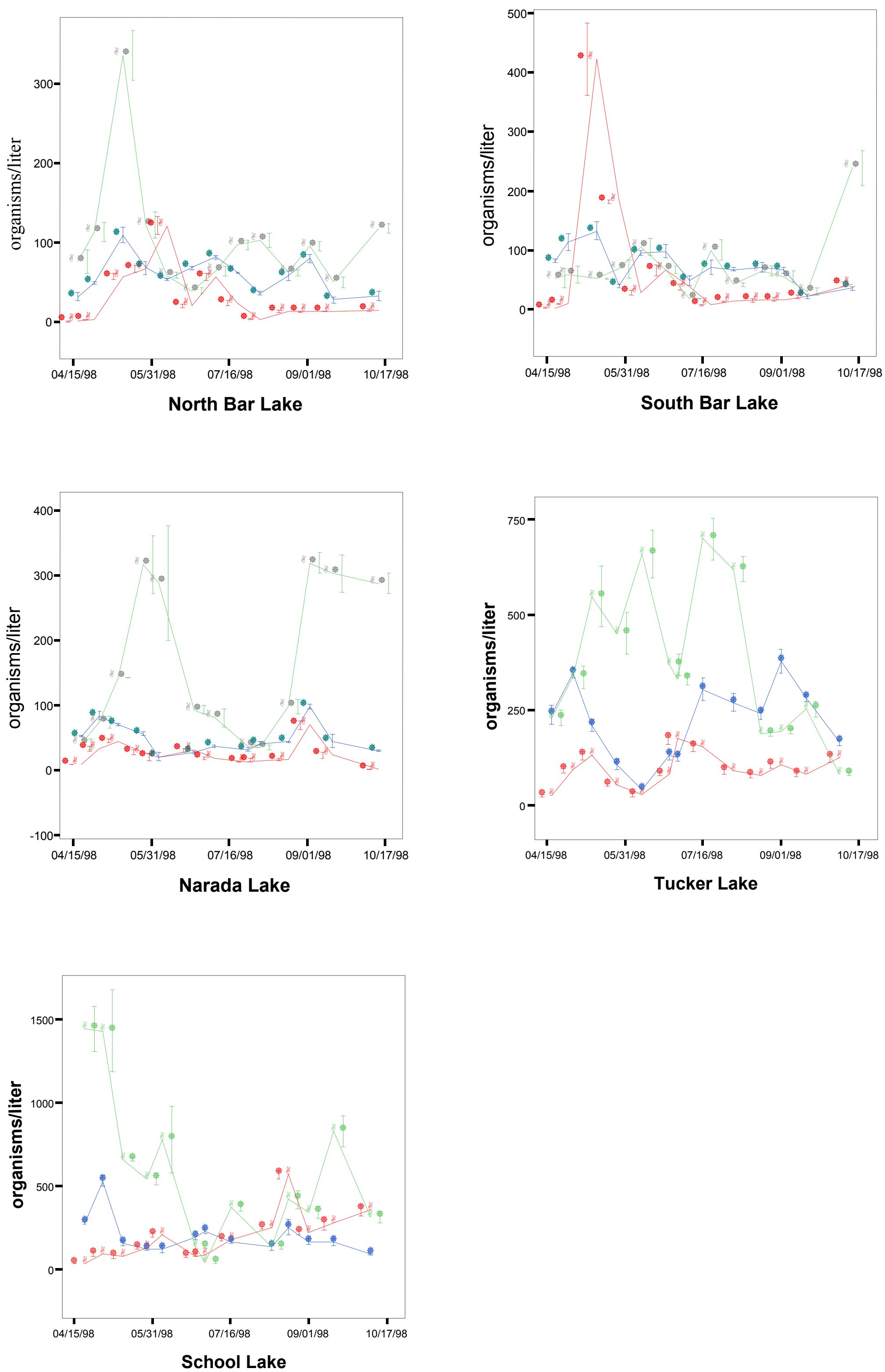


Figure 15. continued.

Species Present in the Lakeshore

In the Great Lakes region nuisance plant species far outnumber all other grous of exotic organisms, but the effects of only a few of these are known (Edsall et al. 1995). In particular, purple loosestrife (*Lythrum salicaria*) has spread throughout the Great Lakes basin, replacing native plants and reducing plant and animal diversity in wetlands. Eurasian water-milfoil *(Myriophyllum spicatum*) has also had a substantial effect – massive beds of the plant impact recreational opportunities and reduce fish and invertebrate populations.

Purple loosestrife is a wetland plant from Europe and Asia. It was introduced into the East Coast of North America in the 1800s (< http://nas.er.usgs.gov:80/bin/nas/plantsstate/MI >). This species forms dense stands that are unsuitable habitat for a number of native wetland-oriented animals. It prefers disturbed, moist soils, usually invading after some type of disturbance, e.g. construction activity. It is difficult to eradicate because one adult can produce 2 million seeds that form a large seed bank in the soil. In addition, this plant is able to re-sprout from roots and broken stems that fall to the ground or into the water. A major reason for its expansion is a lack of effective herbivores in North America. Several European insects (a weevil and two beetles) that only attack purple loosestrife are being tested as possible long-term biological control in Michigan; the national lakeshore has released both beetles since 1998. A long-term goal of a reduction of purple loosestrife abundance by approximately 80 percent is anticipated. However, it could be 10 to 20 years after these insect populations become established before this reduction is seen (< http://nas.er.usgs.gov:80/bin/nas/plantsstate/MI; http://www.great-lakes.net/envt/flora-fauna/invasive/loosestf.html >).

Eurasian water-milfoil competes aggressively with native aquatic plants, tolerates low water temperatures, forms dense canopies that shade surrounding vegetation and contains less value as a food source than the native species it replaces (< http://nas.er.usgs.gov:80/bin/nas/plantsstate/MI >). Water-milfoil can reproduce through fragmentation and boating equipment plays the largest role in introducing fragments to new waterbodies. The existence of 16 species including, *Potamogeton illinoensis* and *P. pectinatus* that occur in the national lakeshore, may be indicators of suitable conditions for Eurasian water-milfoil establishment. A North American weevil (*Euhrychiopsis lecontie)* causes significant damage to Eurasian water-milfoil while having little impact on native plant species, suggesting a potential biological control agent (< http://nas.er.usgs.gov/dicots/my_spica.html >).

Another exotic plant species that interferes with aquatic recreation by forming dense surface mats is the curly-leaf pondweed (*Potamogeton crispus)*. Prior to the appearance of Eurasian water-milfoil (accidentally introduced along with the common carp), this species was the most severe nuisance aquatic plant in the Midwest (< http://www.great-lakes.net/envt/flora-fauna/invasive/pondweed.html >). It has been in the Great Lakes region so long, most people are not aware it is an exotic species.

All three of the above species occur within the boundaries of the national lakeshore. Hazlett (1986) noted that at that time purple loosestrife did not appear to be, as yet, aggressive, occurring locally along the Platte River, along a small section of M-22 and at School Lake. Hazlett recommended immediate action to prevent the spread of this exotic. He suggested removal by hand pulling rather than use of glyphosate in heavily infested areas – care should be taken in using this method because plant fragments can reproduce vegetatively. He further suggested the production of a pamphlet describing the appearance of purple loosestrife and the need for its control, and asking visitors to report any purple loosestrife sightings.

Hazlett (1986) also documented the then current distributions of curly-leaf pondweed and Eurasian water-milfoil in the national lakeshore, as well as for other exotic plant species. The distributions for these two species were similar; both species were present in North Bar Lake, Loon Lake and the Platte River. Other exotic plant species known (circa 1986) from the national lakeshore include watercress (*Nasturtium officinale*) and brittle naiad (*Najas minor*) (See Table 6 for their distribution).

Zebra mussels (*Dreissena polymorpha*) were first discovered in Lake St. Clair in 1988. As of December 1993, zebra mussels had been found in all of the Great Lakes as well as several inland lakes of Michigan. In 1991, a second species of *Dreissena* was discovered. Quagga mussels (*D. bugensis*) have been found in Lakes Ontario, Erie and Huron. Both species are native to an area of Russia near the Caspian Sea.

The rapid spread and abundance of both mussels can be partly attributed to their reproductive cycles. A fully mature female may produce up to one million eggs per season. Egg release starts when the temp warms to 54^{o} F and continues until the water cools below 54^{o} F. Zebra mussel larvae can colonize any firm surface that is not toxic. In fact, zebra mussels readily encrust native North American mussels (Unionidae). The zebra mussel's proclivity for hard surfaces located at moderate depths has made water intake structures susceptible to colonization. Beds of mussels in some areas of Lake Erie now contain more than 30,000 and sometime up to 70,000 mussels per square yard. The life stage most sensitive to low temperature is the larval stage (veliger) and juveniles are more sensitive than adults are. Quagga mussels can live directly on muddy or sandy bottom and appear more tolerant of low temperatures and extreme depths than zebra mussels. Both species can spread to other inland waters either as veligers transported in water or as adults attached to boat hulls, engines, aquatic weeds, or other surfaces.

By filtering significant amounts of phytoplankton from the water, zebra mussels remove the food sources for zooplankton, which in turn, are food for plankton-feeding fish that support important sport and commercial fisheries. It is this ability to filter large amounts of water that allows zebra mussels to accumulate organic pollutants within their tissues to levels that are 300,000 times greater than ambient concentrations. These contaminants are then passed up the food chain and bioaccumulate in fish or waterfowl.

Zebra mussels are presently in Platte Lake, lower Platte River, North Bar Lake, Bass Lake (Benzie Co.), Loon Lake and Otter Lake. In 2000 approximately five zebra mussels were discovered in Otter Lake (Nichols, pers. comm. 2001) attesting to this species ability to colonize rapidly. Otter Lake in 2001 is now completely inundated by zebra mussels.

Zebra mussels have also been implicated in the algal blooms in Platte Bay. Lowe (2000), in a 3-year study for the lakeshore, is investigating the *Cladophora glomerata* blooms in the bay. Blooms have occurred annually since 1995. It is hypothesized that zebra mussels are creating a localized environment in the benthos by raising nutrient levels to a range that will support the high nutrient demands of *Cladophora*. To date, zebra mussels have been found to cover 90 percent of the solid substrates in Platte Bay to a depth of at least 50 feet. Of the area colonized by zebra mussels, *Cladophora* has colonized the zebra mussels at high densities. The densities of both indicate that this is not a temporary condition.

A wetland grass species, *Phragmites australis* (common reed), has an uncertain and problematic status – once considered an exotic species, it is now thought to be native. Nonetheless, this species is acting like purple loosestrife does, namely, invading, dominating, and forming extensive monotypes. Presently, *Phragmites* is invading the wetlands of the ridge and swale habitat and inland lakes of the national lakeshore; park staff consider it to be more of a problem than purple loosestrife. Because expertise on this invasive species is lacking in the Water Resources Division of the National Park Service, the national lakeshore should seek local expertise or contact other national park units that are presently addressing *Phragmites* invasions.

Because *Phragmites* has invaded and formed near-monotypic stands in some North American wetlands only in recent decades, there has been some debate as to whether it is indigenous to this continent or not. However, there is now convincing evidence that it was here long before European contact (see < http://tncweeds.ucdavis.edu/esadocs/documnts/phraaus.html >). There is some suspicion that although the species itself is indigenous to North America, new, more invasive genotype(s) were introduced from the Old World.

A number of explanations have been proposed to account for the recent dramatic increases in *Phragmites* populations in the Great Lake states (see <

http://tncweeds.ucdavis.edu/esadocs/documnts/phraaus.html >). Habitat manipulations and disturbances caused by humans are thought to have a role. In some areas this species may also have been promoted by the increases in soil salinity which result when de-icing salt washes off roads and into nearby ditches and wetlands. *Phragmites* seeds are shed from November through January and may be among the first propagules to reach these sites. If the seeds germinate and become established the young plants will usually persist for at least 2 years in a small, rather inconspicuous stage, resembling many other grasses. Later they may take off and assume the tall growth form that readily identifies this species. It has been suggested that increases in nutrient concentrations, especially nitrates, are primarily responsible for increases in *Phragmites* populations.

Invasive populations of *Phragmites* must be managed in order to protect rare plants that it might out compete, valued animals whose habitat it might dominate and degrade, and healthy ecosystems that it might greatly alter. Biological control does not appear to be an option – no organisms that would damage *Phragmites* but not feed on other plant species have been found. Prescribed burning does not reduce the growing ability of *Phragmites* unless root burn occurs. Root burn seldom occurs, however, because a layer of soil, mud and/or water usually covers the rhizomes. RodeoTM, a water solution of isopropylamine salt of glyphosate is commonly used for *Phragmites* control. This herbicide is not selective and will kill grasses and broad-leaved plants alike. Cutting has been used successfully to control this species, but cutting several times at the wrong time may increase stand density. If cut just before the end of July, most of the food reserves produced that season are removed with the aerial portion of the plant, reducing the plant's vigor. This regime may eliminate a colony if carried out annually for several years.

Species with Potential for the Invasion of the Lakeshore

Ruffe (*Gymnocephalus cernuus*) is a small spiny perch-like fish native to Eurasia. It was introduced to Duluth Harbor on Lake Superior via ballast water and first collected in 1986. Its ability to displace other species in newly invaded areas is due to its high reproductive rate, its feeding efficiency across a wide range of environmental conditions, and characteristics that may discourage would-be predators. Experience in Scotland (dramatic declines of native perch populations) and Russia (preyed heavily on whitefish eggs) points to serious problems for Great Lakes fisheries if ruffe disperses from Lake Superior.

Round goby (*Neogobius melanostomus*) is a benthic fish and a relatively recent (1990) ballast-water addition to the Great Lakes (Jude et al. 1995). This species: 1) is an aggressive feeder that can forage in total darkness; 2) is a multiple spawner for longer periods of time and takes over prime spawning sites used by native species; 3) competes with native fish for habitat; and 4) survives in degraded water conditions. On the positive side this species' diet consists predominately of zebra mussels. However, there may be a direct transfer of contaminants from gobies to the sport fish that eat them. This species is predicted to compete strongly with native sculpins and other benthic species.

Rusty crayfish (*Oronectes rusticus*), although native to parts of some Great Lakes states, has spread to many northern lakes and streams, causing a variety of ecological problems. It is presently in Grand Traverse Bay (Steve Yancho, pers. comm., Sleeping Bear Dunes National Lakeshore). This species: 1) displaces native crayfish; 2) reduces the diversity and density of aquatic plants and invertebrates; and 3) reduces some fish populations. The loss of aquatic plant beds is especially damaging in relatively unproductive northern lakes where aquatic plant beds are not abundant. These beds provide important habitat for aquatic invertebrates, cover for young gamefish, panfish, or forage species, nesting for fish and erosion control.

The spiny water flea (*B. cederstroemi*) is a crustacean with a long, sharp, barbed tail spine. A native of Great Britain and northern Europe east to the Caspian Sea, it was first found in lake Huron in 1984 – probably via ballast dumping –and in all Great Lakes by 1987. It is now in some inland lakes of Michigan. This species may compete directly with young perch and other small fish for food such as *Daphnia* zooplankton. Also, predators because of the sharp tail spine do not heavily consume it. Thus, spiny water flea populations are not naturally regulated and their plankton prey continues to decline.

Cercopagis pengoi is the latest exotic crustacean to invade the Great Lakes (1998). This species is indigenous to the Caspian, Azov and Aral seas. It is similar to the spiny water flea (both occur in brackish and freshwater environments) and both belong to the Cercopagididae family.

The spiny water flea and *C. pengoi* influence greatly the biological communities of the Great Lakes, largely because of their rapid reproductive rate. Most of the time, females reproduce asexually, a method known as parthenogenesis. Males are rarely found when food is plentiful or when environmental conditions favor rapid population growth. Adult females apparently sense declining environmental quality and respond by producing males rather than female offspring. These males mate with surviving females, producing resting eggs. These eggs can remain dormant for long periods of time.

Since 1991 the Great Lakes Panel on Aquatic Nuisance Species has worked to prevent and control the occurrence of aquatic nuisance species in the Great Lakes. The panel was officially convened by the Great Lakes Commission in response to section 1203 of the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (PL 101-646). The panel is directed to identify Great Lakes priorities; assist/make recommendations to a national Task Force on Aquatic Nuisance Species; coordinate exotic species program activities in the region; and, advise public and private interests on control efforts. Panel membership is drawn from US and Canadian federal agencies, eight Great Lakes states and the province of Ontario, regional agencies, user groups, local communities, tribal authorities, commercial interests, and the university/research community.

THREATENED AND ENDANGERED SPECIES

There are no federally listed species of aquatic wildlife (includes insects, mollusks, fish, and reptiles and amphibians) known in Sleeping Bear Dunes National Lakeshore. The deepwater pondsnail (*Stagnicola contracta*) is a state threatened species listed by the Michigan Natural Features Inventory for Leelanau County (< http://www.dnr.state.mi.us/wildlife/heritage/mnfi >), and could be present in the national lakeshore.

The lake sturgeon is listed as threatened by the State; its habitat would include those Lake Michigan waters within the lakeshore boundaries. The pugnose shiner (*Notropis anogenus*), a species that likes heavily vegetated streams and lakes in glaciated areas, is a State species of special concern whose historic distribution includes Leelanau County, although Kelly and Price (1979) did not collect this species.

Blanchard's cricket frog (*Acris crepitans blanchardi*) is a State species of special concern listed by the Michigan Natural Features Inventory for Leelanau County (< http://www.dnr.state.mi.us/wildlife;heritage;mnfi >); therefore, its distribution could include the national lakeshore. In fact, park staff participating in the Michigan Natural Heritage Program's Frog and Toad Survey report hearing this species' call within the boundaries of the national lakeshore (Van Zoeren, 2001, pers. comm., Sleeping Bear Dunes National Lakeshore). However, the historic distribution for this subspecies does not include the northern half of Michigan's Lower Peninsula (< http://www.npwrc.usgs.gov/narcam/idguide/crepitan.htm >). For this reason this species was not included as one of the 23 herptiles known from the national lakeshore (see "Amphibians and Reptiles" section).

Both the wood turtle (*Clemmys insculpta*) and eastern box *turtle (Terrapene carolina carolina*) are State species of special concern that are listed by the Michigan Natural Features Inventory as occurring in Benzie (both species) and Leelanau (only eastern box turtle) counties (< http://www.dnr.state.mi.us/wildlife/hertage/mnfi >). Their occurrence within the national lakeshore is probable. The historic distribution of the wood turtle does not include these counties (< http://www.ummz.lsa.umich.edu/herps/miherps <); it also was not included as one of the 23 herptiles known from the national lakeshore.

The Michigan monkey flower (*Mimulus glabratus michiganenis*) and the cut-leaved water-parsnip (*Berula erecta*) are the only known, protected, aquatic plant species to occur within the national lakeshore. The monkey flower is a federally listed endangered species that is also state threatened. It is known to occur in the national lakeshore at only a few localities primarily because it prefers mucky soil and sand that is saturated or covered by cold, flowing spring water.

Cut-leaved water-parsnip, a state threatened species, was found by Hazlett (1986) in the Otter Creek springs area and by Albert (1992) in the Shalda Creek watershed.

EFFECTS OF CLIMATE CHANGE

Based on historical records and climate prediction models, the climate for the Great Lakes appears to be growing warmer and wetter (Magnuson et al. 1997; Meyer et al. 1999). Since early in the 20^{th} century, spring air temperatures have increased by 0.11^{o} C per decade, periods of ice cover have diminished, and annual precipitation has increased by 2.1 percent per decade. According to Canadian scenarios, by the end of the 21^{st} century the average temperature in the upper Great Lakes region is expected to increase by 2 to 4^{o} C and precipitation could increase by 25 percent (< http://www.climatehotmap.org/impacts/greatlakes.html >). Despite the increase in precipitation, water levels are expected to fall by 1.5 to 8 feet by 2100 because of the higher temperature.

Such climatic changes will reduce lake seasonal mixing that replenishes oxygen to productive lake zones, reduce lake levels, and shorten water residence time (Meyer et al. 1999; < http://www.climatehotmap.org/impacts/greatlakes.html >). Profound effects on ecosystem processes will occur. For example, reduced runoff from drier watersheds could decrease dissolved organic carbon concentrations resulting in reduced biological integrity through increases in water clarity, thermocline depth, and productivity. Changes in the seasonal runoff patterns may also alter water quality. Schindler (1997) found that extended droughts in boreal regions have resulted in acidification of streams from oxidation of soil-based organic sulfur pools in soils.

Potential water level changes in the Great Lakes are of great socioeconomic importance. The potential declines in Great Lake water levels could negatively effect wetlands, fish spawning, recreational boating, commercial navigation, and municipal water supplies (Meyer et al. 1999).

Invasions of warmwater fishes and extirpation of coldwater species are predicted to increase in the Great Lakes region (Magnuson et al. 1997). This will occur via increases in thermal habitat area for warmwater and cool water species and a concomitant decrease for coldwater species. The greatest changes should occur in more productive lakes.

It should be understood that these climatic predictions for the Great Lakes region are occurring in a broader context – ongoing anthropogenic alterations of water quantity, quality (including atmospheric deposition of persistent organic pollutants), sediment and nutrient loads, biological integrity, and exotic species invasions. The effects of climate change may be dwarfed or exacerbated by these other environmental alterations (Meyer et al. 1999). Instream flow needs of aquatic ecosystems are competing with other uses of water – a competition likely intensified by climate change. Changes in hydrologic variability and seasonality appear likely to have a greater impact on aquatic ecosystems than changes in mean annual conditions (Poff 1996). The predicted consequences of climate change in aquatic ecosystems are often a direct result of effects of a changing climate on terrestrial ecosystems. Therefore, a critical aspect of climate change assessment is the terrestrial-aquatic linkage. For example, compositional changes in vegetation and hydrology alterations of riparian zones are particularly crucial.

Meyer et al. (1999) listed the properties of different aquatic ecosystems that are vulnerable to a changing climate (Table 13). Wetlands are sensitive to water balance changes resulting in habitat reductions, increased vulnerability to fire, and altered rates of exchange of greenhouse gasses. The changes identified in lakes are associated with altered mixing regimes, delivery of nutrients and dissolved organic carbon from the watershed, availability of thermal refuges, and top predator population changes resulting in trophic cascades (*sensu* Carpenter et al. 1985). In streams, the ecosystem changes are closely linked with climate impacts on the riparian zone, thermal tolerance of species and modifications in flow regime.

Sleeping Bear Dunes National Lakeshore is a regionally important pool of aquatic biological diversity in a landscape that has a history of logging and agricultural impacts. Given the above-predicted changes to ecosystem processes, the lakeshore's role as a biological refuge could be jeopardized. However, Davis et al. (2000), using fossil pollen in lake sediments, found that past Holocene climate changes appeared more extreme at distances away from the Great Lakes than for sites located along the shores of the Great Lakes. This implies that future climate change would be moderated at Sleeping Bear Dunes National Lakeshore. If future temperature increases are buffered by lake effects, the lakeshore may, at the least, serve as a temporary biological refuge for species unable to survive at inland sites. However, the large-scale, continuing regional changes in temperature and water levels will ultimately be experienced at the lakeshore as well.

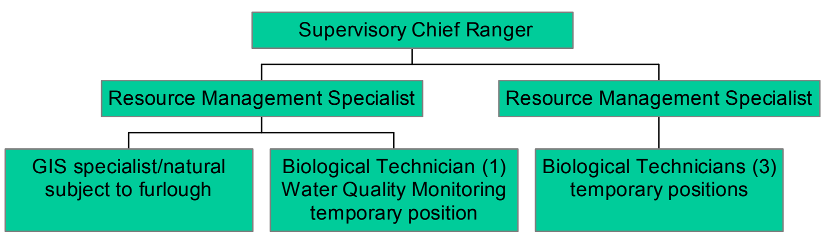
A word of caution – there is uncertainty surrounding these predicted changes as well as the anticipated consequences. Allen (1995) states "The ability of global climate models to forecast precipitation change is limited, and temperature cannot be resolved at a regional scale. Prediction is further complicated by feedback among variables. For example, warming is expected to increase evaporation, which should reduce surface runoff, but elevated carbon dioxide causes the stomata of plants to close down… making more water available for runoff. Because these results are offsetting, the effect of warming on surface runoff is uncertain."

Table 13. A sample of properties of different aquatic ecosystems that are particularly sensitive to climate change possibly altering aquatic ecosystem functioning and health. After Meyer et al. (1999).

LAKES	STREAMS	WETLANDS
Mixing Regime	Flow Regime	Altered Water Balance Leading to Wetland Losses
Nutrient and DOC Inputs	Sediment Transport/Channel Alterations	Fire Frequency
Habitats Meeting Temperature and Oxygen Requirements	Nutrient Loading and Rates of Nutrient Cycling	Altered Rates of Exchanges of Greenhouse Gases
Productivity	Fragmentation and Isolation of Cold Water Habitats	Vegetation Species Composition
Top Predator Changes Leading to Trophic Cascades	Altered Exchanges with the Riparian Zone	Reproductive Success of Many Animal Species
Abundance of Cold-water and Warm-water Fish Species	Life History Characteristics of Many Aquatic Insects	Sensitivity of Invasion by Tropical Exotic Species

PARK OPERATIONS

Natural resource management at Sleeping Bear Dunes National Lakeshore is organized as follows:



Although the lines of responsibility are sometimes fuzzy, one Resource Management Specialist has responsibilities in wildlife and integrated pest management, whereas the other Resource Management Specialist has responsibilities in research activities, inventory and monitoring, vegetation, water, fire and geographic information systems. The latter specialist is directly involved with water resource management no more than 10 percent of the time (0.1 FTE).

Water resource management activities are primarily limited to the water quality monitoring conducted from May through September by a seasonal biological technician (0.5 FTE).   Thus, water resource management at the national lakeshore is being conducted with only 0.6 FTE. The same person has served concurrently in this seasonal position for the last 3 years, so some consistency has been established. The primary duty of this biological technician is conducting water quality monitoring and performing laboratory analyses. Laboratory analyses are done in the water quality laboratory established by the national lakeshore in 1997. The biological technician may be assisted by several volunteers/interns, and together they are responsible for addressing the national lakeshore's water resource issues; however, this is on an *ad hoc* basis and limited in scope. Presently, funding and personnel limitations do not allow pro-active management of other water resources in the national lakeshore, e.g. wetlands, aquatic biology, riparian, air toxics, etc.

Park operations that are of concern in the management of water resources include: the dredging of the Platte River mouth, as well as the docks at North and South Manitou islands; backcountry campgrounds; operation of several lakeshore-owned boats and the potential for transporting exotics within national lakeshore boundaries; and, maintenance of an artificial wetland used for waste treatment at a fish cleaning station on the Platte River. Pit toilets are operated only on North and South Manitou islands as well as the mainland, and coupled with the relatively high water table, glacial till-based soil, and shallow drinking water wells there is a potential for drinking water contamination.

Although the national lakeshore has been diligent in the removal of known underground storage tanks (USTs), some USTs may still exist on older land acquisitions.

As a landowner in the Platte River watershed, the national lakeshore is an active participant in the Platte River Watershed Project, a joint effort by the Benzie County Conservation District and the Michigan Department of Environmental Quality. This project is concerned with nonpoint source pollution and has recently developed a comprehensive watershed management plan (Benzie Conservation District 2002) that updates the knowledge of water pollution in the Platte River watershed and determines a course of action for solving immediate and long-term problems. This Water Resources Management Plan will be an important addendum to the comprehensive watershed management plan.

WATER RESOURCE PLANNING ISSUES AND RECOMMENDATIONS

The National Park Service Water Resources Division and Sleeping Bear Dunes National Lakeshore personnel held a water resources scoping meeting at the national lakeshore in May 1997. Also invited were personnel of the US Geological Survey (Water Resources and Biological Resources divisions), the Crystal Lake Watershed Fund and Aquatic Systems Engineering, Inc, a consultant to the Platte Lake Improvement Association. The purpose of this meeting was to familiarize the Water Resources Division with the water resources of the national lakeshore, and to identify and prioritize water resource issues and management concerns. Subsequent discussions were held with other federal and state personnel and county officials, as well as other water resource professionals in order to further refine potential water resource issues and develop management actions to address these issues.

A total of 16 water resource issues were identified at the water resources scoping meeting, and prioritized into six high priority, three medium priority, and seven low priority issues. An additional visit in 2000 to the national lakeshore by NPS-WRD and USGS-BRD personnel and discussions by the author with Daren Carlisle of the NPS Midwest Regional Office in 2001, modified (through addition, deletion, and combination of issues) the original list of water resource issues. This modification resulted in the following water resource issues. Management actions to address these issues were developed for only the highest priority issues (Appendix). This was considered prudent, given current funding and personnel constraints, i.e. the national lakeshore would only be capable of addressing high priority issues over the life span of this plan. Strategic planning places an additional constraint – water resource issues compete with other national lakeshore issues for priority in the 5-year strategic plan for the national lakeshore.

Recommendations are provided for lesser priority issues, where applicable. These recommendations provide the national lakeshore the ability to respond to these issues, if priorities shift in the future.

HIGH PRIORITY ISSUES

Need for a Permanent, Full-time Water Resource Professional

The Water Resources Division in 1994 compiled water resource information from several databases for all national park units. Water-based resources for Sleeping Bear Dunes National Lakeshore covers 22 percent of the total acreage for the national lakeshore. However, this percentage does not cover some wetland types (e.g., wet meadows) and did not include rivers and streams. Additionally, this estimate includes wetlands from National Wetland Inventory maps that have been determined to greatly underestimate the wetland types and acreage (see “Wetlands” section under “Existing Resource Conditions”) at the national lakeshore. Therefore, a more accurate estimate of water-based resources for the national lakeshore should be in the 25 to 30 percent range. This would rank the national lakeshore approximately 5th out of 55 park units in the Midwest Region of the National Park Service for water-based resources. Couple this with the fact that the majority of recreational activities in the national lakeshore are water oriented, it would be hard not to classify the national lakeshore as a 'water-based' park unit. Yet only 0.6 FTE (0.5 of which is seasonal) are dedicated to the management of water resources.

Our knowledge of water resources at the national lakeshore appears, at first glance to be substantial, but that knowledge only scratches the surface. When species surveys have been done, the results are, for the most part, dated. In some cases virtually nothing of substance is known about some faunal/floral groups (e.g., amphibians). Similarly, our understanding of the national lakeshore's wetland communities is extremely limited; rare, threatened or endangered plants may be undetected. Furthermore, for aquatic biological communities, we know nothing about the 'function' of those communities and can say very little about community or ecosystem health.

Ground water (both quantity and quality) is an unknown commodity in the national lakeshore. Knowledge of surface water quality is limited to the past decade; no consistent monitoring program was in place until the last 2 to 3 years. While consistent, this program, as currently structured, lacks the ability to address local and regional water quality issues, e.g., cultural eutrophication and deposition of air toxics. This program is admirably run by a dedicated seasonal employee who develops an annual water quality monitoring report, as time allows, while unemployed from the national lakeshore. As such these reports are not timely and do not allow management to make timely decisions; however, even with timely reports the necessary expertise is not available to the national lakeshore to interpret the data and participate in decision making.

Because of the quantity and quality of water resources in the national lakeshore; a basic lack of adequate, baseline information; and a water resources management program limited only to water quality monitoring by a seasonal employee, this water resources management plan recommends the addition of a permanent water resources professional (broadly trained in aquatic ecology), when resources become available. Continuation of the status quo will not allow the national lakeshore to address the data gaps, data integration, and issues as outlined in this plan.

Furthermore, it is recommended that the seasonal biological technician position now running the water quality monitoring program be converted to permanent. This position would continue with the majority of the field-based work needed to collect data on physical, chemical and biological aspects of the lakeshore's water resources. This would allow the permanent water resource professional to concentrate on developing and prioritizing research and management needs, developing partnerships with federal, state, local, and non-profit entities, developing program oversight documents, manuals and standard operating procedures, and providing the necessary water resource expertise in the decision making process.

Lack of an Adequate Inventory and Characterization of National Lakeshore Wetlands

A wetland inventory prepared by the U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI) program is available for the national lakeshore, but these maps vary considerably in quality and resolution. The Good Harbor Bay, Burdickville, and Glen Arbor 7.5-minute USGS quadrangles were mapped at the NWI's current standard (based on 1981 1:58,000-scale color infrared photography and plotted on 1:24,000 scale USGS quad maps). Though they meet current NWI standards, these maps are based on high altitude photography with minimal ground-truthing (typically not more than one wetland visited per quadrangle), and tend to omit smaller wetlands and wetlands with forest cover, which are significant in the lakeshore. Most classification errors are probably related to lack of information on water regimes or lumping of habitat types due to small scales. The age of the photos (now 20 years old) could also mean that subsequent fire, drainage, beaver activity, plant growth and succession, or other factors further limit the accuracy of these maps.

NWI maps for the rest of the park, including North and South Manitou islands and the wetland-rich area from Sleeping Bear Point to the southern park boundary, were developed using sub-standard 1975 1:80,000 scale black-and-white photography and plotted on 1:62,500 scale USGS topographic maps. These maps undoubtedly contain significant errors of omission and classification due to the serious limitations imposed by use of dated, very high altitude black-and-white photography and minimal ground-truthing.

An additional problem with the existing NWI maps is the lack of information on plant species associations, substrates (e.g., organic vs. mineral soil), and other factors. For example, two wetlands may be classified identically on the maps as "palustrine emergent saturated wetland," however, without a site visit, park staff may not know that one is a bog habitat harboring rare species and the other is a monoculture of low-value reed canary grass.

The lack of high-quality wetland inventory maps for the lakeshore can have important impacts on management and protection of the park's resources. For example:

1. Park staff cannot properly protect important wetland resources if they do not know they exist. For instance, proposals for shallow ground water pumping or road construction can not be fully evaluated and mitigated unless the potentially affected wetland resources are identified and characterized.

2. Existing threats, particularly invasion of exotic or other undesirable species such as purple loosestrife or common reed (*Phragmites australis*) can be

documented during an enhanced wetland survey. Researchers from the U.S. Geological Survey, Biological Resources Division noted during a 1998 site visit that invasions of such species in interdunal ponds and other wetland habitats appear to be in the early (and therefore controllable) stages at the lakeshore. They cautioned against letting localized exotic plant "hotspots" explode into massive (and perhaps irreversible) invasions, which could result in substantial loss of important wetland habitat as has occurred in comparable areas of Indiana Dunes National Lakeshore. An enhanced inventory would help direct very limited resource management money and time toward those "hotspot" locations where control efforts would be most effective.

3. An enhanced inventory that locates and characterizes wetland habitats would focus other lakeshore research, resource management, and interpretation efforts. For example, the search for a rare plant or animal species for study or special protection, or identification of habitats that the park would like to include in its interpretation programs, could use this inventory as a guide.

Project Statement SLBE-N-002.006 (Appendix) incorporates extensive ground-truthing and produces a higher resolution "enhanced" wetland inventory. The inventory would include characterizations of plant communities and other features as desired by the lakeshore, and would also include survey-level assessments of condition and threats. Kim Santos, NWI coordinator for the U.S. Fish and Wildlife Service's Midwest Region, recently indicated that the Fish and Wildlife Service would be willing to collaborate on a re-mapping effort for Sleeping Bear Dunes National Lakeshore. The U.S. Fish and Wildlife Service may be able to contribute costs such as initial photo interpretation and a portion of map production; however, the National Park Service would be responsible for funding the extensive ground-truthing and condition assessments.

To maximize efficiencies in field sampling and cost effectiveness, this wetland inventory project should also include the quantitative sampling of faunal groups in addition to the plant community characterizations. Because of the lack of information on amphibians and reptiles, this faunal group should be a high priority for sampling; aquatic macroinvertebrates should also be considered a sampling priority.

Revise Current Water Quality Monitoring Program via Development of a Comprehensive Water Quality Monitoring Plan

Water quality monitoring at Sleeping Bear Dunes National Lakeshore has had a short history – a 3-year, water resources assessment begun in 1990 (Boyle and Hoefs 1993) represents its beginning. Since that time to the present, water quality monitoring at the national lakeshore has had its 'fits and starts', primarily attributable to a lack of park resources and expertise. Recent years have seen marked improvement towards the development of a sustainable, cost-efficient, and consistent monitoring program because some resources and expertise, albeit limited, infused the program. However, that program is based only on seasonal (summer) sampling of lakes and streams for physicochemical parameters, and lacks adequate rationale for the measuring of those parameters, biological monitoring and stream discharge determinations. In the latter case, the national lakeshore is already seeing the importance of flow measurement (see Crystal River issue below). Monitoring is focused only on surface water resources; ground water resource quantity and quality are unknown commodities. An annual water quality monitoring report is produced on a 'catch-as-catch-can' basis, thereby a year or more in arrears, lacking adequate interpretation of data and not timely to national lakeshore management for decision making. The existing monitoring program is structured such that it samples basic water quality constituents that are unlikely to address such important issues as air deposition of persistent organic pollutants and their bioaccumulation in the aquatic food chain, recreational use impacts, biological integrity, and the detection of exotic species and the determination of the status of their populations. An important water resource issue for the national lakeshore is the cultural eutrophication (point and nonpoint source of nutrients) of its lakes and streams. In this regard the current monitoring program is measuring the appropriate parameters, but lacks the analysis and interpretation necessary to define the extent of the problem. Consistency remains a problem; parameters are added or deleted without the development of appropriate rationale, including the best sampling frequency for detection of change. These problems are not unique to the national lakeshore; they are common to fledgling water quality monitoring programs, especially ones that lack adequate resources and expertise. One step in the right direction is that national lakeshore staff recognize the importance of partnerships and cooperation in stretching monitoring resources. A case in point is the discussion with the Michigan Department of Environmental Quality on lake sediment monitoring for persistent organic pollutants. The national lakeshore would collect the samples with the analysis performed by the Department.

Without more comprehensive and consistent water resource information and adequate baseline data, changes will be difficult to document and incremental impacts on water resources will probably remain undetected until the cumulative result of those impacts is irreversible and irretrievable. Determining the status of contaminants on water, sediment and the biota in the national lakeshore would serve as a benchmark for future comparisons and would help to identify problem contaminants and/or sites for possible remedial action. At a minimum, waters entering the national lakeshore should be in compliance with state water quality standards. A comprehensive water quality monitoring program for surface and ground waters is essential to develop adequate baseline information and to determine compliance with water quality standards. An important first step in the revision of the water quality monitoring program is the development of a water quality monitoring plan and analysis of water quality information (see Project Statement SLBE-N-002.007, Appendix). Presently, Daren Carlisle of the Midwest Regional Office is assisting the national lakeshore with a review of its water quality monitoring program, and the development of a water quality monitoring plan would codify the results and recommendations of that review.

Sanders et al. (1987) and MacDonald et al. (1991) provide excellent discussions on monitoring plans or aspects of these plans. This monitoring plan should establish a quality assurance/quality control program (see Irwin 2001). This program would include, at the least, the delineation of field sampling and laboratory analytical methods, data storage and retrieval methods, and data analysis and interpretation. In particular, the national lakeshore is encouraged to use its capability in GIS as a data analysis and interpretation tool. The repository for all National Park Service water quality data is the U.S. Environmental Protection Agency's national STORET database. Water Quality data should be uploaded to this database on a regular schedule. The Water Resource Division (Dean Tucker, 303-225-3516) can provide assistance in understanding and communicating with STORET.

Annual summary reports should be prepared. These reports should include the tabular presentation of the data, data analysis and data interpretation. For a variety of reasons many monitoring programs do not follow through on this step, and in such cases the worth of conducting the monitoring program must be questioned. In general, the multiple demands on staff time mean that the monitoring data will be used only if they are summarized and interpreted. The data are more likely to be evaluated by managers and used for their original purpose, namely the guidance of management decisions. The Water Resources Division can review these reports; these reviews would act as a feedback loop that provides input into the continued adequacy of the monitoring program. These annual summary reports should be shared with other federal, state and local agencies, as applicable. This will facilitate discussions with appropriate regulatory authorities when corrective action is necessary.

An important factor to consider in the development of the water quality monitoring plan is that the Great Lakes Inventory and Monitoring Network of the Midwest Region of the NPS will be developing a long-term water quality monitoring program using funds appropriated under the Natural Resources Challenge. It is imperative that the national lakeshore develops its water quality monitoring plan in cooperation with or as part of this Network effort in order to avoid duplication of effort. In addition, cooperation between park and Network programs could produce more cost effective monitoring in the national lakeshore.

The following topical discussions are provided to assist in the development of the water quality monitoring plan:

1) Stream discharge is a parameter that should be measured on all of the streams of the national lakeshore. A stage-discharge relationship will need to be established. This may require purchase or long-term loan of a flow meter. The purchase price of a quality flow meter ranges from $1000 to $3000.

At each potential station to be used for discharge determination, a general reconnaissance should be made so that the most suitable site for the gage is selected. In selecting a site consideration should be given to the following items (Carter and Davidian 1968):

- channel characteristics;
- possibility of backwater from downstream tributaries or other sources;
- availability of a nearby cross section where good discharge measurements can be made;
- proper placement of stage gage with respect to the measuring section and to that part of the channel which controls the stage-discharge relationship; and,
- possibility of flow bypassing the site in ground water or in flood channels.

The stage of a stream is the height of the water surface above an established datum plane. Measurements of stream stage are used in determining records of stream discharge. A record stage can be obtained by systematic observations of a non-recording stage. The advantages of the non-recording gage are the low initial cost and the ease of installation. For example, attach a staff gage to a steel fence post and drive it into the stream bed so that some part of the scale is still immersed at the lowest expected water level of the sampling period and the top of the scale protrudes above the water at the highest level.

The frequency of the staff gage readings is determined by accuracy requirements and the degree of expected water-level fluctuations. When unexpected alterations in the water supply occur which affect water level, a change in the predetermined visiting schedule is warranted.

Discharge measurements are normally made by the current-meter method, which consists of determinations of velocity and area in the parts of a stream cross section. The following is taken from Carter and Davidian (1968):

> …the cross section is divided into 20-30 partial sections [this will depend on stream width], and the area and mean velocity of each is determined separately. A partial section is a rectangle whose depth is equal to the sounded depth at the meter location (a vertical) and whose width is equal to the sum of half the distances to the adjacent verticals. At each vertical the following observations are made: (1) the distance to a reference point on the bank, (2) the depth of flow, and (3) the velocity as indicated by the current meter at one or two points in the vertical. These points are at either the 0.2 or 0.8 depths (two-point method) or the 0.6 depth (one-point method) from the water surface. The average of the two velocities or the single velocity at 0.6 depth is taken to be the mean velocity in the vertical. The discharge in each partial section is computed as the product of mean velocity times depth at the vertical times the sum of half

the distances to adjacent verticals. The sum of the discharges in all partial sections is the total discharge of the stream.

Determination of discharge at a large majority of gaging stations is a result of the relationship between stage and discharge. These stage-discharge relationships are rarely permanent, particularly at low flow, because of changes in the stream channel such as scour and fill, aquatic growth, ice, or debris or because of changes in bed roughness. Frequent discharge measurements are necessary to define the stage-discharge relationship at any time.

The stage-discharge relationship is developed from a graphical analysis of the data plotted on either rectangular coordinate or logarithmic plotting paper. Kennedy (1984) provides an in depth discussion for determining the stage-discharge relationship. Stage is plotted on the abscissa and discharge on the ordinate of log-log paper, or a least-squares equation is calculated from these data pairs. Subsequent estimations of discharge require only a stage measurement, which is used on the plotted curve or in the regression equation to calculate discharge.

2) During the sampling of each monitoring station, digital, color photographs should be taken looking upstream and downstream of each station. Digital photographs are easily stored on compact discs and have the advantage over color film of not fading over time. Photographic monitoring is an inexpensive method to assess changes in stream geomorphology, the riparian zone, and other physical habitat features that may be associated with site and watershed conditions. A series of photographs may also allow detection of slow, progressive changes in physical habitat features that otherwise might go undetected until the accumulation of impacts is noticeable.

3) Assessment of biological integrity should be conducted on at least one station of each stream of the national lakeshore. The preferred frequency for these assessments is annually; however, less frequent assessments may be used depending upon the objectives of the program.

The phrase “biological integrity” was first used in 1972 to establish the goal of the Clean Water Act: "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." This mandate clearly established a legal foundation for protecting aquatic biota. Unfortunately, the vision of biological integrity was not reflected in the act's implementing regulations. Those regulations were aimed at controlling or reducing release of chemical contaminants and thereby protecting human health; the integrity of biological communities was largely ignored (Karr 1991). As a result, aquatic organisms and aquatic environments have declined in recent decades. The assessment of water resources extends beyond pollutant-caused degradation of water quality; in addition, we face loss of species, homogenized biological assemblages, and lost fisheries.

Biological integrity refers to the capacity to support and maintain a balanced, integrated, and adaptive biological system having the full range of elements (e.g., populations, species, assemblages) and processes (e.g. biotic interactions, energy dynamics, biogeochemical cycles) expected in a region's natural habitat (Karr et al. 1986). The biological integrity of water resources is jeopardized by altering one or more of five classes of environmental factors: alteration of physical habitat, modifications of seasonal flow of water, changes in the food base of the system, changes in interactions within the stream biota, and chemical contamination (Karr 1990). Urbanization, for example, compromises the biological integrity of streams by severing the connections among segments of a watershed and by altering hydrology, water quality, energy sources, habitat structure, and biotic interactions.

Water managers are increasingly being called upon to evaluate the biological effects of their management decisions, for no other aspect of a river gives a more integrated perspective about the condition of a river and its biota. Widespread recognition of this and the continued degradation of our water resources have stimulated numerous efforts to improve our ability to track aquatic biological integrity (Davis and Simon 1995). Comprehensive, multimetric indexes (Barbour et al. 1995) were first developed in the Midwest for use with fishes (Karr 1981; Fausch et al. 1984; Karr et al. 1986), and modified for use in other regions of the U. S. (Miller et al. 1988) and with invertebrates (Ohio EPA 1988; Plafkin et al. 1989; Kerans and Karr 1994; Deshon 1995; Fore et al. 1996). The conceptual basis of the multimetric approach has now been applied to a variety of aquatic environments (Davis and Simon 1995), including large rivers, lakes, estuaries, wetlands, riparian corridors, and reservoirs, and in a variety of geographic locations (Lyons et al. 1995).

Presently, more comprehensive approaches have been developed and are being adopted by state and federal agencies. Forty-two states now use multimetric biological assessments of biological condition and six states are developing biological assessment approaches; only three states used multimetric biological approaches in 1989 (U.S. Environmental Protection Agency 1996). Efforts are at last being made to monitor the biological integrity of water resources as mandated by the Clean Water Act 28 years ago (Karr 1991; Davis and Simon 1995; U.S. Environmental Protection Agency 1996).

The set of metrics incorporated into a multimetric index integrates information from ecosystem, community, population, and individual levels (Karr 1991; Barbour et al. 1995). Multimetric indexes are generally dominated by metrics of taxa richness (number of taxa) because structural changes, such as shifts among taxa, generally occur at lower levels of stress than do changes in ecosystem processes (Karr et al. 1986; Schindler 1987, 1990). However, the most appropriate and integrative multimetric indexes embrace several concepts, including taxa richness, indicator taxa or guilds (e.g. tolerant and intolerant), health of individual organisms; and assessment of processes (e.g., as reflected by trophic structure) of the sampled assemblage.

Like the multimetric indexes used to track national economies, multimetric biological indexes measure many dimensions of complex ecological systems (Karr 1992). Multimetric economic indexes assess economic health against a standard fiscal period; indexes of biological integrity assess the biological well being of sites against a regional "baseline condition" reflecting the relative absence of human influence. The goal is to understand and isolate, through sampling design and analytical procedures, patterns that derive from natural variation in environments.

The systematic, biological assessment of species assemblages using multimetric indexes is presently one of a few practical and cost-effective approaches to determine if human actions are degrading biological integrity (Davis and Simon 1995). Such monitoring provides both numeric and narrative descriptions of resource condition, which can be compared among watersheds, across a single watershed, and over time (Karr 1991), and it does so at costs which are often less than the cost of complex chemical monitoring. Costs per evaluation are low for ambient biological monitoring (based on a decade of sampling and including equipment; supplies; and logistical, administrative, and data analysis and interpretation activities: benthic invertebrates, $824/sample; fish, $740/sample; Yoder and Rankin 1995) in comparison with chemical and physical water quality ($1,653) and bioassays ($3,573 to $18,318).

The Index of Biotic Integrity (IBI; Karr 1981), the first of the multimetric indexes and centered on fish communities, was conceived to provide a broadly based and ecologically sound tool to evaluate biological conditions in Midwestern streams. The IBI and its sister indexes are based on a series of assumptions and intuitions of how biotic assemblages change with increased environmental degradation (Table 14). A single sample from a stream reach is evaluated using 12 metrics to determine the extent to which the resident fish community diverges from that expected of an undisturbed site in the same geographic area and of the same stream size. Unlike efforts to define chemical criteria that do not take variation by geographic region into account, this approach explicitly recognizes natural variation in water resource conditions. Ratings are assigned, summed, and placed into integrity classes (excellent, good, fair, poor, and very poor) to provide an assessment of the biological integrity or health of a system.

Regardless of whether fish, invertebrates, or other taxa are used, the search for a small set of metrics that reliably signals resource condition along gradients of human influence yields the same basic list of metrics (Miller et al. 1988; Karr 1991; Davis and Simon 1995). With usually only minor modification, the list can be adapted to specific regions (Miller et al. 1988).

Table 14. Typical effects of environmental degradation on biotic (primarily fish) assemblages as suggested from studies of fish communities (from Fausch et al.1990).

* The number of native species, and those in specialized taxa or guilds declines
* The percentage of exotic or introduced species or stocks increases
* The number of generally intolerant or sensitive species declines
* The percentage of the assemblage comprising tolerant or insensitive species increases
* The percentage of trophic and habitat specialists declines
* The percentage of trophic and habitat generalists increases
* The abundance of the total number of individuals declines
* The incidence of disease and anomalies increases
* The percentage of large, mature, or old-growth individuals declines
* Reproduction of generally sensitive species declines
* The number of size- and age-classes declines
* Spatial or temporal fluctuations are more pronounced

The State of Michigan uses what is commonly referred to as GLEAS Procedure 51 (Michigan Department of Natural Resources 1991) in all of its surface-water biological assessments of wadable streams. The procedure uses biometrics that represent a wide array of criteria for the majority of biological and habitat conditions known to occur in respond to various stream-quality conditions. The portion of this procedure that is important to the national lakeshore is the one that analyzes the stream habitat and macroinveterbrate community quality to produce assessment scores for the sites. These scores are then compared to suitable reference sites. The accuracy of the assessment depends on the choice of the reference site. Because scores are produced for sites before the comparison with the reference site, the use of procedure 51 will also allow comparisons to sites assessed by the State in the ecoregion surrounding the national lakeshore.

The national lakeshore should consider the use of Procedure 51 in the assessment of its waters. The use of this approach is the most cost-effective to the national lakeshore simply because the State has been using this approach for some time and has gone through the trial and error phase. While there may be other candidate approaches, these would, for the most part, have to be tested for applicability to this area of Michigan and may have to be modified. This would require substantial, up front costs and time prior to any use of a new approach. However, it should be noted that Procedure 51 is a qualitative procedure and the habitat measures are subjective. What method of biological assessment, if any, to use depends on the objectives and costs associated with the development of the water quality monitoring program for the national lakeshore.

The U.S. Geological Survey, Biological Resources Division developed Project Statement SLBE-N-002.010 (Appendix). This statement proposes to sample burrowing mayflies (*Hexagenia*) as indicators of aquatic ecosystem health in the

Platte River System. Although not a multimetric approach, this proposal holds promise for measuring lake eutrophication, appears to be relatively inexpensive, and has been tested elsewhere in the Great Lakes area.

4) The study by Whitman et al. (2002) was an attempt to sample and analyze lake zooplankton communities in the national lakeshore and deduce commonalties within the zooplankton communities that would lead to the development of metrics for use in a biological assessment approach for lakes similar to that for streams. However, while this research must be considered a step in the right direction, much more work is need in the development and testing of any assessment technique based on zooplankton. In addition the laboratory time required for zooplankton identification is substantial. Therefore, the applicability of a zooplankton-based bioassessment tool for lakes may not be sustainable by the national lakeshore.

Whitman's study does provide the national lakeshore a valuable baseline of its lake zooplankton communities – especially changes in community composition with time. The national lakeshore may want to consider the re-sampling of zooplankton communities on an every 5-year basis. In this way any structural and functional changes in the zooplankton communities can be determined and correlated with the ongoing physicochemical monitoring of the lakes. Similarly, the national lakeshore will be able to assess zooplankton community changes in response to exotic species invasions, especially zebra mussels.

Are National Lakeshore Waters Affected by Bacteriological Contamination?

The park staff expressed an immediate concern about possible bacterial contamination to national lakeshore waters especially the effects of animals (dogs, waterfowl) and their waste products on areas involving primary (swimming) and secondary (canoeing, tubing) water contact recreation. This concern led to a ban of dogs on some beaches within the national lakeshore. To determine whether this action was warranted, an assessment of bacteriological conditions was needed. A co-lateral decision by the national lakeshore and the Water Resources Division of the NPS refocused a WRD-funded, national lakeshore project to address this need prior to the completion of the water resources management plan.

A pilot bacteria monitoring program was initiated at the national lakeshore in the summer of 1997 to determine if waters of the park were affected by *Escherichia coli* contamination (Whitman 1997). This study sought to characterize the distribution of *E. coli* in lakeshore waters and also to observe related factors influencing their concentrations.

It is not the high concentration of *E. coli*, in itself, that causes public health concerns, but the harmful pathogens often associated with *E. coli* from fecal contamination. *E. coli* is widely used as an indicator of fecal contamination because it is difficult to test for many of these pathogens. Given that high bacteria concentrations could pose a public health threat, the State of Michigan has set bacteria-based water quality criteria for swimming beaches. Because no lakeshore-based, bacteria monitoring program was in place at that time to determine protocols for beach closing, the 1997 study was also to determine if bacterial concentrations warrant the implementation of such program.

Whitman (1997) collected samples twice weekly from June 16 to July 14; thereafter, once a week at 11 sites to September (Table 15). Sites were popular swimming areas or areas presumed to be subject to fecal contamination. Whitman also conducted more frequent sampling around two rain events to record potential runoff-induced high bacteria concentrations. Several sites had high bacteria counts once or twice during the summer of 1997 (Table 15). Little Glen Lake [called Glen Lake Central; added two more sites (East and West after July 3)] experienced elevated bacteria counts. All three sites exhibited elevated bacteria concentrations after a July 8 rain event. Whitman (1997) concluded that elevated counts were due primarily to waterfowl defecation.

The results of Whitman's (1997) study suggested that elevated bacteria counts are localized and generally infrequent. With the exception of Little Glen Lake Whitman did not believe that a bacteria monitoring program would enhance visitor health protection. However, National Park Service Director's Order 83: Public Health (dated August 2, 1999) now directs NPS park managers to reduce the risk of waterborne disease by requiring the monitoring of designated bathing beaches and recommending that other heavily used recreational waters be appropriately monitored. Guidance pertaining to this monitoring is found in Reference Manual 83 (National Park Service 1999) and includes:

- Conducting a sanitary survey
- Preparing a bathing beach monitoring protocol
- Sampling for *Enterococcus* or *E. coli* bacteria levels, and
- Issuing swimming advisories when bathing beach waters exceed the bacterial standards.

While Sleeping Bear Dune National Lakeshore does not contain designated bathing beaches, some swimming, wading, tubing and canoeing are popular at most of the lakeshore's streams and lakes. This being the case, prudent management dictates that a recreational water quality monitoring program be a high park priority for the national lakeshore.

Table 15. *E. coli* counts (# colonies/100 ml) for all sites sampled by Whitman (1997). **Bold** numbers indicate counts over the state of Michigan limit for swimming (300 colonies/100 ml).

Date	Site																		
	Plover Pt.	Lake Mich. Platte	Platte R. Mouth	El Dorado	Canoe Launch	Esch Beach S.	Esch Beach N.	Otter Creek	Aral Marsh S.	Aral Marsh N.	North Bar Lake	Lake Mich. N. Bar	Glen Lake West	Glen Lake Central	Glen Lake East	Glen Haven	Crystal River	Good Harbor S.	Good Harbor N.
16-Jun-97	12	18	52	19	10		47	99			66	97		8		0	8	0	3
20-Jun-97	0	39	8	16	19		19	11	**450**	80	87	67					16		
06-Jun-97 rain	11	68	40	24	32	19	44	58			180	50					50		
23-Jun-97	137	6	72	53	19	37	9	109	**2390**	230	57	0		**300**		0	163		2
27-Jun-97	20	12	24	3	8	4	10	9	100	280		4		**510**		1	15	4	44
30-Jun-97	15	29	44	5	53	31	60	27			19	11		4		26	110	29	11
30-Jun-97 rain	15	34	75	49	21														
01-Jul-97	95	71	110	80	19						4			**529**					
03-Jul-97	**300**	109	77	39	10	90	86	141	10	180	251	95		7		233	1	213	**600**
07-Jul-97	8	27	35	15	6	1	16	16	140	190	10	0	40	114	59	6	8	9	19

Table 15. Continued.

Date	Site																		
	Plover Pt.	Lake Mich. Platte	Platte R. Mouth	El Dorado	Canoe Launch	Esch Beach S.	Esch Beach N.	Otter Creek	Aral Marsh S.	Aral Marsh N.	North Bar Lake	Lake Mich. N. Bar	Glen Lake West	Glen Lake Central	Glen Lake East	Glen Haven	Crystal River	Good Harbor S.	Good Harbor N.
08-Jul-97 rain	54	205	89	124	104								1460	6800	410				
08-Jul-97 post rain	58	302	42	90	28								790	2130	1690				
09-Jul-97	112	34	104	20	6								2030	1130	160				
10-Jul-97	5	34	21	26	14	3	3	13	0	30	27	2	20	30	30	1	6	2	23
14-Jul-97	234	76	300	369	221	27	26				31	2	80	18	20	25	14	307	424

Table 15. Continued.

	Site										
Date	**Plover Pt.**	**Platte R. Mouth**	**El Dorado**	**Canoe Launch**	**Esch Rd. (Aral Bch)**	**Good Harbor N.**	**Good Harbor S.**	**Glen Lake**	**Mill Pond**	**Lake Mich. N. Bar**	**North Bar Lake**
24-Jul-97	5	17	0	3	3	5	12	47	44	31	69
30/31-Jul-97	18	11	5	7	20	72	9	47	5	139	7
06-Aug-97	0	11	12	9	4	6	1	4	103	165	5
14-Aug-97	0	10	0	3	5	6	1	25	197	4	5
21-Aug-97	0	14	8	18	**343**	64	39	18	**401**	**459**	1
28-Aug-97	36	17	12	9	248	21	51	2	**547**	214	2
04-Sep-97	10	31	7	17	2	19	3	8	45	1	1

In 1998, the national lakeshore conducted sampling for *E. coli* at only one site (Little Glen Lake Picnic area) and between late August and early September. In 1999 sampling was conducted again at the Little Glen Lake Picnic area; however, sampling was conducted weekly from late May to mid-September. Additionally, sampling was conducted infrequently during rain events. Other monitoring sites included North Bar Lake, Shalda Creek, and at two sites along Good Harbor Bay.

Recreational monitoring of *E. coli* became a major part of water quality monitoring at the national lakeshore in 2000. Monitoring for *E. coli* occurred at 20 sites – nine on national lakeshore streams, nine on Lake Michigan, and two on inland lakes. Sampling occurred weekly from the end of May to the middle of September. The national lakeshore conducts its own analysis of samples for *E. coli* using the membrane filtration technique described in the Standard Methods for the Examination of Water and Wastewater (1992).

The national lakeshore should insure that it is in compliance with the guidelines in Reference Manual 83 (National Park Service 1999). However, Project Statement SLBE-N-002.008 (Appendix) proposes the use of a more cost-effective *E. coli* monitoring technique that will enable the national lakeshore to screen more sites to determine areas that are a public health concern. This technique is the Idexx Quanti-tray 2000 test (< http://www.idexx.com/Water/Products/prod.cfm?ID=3 >). The use of this test does not require special expertise or training. Therefore, other park personnel, e.g. park rangers, can quickly take samples as a collateral duty during their routine checks.

A recreational monitoring program is an essential part of the national lakeshore's overall water quality monitoring program. It should be delineated within the proposed water quality monitoring plan discussed above, and a detailed quality assurance/quality control program formulated. This will become important if the national lakeshore is interested in closing recreational use areas due to sustained bacteriological contamination – the program will need to stand up to public scrutiny.

Crystal River Flow below Glen Lake Association Dam under Drought Conditions

The Glen Lake Association regulates a dam on the Crystal River according to a 1945 court order that dictates Glen Lake summer lake levels for the boating season and winter lake levels to decrease ice damage. In June 2001 the Association replaced the old stop-board dam and wooden spillway with a concrete spillway and adjustable metal gates to regulate flow. However, during construction of this new dam a fish kill occurred because river flow was reduced or shut down for approximately 18 hours. This situation was exacerbated by already low flow conditions caused by a severe drought. As a result downstream riparian owners/users held the Glen Lake Association responsible for drying up the river, killing fish, and ruining the summer canoe livery business. A Crystal River riparian group, the "Glen Lake-Crystal River Watershed Riparians", organized shortly thereafter.

In September 2001 the "Glen Lake-Crystal River Watershed Riparians" filed a complaint and petition in Circuit Court to modify the 1945 court order and change how the Glen Lake Association regulates flow over the dam. The end result could be a minimum flow in the river that protects habitat, allows recreational use and protects riparian owner rights. A Circuit Court judge issued a temporary order for no immediate relief, i.e. the Glen Lake water level does not need to be adjusted immediately to protect the Crystal River. A full hearing was expected by the end of May 2002. To avoid litigation, the parties have been ordered by the Court to participate in settlement mediation. Although the lakeshore has not been named as a party in the suit, it has mission-critical interests on both sides. Under legal guidance by the Office of the Solicitor, the lakeshore worked with the litigating parties in the mediation process to address lakeshore issues.

This situation is important to the national lakeshore because it is the major riparian owner on the Crystal River below the dam. As such, the lakeshore is strongly interested in working cooperatively towards a mutually beneficial solution that simultaneously protects river habitat and biota, allows for a quality recreational experience on the river, and protects Glen Lake owners' recreational pursuits and infrastructure. In this regard, the national lakeshore requested technical assistance in 2001 from the Water Resources Division of the National Park Service. Specifically, the national lakeshore wanted a better understanding of historic streamflows as well as the relationship between flows and conditions that influence instream recreation uses and aquatic habitat conditions. The basic question is how do lake levels (via dam management) influence the hydrology of the Crystal River? This question can be answered by developing rating curves based on the following relationships: lake level/stream discharge and dam discharge/stream discharge. The idea is to quantitatively link lake levels to dam operations to river flows to river depths and velocities. This information could be used to better forecast late summer drought conditions by augmenting lake levels earlier in the summer, i.e. provide a minimum flow that allows recreation to continue and at the same time protects in-stream biological communities under drought conditions. In all probability recreational use under drought conditions is probably more damaging to stream/riparian biological communities, via boat dragging through stream and riparian zone and excessive wading, than the flow regulation. Given that ground water strongly controls the flow conditions of the Crystal River providing both an annual and multi-year stability, and that biological communities are likely less physically structured because of this stability, it may be possible to determine a minimum flow for a quality boating experience that protects in-stream biological conditions.

The results from the Water Resources Division study move the state of the science on the Crystal River towards an understanding and quantitative determination of minimum flow, but fall short due to an inadequate hydrologic record upon which to base an instream flow assessment. Additionally, that record is inadequate to develop a quantitative understanding of the relationship between lake levels and dam releases. However, the study did develop indirect rating curves and cross-section profiles of flows at two locations downstream of the dam. Although very approximate, the methods used suggest an approach to better understanding of the relationship between dam discharge and downstream flow that supports instream recreation and biological conditions. For example, a recreation flow assessment study (Shelby et al. 1992) would conduct surveys along the Crystal River to estimate the number and type of riverine recreation users and their preferences for various flow regimes during the summer. Interviews with recreation users will provide information about the recreation users (age, etc.), the type of recreation, impressions of the interviewees about water conditions (too high, too low, ideal, etc.), and notes on any problems that recreation users see. The interviewee information would be compared to river flow information measured at the time of the interview.

The second aspect of this assessment would be to determine the relationship between river discharge and hydraulic geometry and to define stream flow-hydraulic geometry relationships for specific recreation activities along the river. That is, assess the dependency of hydraulic variables such as depth, top-width, wetted perimeter and velocity on discharge. Then assess the relationships of these physical assessments to the surveys of recreational users' preferences for flows.

The Water Resources Division report recommends: 1) the development of a daily discharge record at the dam for a period of at least 3 years; 2) the development of a more quantitative and scientifically-based understanding of the relationship between dam discharge and instream recreational and biological values; 3) the development of a measured relationship between changes in dam discharge at water levels in Glen Lake; and, 4) establishing a more quantitative (hydrologic) understanding of the needs of the mediation parties and the implications to each other of meeting those needs.

Finally, the national lakeshore is interested in methods to determine the carrying capacity of its water resources. That is, at what level of recreational use does significant environmental impact occur that would not allow the national lakeshore to comply with the mandates of the Organic Act of 1916? While this concept is rather straightforward, the actual determination of a stream's carrying capacity is problematic – the National Park Service continues to struggle with its evaluation. Typically, we are interested in the maximum allowable recreation use before significant environmental impacts occur. However, the determination of a minimum flow for a 'quality' recreational experience on the Crystal River approximates resource carrying capacity albeit with some reverse logic. It is a drought condition, exacerbated by flow regulation that presumably has the greatest environmental harm. Therefore, the establishment of a minimum flow that allows recreation use and is still protective of biological conditions defines a 'minimum' point (i.e., carrying capacity) below which recreational use is not advisable because of the potential for significant environmental impacts.

Recreational Use of National Lakeshore Streams

The recreational flow assessment (Shelby et al. 1992) described above for the Crystal River is something that could be done for all streams in the national lakeshore. Given the increasing recreational use of all of the national lakeshore's streams, it is important to understand just what is the level of recreational use and determine environmental impacts from this use, if any. However, the Crystal River situation is unique in that it is the only stream in the national lakeshore that is flow regulated via a dam; drought conditions are accentuated. Therefore, the national lakeshore should conduct, at the minimum, the first part of this recreational flow assessment – an assessment of recreational use by surveying the users. Through this vehicle, the national lakeshore would understand levels, types and patterns of recreational use. Once recreational use is known, the national lakeshore should conduct regular assessments of stream/riparian resource condition.

Project Statements SLBE-N-002.009 and SLBE-N-002.011 (Appendix) provide two alternative ways to assess the condition of stream/riparian resources. Information on impacts could then be correlated to data from the recreational use survey to suggest impacts from recreational use. However, a true cause-and-effect relationship will be problematical.

Project Statement SLBE-N-002.009 proposes the assessment of riparian systems of the national lakeshore. The maintenance of healthy riparian systems is essential in obtaining and sustaining biologically diverse Great Lake ecosystems. Healthy riparian systems can be described as being geologically stable with stream flow and sediment discharges that are in dynamic equilibrium with their upland watersheds, and as having wetland and riparian vegetation that has appropriate structural, age, and species diversity. When these attributes are maintained, riparian systems provide forage and cover for wildlife and improve water quality by filtering sediment and recycling nutrients. If, however, any of the essential attributes are missing or degraded, or if the system becomes geologically unstable, widespread erosion may occur that will degrade water quality and cause damage or loss of wetland and riparian habitats.

Other than a cursory understanding of the presence of plant species (Hazlett 1986; Albert 1992), the riparian zones (of streams and lakes) in Sleeping Bear Dunes National Lakeshore are unstudied. To properly manage these important resources, park management must be able to assess riparian conditions and take steps to resolve any problems. All too often, however, when we are asked to assess the condition or overall health of our riparian areas we are at a loss to respond with much more than “they look OK to me” or “they look terrible,” without a strong rationale for either conclusion. Given our critical role in the conservation of soil, water, vegetation, and wildlife resources, it is essential that natural resource managers have proper tools to evaluate the health of the riparian systems under NPS stewardship, especially when multiple competing uses are present.

The U.S. Bureau of Land Management has developed guidelines and procedures to rapidly assess whether a stream riparian area is functioning properly in terms of its hydrology, landform/soils, channel characteristics, and vegetation (Prichard et al. 1993, rev. 1995). This assessment, commonly called Proper Functioning Condition or PFC, is useful as a baseline analysis of stream condition and physical function. Water Resources Division staff have successfully used this assessment in several park units since 1995 (< http://www1.nature.nps.gov/wrd/chrisrpt.htm >).

PFC uses an interdisciplinary team, consisting of soil, vegetation, hydrology and biology specialists, to assess riparian area "functionality" according to 17 hydrological, vegetation, and stream geomorphologic (e.g. erosion, deposition, channel geometry) factors. PFC is not a quantitative field technique. An advantage of this approach is that it is less time-consuming than other techniques because measurements are not required. It provides an initial screening that can separate areas that are functioning well from those in need of more intensive evaluation or management actions. In this way, money and effort can be targeted toward the higher priority issues. Originally developed by the Bureau of Land Management for assessment of riparian areas managed by that agency, the method is now being applied throughout the western U.S. by the U.S. Forest Service and the Natural Resources Conservation Service. Use of this tool on eastern U.S. riparian areas is a logical extension.

PFC is a methodology for assessing the physical functioning of a riparian-wetland area. It provides information critical to determining the health of a riparian ecosystem. PFC considers both abiotic and biotic components as they relate to the physical functioning of riparian areas, but it does not consider the biotic component as it relates to habitat requirements. That is, those aspects of the biotic component that define the habitat for a particular species or habitat guild are not measured.

The "functioning condition" of a riparian area refers to the stability of the physical system, which in turn is dictated by the interaction of geology, soil, water, and vegetation. A healthy or stable stream/riparian area is in dynamic equilibrium with its stream flow forces and channel processes. In a healthy system, the channel adjusts in slope and form to handle larger runoff events with limited perturbation of the channel and associated riparian-wetland plant communities.

Project Statement SLBE-N-02.011 is authored by the U.S. Geological Survey on behalf of the national lakeshore and submitted for funding to the National Park

Service-U.S. Geological Survey Clean Water Initiative Program. This project statement proposes use of the Michigan Department of Environmental Quality's habitat and macroinvertebrate assessment procedure (GLEAS Procedure 51) as degradation indicators to evaluate recreational impact on the Crystal River. While the premise of this proposed study remains sound, it would require the national lakeshore to implement the study protocols for its monitoring program once the study ended. Given the current resource constraints on water resources management at the national lakeshore, it would not be feasible for the national lakeshore to sustain this program, especially for only one river. However, elements of the proposal (e.g., biological and habitat assessments using the State's procedure) remain viable and could be incorporated into the development of a sustainable water quality monitoring program for the national lakeshore.

Need for an Adequate Baseline of Information on Amphibians and Reptiles in the National Lakeshore

Amphibians in many parts of the world have recently declined in number and geographic ranges (Wake 1991; Livermore 1992). The situation is complex, but many believe that a global problem faces amphibians and that this problem is largely the result of habitat modifications by humans. Acid precipitation, shifts in precipitation patterns, intensive agriculture, deforestation, urbanization, highway construction, wetland draining, dam construction, pollution by pesticides and heavy metals, and the introduction of fishes and other predators can all adversely affect amphibians. Baseline information on the status and health of US populations of amphibians and reptiles is scarce (McDiarmid 1994) and there are no long-term quantitative data on amphibians and reptiles in the Great Lakes region. Amphibians in the Midwest do not seem to be experiencing the drastic declines occurring elsewhere, but local declines are apparent for both amphibians and reptiles.

In light of these amphibian declines and that amphibians are considered excellent 'canary-in-the-mine' indicators of ecosystem perturbations, it is important that an intensive survey be conducted for amphibian and reptile species in the national lakeshore. The national lakeshore is strongly encouraged to develop and conduct a systematic survey of amphibian and reptile species. This survey should be funded through either the Inventory and Monitoring or the Natural Resources Preservation programs of the National Park Service. As a start, the national lakeshore should contact the University of Michigan Museum of Zoology (or some other entity with adequate expertise) and explore the availability of herpetological expertise at the Museum or elsewhere in the state.

MEDIUM PRIORITY ISSUES

Are High Nitrogen Values in Otter Creek Natural or Anthropogenic?

Boyle and Hoefs (1993) noted a consistent pattern of higher nitrogen concentrations in Otter Creek versus the other streams in the national lakeshore (see Table 3). There are a number of springs in the lower reach of Otter Creek whose source is in the moraine to the east-northeast. Boyle and Hoefs hypothesized that, because there is no extant human development, the increased nitrogen concentrations (especially at the downstream – Table 3) could be due to increased concentrations in groundwater additions from the springs. However, whether this represents a natural condition or is due to relict deposits from the occupation of the old town of Aral is unknown.

This pattern has persisted. National lakeshore sampling in Otter Creek in 1999 revealed nitrogen concentrations in lower Otter Creek of 0.22 mg/l. Eight springs were sampled twice during 1999 with an average nitrate level of 0.32 mg/l. These concentrations are not criteria violations for nitrate, but this consistent pattern may point to a problem that has not manifested itself in degradation of water quality. Based on this, it appears that indeed the increased nitrate concentrations in lower Otter Creek are influenced by the additions of nitrate from the spring flows. The question remains whether this a natural condition or due to some anthropogenic source.

Outside of the hydrologic watershed boundary is a landowner (private inholding) that continues the practice of land application of raw sewage. In addition there are old agricultural facilities within the national lakeshore boundary. A majority of the time this practice would not be suspect, because this land or these facilities are outside of the watershed boundary. However, given the glacial geology and the hydrologic nature of the surficial aquifer, the possibility exists that the surface watershed boundary is not coincident with the watershed for ground water. In this case ground water, enriched by the land application of sewage or by other sources, may find its way into the Otter Creek drainage from outside the morainal watershed divide to the east. To determine that this is the case, a study of the ground water flow path is needed. The national lakeshore is encouraged to submit a technical assistance request to the NPS-WRD to conduct an initial assessment of the ground water flow path near the eastern surface watershed boundary of Otter Creek, perhaps via a dye tracer study. If the situation were determined to be more complex, the NPS-WRD would work with the U.S. Geological Survey and the national lakeshore to develop a competitive project statement.

Potential Effects of Phosphorus Loadings on National Lakeshore Waters from Platte River Anadromous Fish Hatchery

A State-operated trout rearing station, located approximately 8 mi upstream of the Plate Lake, was converted in 1969 to anadromous fish production. This

facility is the major supplier of coho and chinook salmon and steelhead trout for the State's recreational fishing program. In the early 1980s approximately 24 to 30 percent of the salmon reared at the hatchery were released to the Platte River and migrate to Lake Michigan through Platte Lake. Most of the returning adults are harvested at a State-owned weir located downstream of Loon Lake within the park boundaries. However, sufficient adults are allowed passage upstream to supply the egg-taking operation at the hatchery and allow for sport fishing.
The hatchery design did not allow for phosphorus removal from the discharge waters primarily because phosphorus was not recognized at that time as an area of concern for water quality in general or hatchery management in particular.

The hatchery had operated under a National Pollution Discharge Elimination System permit since 1976. When the permit came up for renewal in 1979, Platte Lake property owners cited greatly reduced water clarity and hypolimnetic oxygen depletion and other changes in the ecosystem as evidence of declining water quality. Grant (1979) believed that the hatchery was the major cause of the perceived water quality decline in Platte Lake because it was the only point source of phosphorus in the Platte River watershed. Grant determined that the hatchery discharged approximately 3312 lb/yr of phosphorus from 1978 to 1979 and estimated that 90 percent of this load (2981 lb/yr) eventually reached the lake. Based on this report, the 1980 permit limited the hatchery to a discharge that contains no more than 1400 lb/yr of phosphorus.

Later studies disputed the results by Grant (1979). Kenaga and Evans (1982) estimated a hatchery phosphorus discharge of 2245 lb/yr. However, the Michigan Department of Natural Resources (1983) calculated an effective hatchery loading of 1696 lb/yr for 1981. Furthermore, the State determined that for 1982 the net load (based on monthly averages from operating reports) was only 1083 lb/yr, well below the permit limit of 1400 lb/yr. The drop in phosphorus between years was attributed to use of less fish food and to changes in hatchery management. The State concluded that no in-lake restoration techniques were required at Platte Lake – water quality was relatively high despite recent impacts. Alternative watershed controls included various methods of improving management of wastewater at the Platte River hatchery to immediately reduce phosphorus loading to the lake.

Platte Lake property owners, however, continued to believe that reductions in Secchi disk transparencies did not occur prior to the reconstruction of the hatchery. They also believed that symptoms of eutrophication such as reductions in crayfish populations, disappearance of sensitive vegetation, reductions in mayfly hatches, the occurrence of dark polluted matter on docks and boats and a reduction in the fishing experience have occurred because of the hatchery effluent.

Because of a perceived lack of movement on this issue, the Platte Lake homeowners, through the Platte Lake Improvement Association (PLIA), sued the

Michigan Department of Natural Resources in 1986 under the Michigan Environmental Protection Act. Points by the PLIA in the suit were: 1) the 1985 NPDES permit level of 1400 lb/yr of phosphorus was not protective; 2) not all sources of phosphorus were monitored or considered and that weirs, smolt stocking and hatchery discharge were all sources; and 3) the Department was not actively taking steps to limit phosphorus inputs to the Platte River system. In 1988 the court agreed with PLIA and required significant changes in the operation of the facility.

The 1988 court opinion required the Department to: 1) reduce the 1988 loading of 926 lb/yr with the intent of maintaining a Platte Lake phosphorus standard of 8 ug/l; 2) feed fish food low in phosphorus; 3) deepen treatment ponds and improve waste removal; 4) hire a court master to oversee the court order; and 5) stop the migration of salmon at the lower weir. The migration order was later modified to allow the Department to pass at the lower weir the first 20,000 fish, then 1,000 fish/week from August 15 to December 15. In response to this court order the Department dredged the treatment pond in 1990; switched entirely to low phosphorus diets; installed a solids collection systems; operated the lower weir as required; and initiated a lower weir egg take facility feasibility study.

Overall, watershed phosphorus loadings to Platte Lake decreased from the early 1980s to the mid-1990s (Figure 16). Platte Lake Secchi disk transparencies during the warm period, May to September, improved from an average of 6.5 feet meters in the 1970s to 11.4 in the 1990s. However, several marl deposition events with transparencies less than 3 feet still occur although less frequently. The PLIA contended that the impact of phosphorus loadings from the hatchery occurs in the spring when conditions are optimal for marl deposition. From 1990 to 1995 the greatest average phosphorus discharge occurred in April and May, a critical time for the health of Platte Lake. Additionally, there was a significant correlation between lake phosphorus and transparency because of the influence of phosphorus on algal production, which in turn influences pH and marl formation. Finally, the Secchi depth readings recorded June 1995 were the shallowest on record which correlated with the lowest June flow on record, and, at the same time, the hatchery discharge was just over $1/5^{th}$ the total river flow recorded at Honor, MI. The question that the PLIA asked -- When flow is substantially reduced due to environmental conditions and the same number of pounds of phosphorus are discharged is not the concentration of phosphorus increased especially when the hatchery effluent makes up a higher percentage of the flow? Basically, permit levels based on an annualized maximum loading do not factor in the spatiotemporal nature of environmental conditions. In this case it seemed that maximum monthly phosphorus discharge levels were more ecological important.

Given the water quality improvements in Platte Lake, the Department drafted a NPDES permit (in 1995) that proposed an 865-lb/yr limit for phosphorus, despite the fact that in 1995 Platte Lake still experienced problems. The national

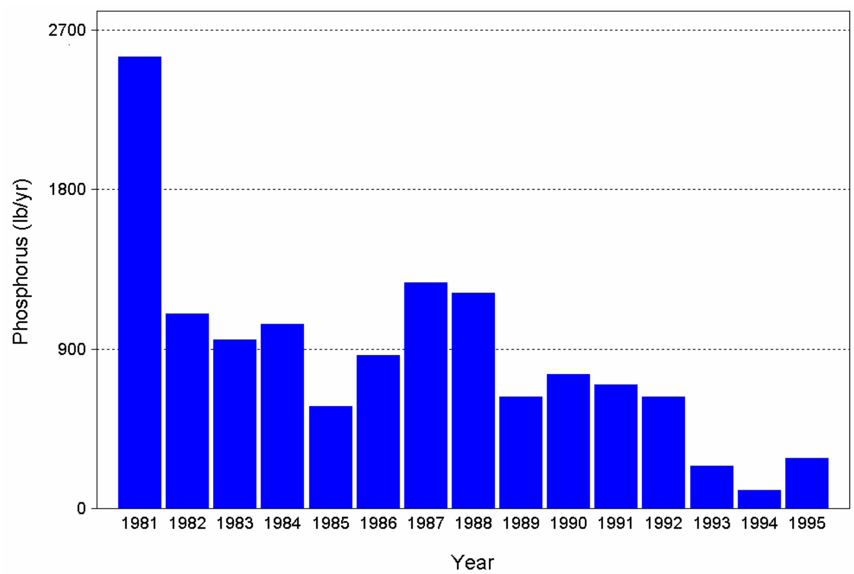


Figure 16. Annual phosphorus loadings to Platte Lake from 1981 to 1995. Data from Platte Lake Improvement Association.

lakeshore also objected to this permit because of the anti-degradation policy associated with its waters such that their water quality can not be lowered for any reason. The Department received a renewed permit in 1998 that restricted discharge to 440 lb/yr with no more than 121 lb in any 3 months. The PLIA contested this permit; the permit was under administrative review by the court until recently.

The court announced a Consent Decree in 2001. The NPDES permit was revised to 175 lb/yr of phosphorus with no more than 55 lb in any 3-month period. The 175 lb/yr of phosphorus was an estimate of the pre-salmon program phosphorus discharge from the pre-1969 facility.

From a national lakeshore perspective, this hard-fought victory for Platte Lake is also a victory for lakeshore waters, primarily Loon Lake, just downstream from Platte Lake. Park staff were always concerned that an increase in a limiting nutrient such as phosphorus would accelerate eutrophication of Loon Lake. While a possibility, the Loon Lake situation has two natural phenomena in its favor – Platte Lake is a natural, upstream sink for phosphorus and Loon Lake has a very short residence time (Stockwell and Gannon 1975). Although the impaired water quality conditions noted for Platte Lake did not appear to manifest in Loon Lake (subjective – no long-term monitoring data), a continuation of past phosphorus loadings might have had some cumulative impact on Loon Lake.

The question, however, remains Should the national lakeshore be concerned with phosphorus levels in the Platte River and associated lakes? The answer is definitely yes. Cultural eutrophication from nutrient inputs, both point and nonpoint sources, is and will continue to be a concern for all national lakeshore waters. The national lakeshore should work closely and cooperatively with the Platte Lake Improvement Association because that Association still maintains an active and sound monitoring program for phosphorus inputs to Platte Lake. Recently, the Association conducted a comparison of 2000 versus 2001 tributary and hatchery phosphorus loadings to Platte Lake (for first 6 months of each year) (W. Swiecki, Platte Lake Improvement Association, pers. com. to the national lakeshore 2001). Overall tributary phosphorus to Platte Lake showed an increase in 2001 – 1844 lbs in 2000 versus 1979.6 lbs in 2001. At the same time the phosphorus loading attributable to the hatchery showed a decrease – 101.34 lbs in 2000 versus 86.55 lbs in 2001. Clearly, other sources of phosphorus, primarily nonpoint sources within the upper Platte River watershed, are important. Similarly, the in-lake phosphorus loading for Platte Lake showed an increase of 693 lbs in 2001.

These results underscore the need for the national lakeshore to be vigilant in its monitoring for the effects of cultural eutrophication. While the reductions in phosphorus inputs via the hatchery are important, it is the nonpoint source inputs that will continue to be the problem. This is not an exception but is clearly the norm across the country – nonpoint source inputs of nutrients are the primary cause of eutrophication.

Another issue that is intimately tied to hatchery phosphorus loadings is the proposed development of an egg-take station at the Department's weir within the boundaries of the national lakeshore. Prior to a 1993 court order in the above case, a hearing was held annually to determine whether salmon should be allowed to pass the lower weir. During the fall of each year, nearly simultaneous to the returning salmon migration, a spike was detected in the phosphorus concentration of Platte Lake. Many studies addressed the issue over the years, including intensive creel surveys; searches of the river and lake for dead salmon, and camera searches of the lake's bottom. In 1992 the Court ordered the weir closed, and no salmon were allowed to pass. Even with no salmon present, the fall spike again occurred. The 1993 Order re-established the salmon passage past the lower weir.

It is not sure why, given the 1993 Order, but the Department requested funds to build an egg-take facility at the lower weir, thereby eliminating the need for the salmon to migrate through the watershed. Although the existing facility at the lower weir is used to harvest salmon, the harvested fish are not ready to produce fully mature eggs, and they are in such a condition that transporting them could severely hinder egg production. Thus, an egg-take facility would incorporate a smaller version of a hatchery, with facilities to hold the fish until the eggs are ready for harvesting.

In July 1997 the Court ordered the Department to conduct a feasibility study for an egg-take facility at the lower weir. The study was not to exceed $100,000 and be completed in March 1999. By the spring of 1998 MDNR approached the Court with a study cost in excess of $200,000 and asked to postpone the work. It was subsequently learned that the Michigan legislature had budgeted for the construction of this facility and would not allow the study to be postponed. In July 1998 the legislature officially provided MDNR with the money to construct the egg-take facility. The study proceeded with the drilling of test wells. However, no further aspects of the feasibility study have been implemented. Given the recent Consent Decree, the Department has apparently decided not to proceed with development. Presently, the continuous yield from four of the test wells (2000 gal/min; presumably from the surficial aquifer) is discharged into an artificial run to draw returning salmon. Whether this ground water discharge significantly affects the water table and hence the health of surrounding wetlands is not known. The national lakeshore could install monitoring wells (with continuous recorders) in an adjacent wetland to determine if any significant water table draw down is occurring. For technical assistance in this endeavor the lakeshore should contact Larry Martin of the Water Resources Division.

Restoration of Waterwheel Site on Platte River

The Waterwheel Site is an approximately 300-foot reach of the Platte River just upstream of highway M-22. The rightbank of the channel is a deteriorating concrete wall and the left bank has a wood wall segment, a remnant of a canoe livery operation. Fill material was placed behind these artificial walls. The walls have encroached into the channel, increasing depth and flow velocity, and prevent the river channel from developing a natural, stable cross-section form and natural vegetation. Finally, the left bank contains a 110-foot long, 30-foot tall steel sheet that was installed in the early 1990s. This steel sheet was installed (and covered with 6-inch diameter cobble) to prevent fuel from entering the river during the removal of nearby underground storage tanks. The steel sheet and cobble are no longer needed, and they prevent the restoration of natural stable channel banks and vegetation.

Recently, the Geologic Resources Division of the National Park Service (Pranger 2002) determined that restoration of the site would be relatively straightforward. The concrete and wood walls, backfill, and steel sheet and cobble should be removed and disposed. The original river channel banks need to be uncovered or reconstructed and re-vegetated with appropriate native plant species. The total cost of the restoration is estimated to be in excess of $38,000 and involves the following nine tasks:

- Install siltation control;
- Remove sheet pile from left bank;
- Remove cobble from left bank;
- Clear and grub left bank;

- Excavate and dispose of left bank encroachment;
- Clear and grub right bank;
- Demolish and dispose of right bank concrete wall;
- Excavate and dispose of right bank encroachment; and
- Revegetate.

National lakeshore staff will work closely with the Geological Resources Division to develop a project statement for submission to the National Park Service's National Funding Call.

Platte River Dredging

In its natural state, the mouth of the Platte River functioned essentially as an estuary, and was characterized by many of the same types of physical and biological processes that occur where rivers or streams empty into oceans.

In contrast to the essentially fixed configuration maintained by ongoing dredging and spoil deposition (annually beginning in September), the form and location of the natural river outlet to Lake Michigan would have been more dynamic. The Platte River is indicative of a river mouth where the strength of lake processes (e.g., longshore sand transport and seiches) exceeds river processes (e.g., discharge); sediment carried to the lake by the river is reworked and shaped more by the lake forces than by river forces.

Normally, fluctuation in river discharge is an important force that needs to be factored in when discussing processes active at river mouths. During periods of high discharge riverine processes may temporarily dominate lake processes. But that does not appear to happen at the Platte River mouth. The Platte River is relatively short, and in its course it flows through six lakes. Those lakes moderate its discharge during and after storms so that large fluctuations in stage are generally absent. The result of the absence of high peak discharge is that the river never has the power to overcome the energy originating in Lake Michigan.

Over the Recent geologic history of the Platte River, the lake has reworked the sediment accumulating at the mouth into a sand spit which forces the mouth to deflect in the direction of the longshore sediment movement (Environmental Resources Management 1985). Thus, as the river reaches the vicinity of the lakeshore, it is forced eastward before it has sufficient power to break through to the Lake. As the river channel lengthened behind the sand spit, hydraulic gradients (and flow velocities) would diminish to the point that longshore transport would have dominated and the outlet would have been partially blocked or completely closed. Water would then have built up behind the sand barrier until it eroded a new outlet channel. This would most likely have occurred at the shortest route to the lake (back to the south where the river first approaches the shoreline), only to start the northward outlet migration cycle again. We do not know the frequency of the outlet closure-opening-migration cycle for this site, but such cycles can range from several times a year in very small systems to once in several years in larger systems.

Therefore, it is likely that the wetlands in the lower Platte River were historically exposed to cycles of rising water after river mouth closures, followed by rapid declines when the river eroded through the sand spit barrier again. It appears that the reported 1 to 2 foot drop in upstream water level after dredging begins probably does not expose the affected areas to erosional effects that are outside the bounds of what occurred naturally in the recent past.

Impacts of dredging, other than those direct impacts at the dredge site [see Environmental Resources Management (1985)], are more likely to be associated with key biological processes that may be occurring in the lower Platte River and associated wetlands in September when dredging occurs. An example of such an effect might be a loss of marsh refugia for larval or juvenile fish, which may be flushed into the channel and subjected to excessive predation when the water level drops. It would be difficult to get at cause and effect in an investigation of this 'loss of refugia' hypothesis; therefore, it would be a low priority for the national lakeshore. However, past discussions with Ed Rutherford of the University of Michigan suggested an initial study that could begin to evaluate this possible effect by sampling aquatic organisms in the lower Platte River before, during, and after dredging episodes.

Another example is the possible effect that water level draw down has on wetland plant communities, including the increased possibility of establishment of exotic/nuisance wetland plants such as purple loosestrife or common reed (*Phragmites australis).* An assessment is needed to determine if annual September water level drawdowns have caused adverse impacts on plant communities, or have the potential for such impacts. This could be accomplished through aerial photo assessments, literature reviews, and onsite evaluations that are part of Project Statement SLBE-N-002.006 (Appendix).

As mentioned above, dredging the channel in its current location maintains the channel in its present, essentially fixed configuration. This configuration requires frequent dredging at the outlet because the long channel paralleling the lake has a low gradient and is very susceptible to periodic closure. A serious problem is that sand is removed from the system in ever increasing quantities. The short-term effect of that is to increase erosion on the beach immediately downdrift of the river mouth. In recent years the dredged material is a combination clay and rock – this combination is armoring the beach area and further removing any buried sand from the system. The long-term effect will be progressively more erosion downdrift, unless the material is again made available for longshore transport (Environmental Resources Management 1985).

Rather than a scenario of annual dredging of the Platte River mouth in perpetuity, two options are potentially available to the national lakeshore. First, moving the boat ramp to a location away from the lower Platte River (perhaps to the north) would eliminate the need for dredging at the present location. This would allow the river mouth to revert to natural coastal processes and would end concerns about the effects of dredging on the lower Platte River ecosystem. However, it is recognized that this option could have other long-term impacts. Second, if such an alternative boat ramp location were not feasible, it may be desirable to change the location of dredging to a point at the southern end of the barrier spit (i.e., where a new outlet would be likely to form under natural conditions). This outlet location may not close as frequently as the current location because of the steeper gradient thereby saving some dredging costs. However, this would still be a managed system that would need to be evaluated against the current configuration in terms of environmental effects. A coastal geomorphologist/engineer would need to be consulted to examine these alternatives in detail.

LOW PRIORITY ISSUES

Tucker Lake Hazardous Waste Site

The Tucker Lake hazardous waste site is roughly triangular in shape and covers an area of approximately 5 to 6 acres (Figure 17). The majority of the area with the exception of the southwest corner and western edge consists of wetland.

In conducting a phase I environmental site assessment Enviroscience (1995) characterized the site as follows:

> Miscellaneous debris, consisting mostly of tin cans, glass bottles, and sheet metal was observed scattered over the site. The highest concentration of debris was in an area adjacent to Tucker Lake and consisted of concrete blocks, fencing, asphalt, a few small appliances, and some car parts. Few potentially hazardous material containers, consisting primarily of empty paint cans and fuel storage cans, were evident at the site. No stressed vegetation was observed and with the exception of limited areas of rust-stained sediments and water, stained soils or discolored surface water were not evident.

Also present was a sludge pit (38 X 18 ft) that was underlain by concrete with a thin layer of black tar-like substance, resembling sludge. This site was operated as a ‘town dump’ by Glen Arbor residents from the early 1900s to the late 1960s (Enviroscience 1995). The wetland was not present in 1970; beavers have dammed the drainages in the area since that time. The sludge pit was constructed by the local fire department to practice putting out fires.

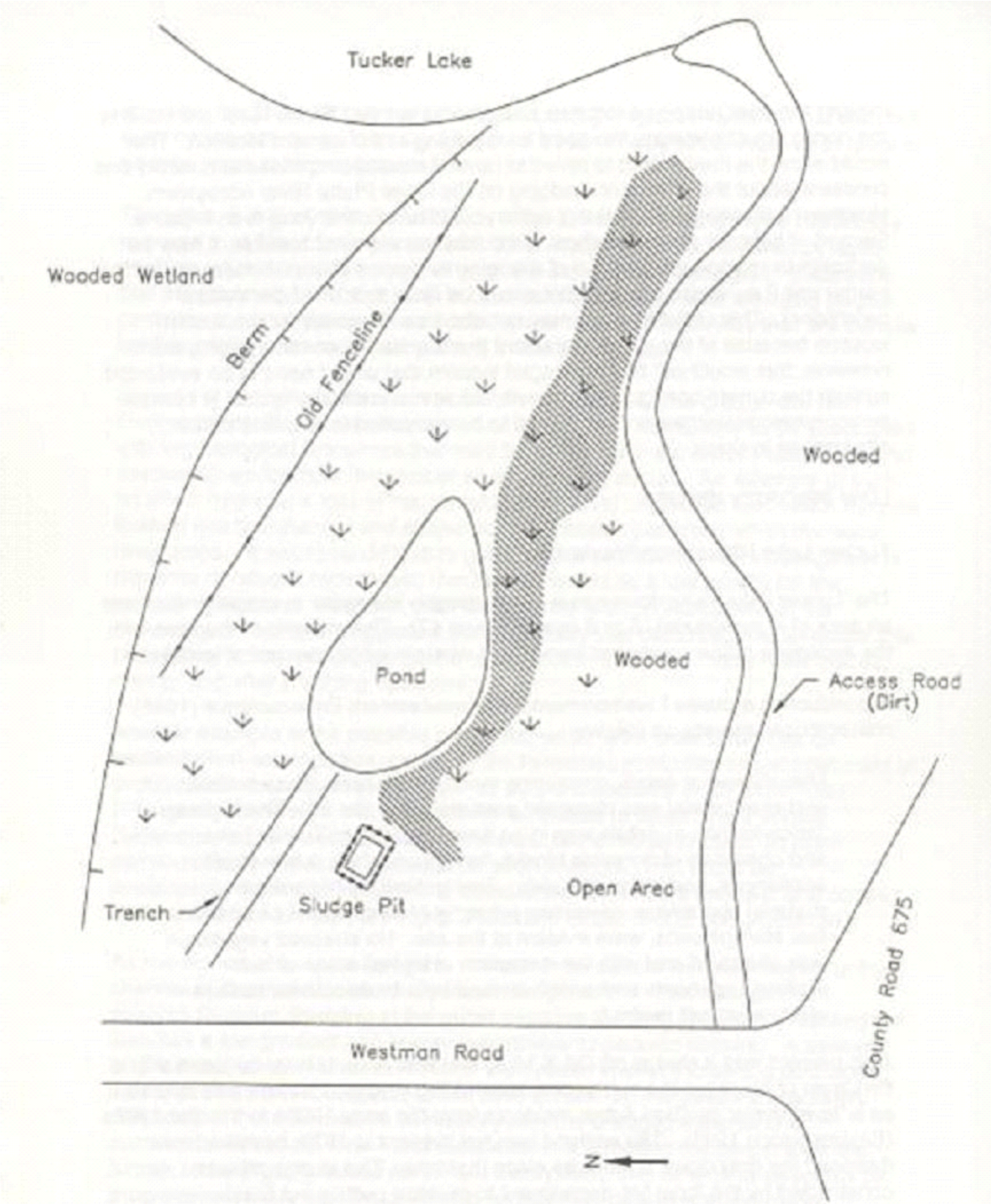


Figure 17. Tucker Lake hazardous waste site.

Previously, contaminant screening of the wetland water, dump sediments and pit sludge failed to reveal the presence of acute toxicity via 48-hr amphipod, isopod, and mayfly bioassays (Enviroscience 1995). Chemical analysis of the sediment and sludge samples indicated elevated concentrations of metals and traces of volatile organic constituents. In particular the lead concentration in the sludge was 26,700 ppm.

Enviroscience (1995) concluded its environmental site assessment noting that a release of potentially hazardous substances to the surficial aquifer is suspected due to the shallow water table and poor containment of waste. A release to surface water was likely. Additional environmental assessment work was recommended.

A phase II environmental site assessment was conducted in 1996 (Enviroscience 1996). During phase II the sludge, concrete pad of sludge pit and soil underneath the pad were removed based on concentrations of volatile organic compounds (VOC), semi-volatile organic compounds (SVOC) and TLCP (Toxic Characteristic Leaching Procedure) metals that were non-hazardous. Surface water samples showed no hazardous concentrations of VOC, SVOC and TLCP metals. Petroleum contamination was present in one ground water monitoring well; however, it was determined not to be a threat to human health or the environment. Enviroscience determined, based on these results, that no additional assessment work was needed and that all monitoring wells installed on the site be removed and abandoned.

Because of the thoroughness of the environmental site assessment conducted by Enviroscience (1995; 1996), the national lakeshore should consider the Tucker Lake Dump Site successfully remediated.

Condition of Day Mill Pond

Historically, Day Mill Pond was larger than at present and was connected to Little Glen Lake by a small channel. Around 1900, this wetland area was modified by a lumber operation that used the site for storage, and built a road for access. The road (Michigan 109) at that time went along the Little Glen Lake Shoreline and was called Pike Road. A wooden bridge was built for traffic to cross over the channel between Day Mill Pond and Little Glen Lake. The channel was used to transport logs out of Glen Lake to Day Mill Pond for storage until processed into lumber products.

In 1929 during the improvement of Michigan 109 the Day Mill Pond was filled in to relocate the road away form the lakeshore. The channel was also filled in and a culvert placed between the Day Mill Pond and Little Glen Lake. Prior to this road project, fisherman would fish at the mouth of the channel in Little Glen Lake and catch large northern pike. Day Mill Pond also apparently was spawning habitat for northern pike, with fish migrating into Day Mill Pond using the channel.

The first winter after the re-alignment of Michigan 109 Day Mill Pond experienced a fish kill. Since that time fishing for northern pike in Little Glen Lake has been limited.

Presently, there appears to be no fluvial connection between Day Mill Pond and Little Glen Lake through the culvert. The culvert is partially submerged on the Day Mill Pond side of the Michigan 109. On the lakeside, the culvert is clear and dry and about 2 ft from the lake water. The culvert is probably plugged, perhaps at its 45^{o} bend (Paul Murphy, Sleeping Bear Dunes National Lakeshore, pers. comm.). Therefore, there is no opportunity for fish migration through the culvert. Additionally, the changes in Day Mill Pond wrought by the road realignment now do not qualify it as northern pike spawning habitat.

Interviews with long-time residents indicate that in the past the site was a productive wetland, but in 2000 it appeared to be “dying” -- vegetation appeared to be in a degraded condition and some pond bottom was exposed. The Glen Lake Association in 2000 requested that the national lakeshore investigate the situation and ‘improve’ the management of the Day Mill Pond wetland complex.

Complicating the situation at the time of the request from the Association was an ongoing, severe drought (Lake Michigan was 54 in. below then recent highs). During a visit to the national lakeshore in 2001, the bottom was no longer exposed and emergent vegetation along the shore of Day Mill Pond was abundant and did not appear to be stressed. Because the national lakeshore has not implemented any new management of Day Mill Pond since the 1998 Glen Lake Association request, the differences in the condition of Day Mill Pond from 1998 to 2001 may simply have been the result of natural climatic cycles. One possible way to determine this likelihood is to look at historic aerial photographs to determine if vegetation communities fluctuated along with cycles of wet and dry periods.

The national lakeshore could also install staff gages in Day Mill Pond and Little Glen Lake that would be read on a weekly basis by park staff. In the long term this could allow the determination of any correlation between water levels and spring/summer/fall precipitation. However, winter precipitation could be as important or more important to ground water recharge and ultimately lake water levels than summer precipitation.

Beaver Colonization of National Lakeshore Watersheds

Beaver continue to colonize parts of all four watersheds within Sleeping Bear Dunes National Lakeshore. Park staff have expressed concern that beaver dams, built using road culverts as part of the infrastructure, may cause flooding of park roads or visitor use areas. The national lakeshore has eliminated some beaver dams via several methods. However, beaver will undoubtedly continue to colonize areas of the national lakeshore. Although traditionally considered a nuisance species, the beaver and its actions affect the general ecology of an area in many beneficial ways. An understanding of the ecology of the beaver is necessary before any attempts at control or removal are made.

The North American beaver (*Castor canadensis*) has historically been one of the most important keystone species because it fundamentally influences the ecology of headwater streams and adjacent riparian areas. Excellent reviews on the impacts of beavers on small stream ecology can be found in Hammerson (1994) and Olson and Hubert (1994) (Table 16). In general a beaver pond tends to shift a stream from a running water ecosystem to more of a shallow lake environment. Locally, the beaver ponds trap sediments and organic matter, and increase algal productivity. Beaver ponds help retain and store small floods, but the dams can wash out during extreme floods and thereby increase downstream flood damage. The dams often raise the local water table and create a greater connection with the floodplain. Beaver activity breaks the forest canopy, but the ponding water often kills other trees whose roots cannot tolerate inundation. These conditions, in turn, favor the growth of riparian tree species such as alders and willow, which are the preferred food sources for the beaver. The patches, edges and dead standing trees can result in a three-fold increase in songbird species (Medin and Cleary 1990), and can dramatically enhance amphibian and mammal habitat as well (Olson and Huber 1994).

Beaver dams function much like a stormwater pond and exert a similar influence on downstream water quality. For example, Maret et al. (1987) found that beaver pond complexes sharply reduce total suspended solid concentrations, and reduce phosphorus and nitrogen by 20 to 50 percent. Beaver ponds are usually an effective buffer and tend to increase the pH of water.
At the same time, beaver ponds increase downstream water temperature that can adversely affect trout populations at lower elevations and latitudes. In addition decomposition and microbial action occurring within the beaver pond typically lowers the dissolved oxygen content downstream. The aquatic insect community often becomes less diverse both within and below beaver ponds, with running-water species being replaced by pond taxa (Smith et al. 1991).

Beaver dams act as important retention devices, counteracting the tendency for export to dominate the fate of organic matter in flowing water. These obstructions clearly play a significant role in ecosystem function, allowing organic matter to accumulate. This enhances ecosystem processing relative to downstream export, and perhaps favors the formation of localized hotspots of biological activity. In the absence of retention devices the stream functions more like a pipe, allowing inputs to be flushed from the system, including a higher fraction of particulates.

Historical arguments against beaver include dead timber being an eyesore, blocked fish migration, and increased mosquito production. However, the greatest disturbance associated with beavers is flooding when the dam is

Table 16. Local or downstream changes caused by beaver dams [modified from Hammerson (1994).

1. Storage of precipitation, gradual release during dry weather
2. Reduced current velocity
3. Increase in wetted surface area of channel by several orders of magnitude
4. Increase in water depth
5. Higher elevation of the local water table
6. Decrease in amount of forest canopy
7. Loss of habitat for species that depend on live deciduous trees
8. Enhanced or degraded fish habitat and fisheries
9. Creation of habitat for species that prefer ponds, edges and dead trees
10. Shift of aquatic insect taxa within pond to collectors and predators, and away from shredders and scrapers
11. Increase in aquatic insect emergence per unit length of stream
12. Increase in algal productivity
13. Increase in trapping of sediment and decreased turbidity
14. Favorable conditions for willow and alder
15. Increased movement of carbon, nitrogen and other nutrients into streams
16. Reduced stream acidity
17. Lower oxygen levels in the spring and early summer due to decomposition
18. Increased resistance to ecosystem perturbation.

breached or blockage of culverts (Kwon 2000). With respect to the latter, the beaver can quickly plug up a culvert and backwater up to form a pond. The culvert will no longer convey runoff from large storm events, increasing the probability that the road will be flooded or the earthwork washed out.

Management alternatives to eliminate or discourage beavers generally fall into two categories: beaver removal or water level control. Neither of these categories has proven to be completely effective, i.e. they can reduce beaver damage but seldom can reduce beaver populations. Muller-Schwarze (1979) listed five population management alternatives for Acadia National Park:

1. Non-interference (allow the population to fluctuate with the available habitat)
2. Regulated harvest by commercial trappers
3. Harvest by park personnel
4. Live-trapping and transplanting on an annual basis
5. Large scale beaver sterilization.

At Acadia the park adopted a modified alternative 1 by managing water levels and allowing beaver to utilize the available habitat, thus reducing the suitability of the area for beaver in the future. Alternatives 2 and 3 were rejected as contrary to National Park Service policy. Alternative 4 was determined to be unfeasible from the standpoint of time and money. Alternative 5 was determined to be unwarranted by park officials.

An alternate approach is to drain the pond by installing pipe under the dam or through a clogged culvert. This approach is simple and can work fairly well if the intake is well protected. Otherwise, beavers will try and plug it with mud and wood to restore water levels.

D'Eon et al. (1995) reviewed a handful of pipe schemes to control water levels and one of the most effective appears to be the Clemson Beaver Pond Leveler. The idea behind this pond leveler is to keep the rise in water table to a minimum by using pipes to continually drain the pond. This simple mechanism requires the installation of 20-cm PVC pipe through the dam with an attached multi-hole intake device guarded by fencing. This method requires little maintenance and is widely used. The Clemson Beaver Pond Leveler was tested at 50 beaver ponds in the southeastern US and was never plugged by beavers. It is easy to fabricate and install, and costs less than $400 per unit. It can be used for culvert protection as well.

Since maintaining biological diversity is a stated National Park Service goal, management actions should be considered that would prolong beaver colonization within the national lakeshore. Beaver population control or manipulation should only be undertaken when human safety or structures are at risk.

FURTHER RECOMMENDATIONS

The Lake Michigan Lake-wide Management Plan and Sleeping Bear Dunes National Lakeshore

The Lake-wide Management Plan (LaMP) is mandated under the Great Lakes Water Quality Agreement Amendments of 1987 and Section 118(c) of the Clean Water Act. The U.S. Environmental Protection Agency is leading a collaborative effort to develop a comprehensive, sustainable ecosystem management approach in partnership with other federal agencies; state, tribal and local governments; and the public. The development of the Lake Michigan LaMP 2000 is an iterative process, and LaMP 2000 lays the foundation for the development of LaMP 2002.

The LaMP defines vision, goals and ecosystem objectives for the Lake Michigan basin. LaMP goals are linked to beneficial use impairments, the development of indicators, the monitoring and reporting on indicators, effective implementation strategies, and stakeholders. Noteworthy to the national lakeshore are the following proposed indicators: contaminants in edible fish tissue; *E. coli* and fecal coliform levels in nearshore recreational waters; atmospheric deposition of toxic chemicals; native Unionid mussels; nitrates and total phosphorus in coastal waters; amphibian diversity and abundance; and presence, abundance and expansion of invasive plants.

As part of the LaMP program structure, the Lake Michigan Monitoring Coordinating Council responds to the need for enhanced coordination, communication, and data management among the many agencies and organizations that conduct or benefit from environmental monitoring efforts in the Lake Michigan basin. The Council provides a forum for identifying gaps and establishing monitoring priorities; exchanging information; and forming partnerships. The Council will also work in cooperation with the LaMP to develop and periodically update a monitoring plan for the Lake Michigan basin. This approach will result in cost-saving efficiencies for all involved and will provide data needed to determine a current status of the lake ecosystem (< http://www.wi.water.usgs.gov/lmmcc/links.html >).

The LaMP 2000 (http://www.epa.gov/grtlaksk/lakemich/) is primarily concerned with 10 designated "Areas of Concern" in the Lake Michigan basin. None of these areas is close to the national lakeshore. However, based on past experience and noting the example of a broad-based coalition of local organizations that promotes the preservation of environmental quality in Grand Traverse Bay area, the Lake Michigan Forum introduced a concept of self-designation, Areas of Stewardship. This designation would help target agency technical assistance to those watersheds in the basin in which local partnerships are engaged in developing visions, identifying environmental concerns, setting priorities, and designing and implementing comprehensive plans for sustainable landscapes. This program would focus planning efforts on watersheds, thus crossing political boundaries.

The LaMP outlines 15 general recommendations with specific action examples. These recommendations and actions are part of the overall strategic plan for Lake Michigan that is included in the LaMP. Of particular interest to the national lakeshore is the 'Measure and Report' recommendation. This recommendation calls for continued development of a monitoring plan for Lake Michigan that includes expanding the U.S. Geological Survey National Water Quality Assessment (NAWQA) Program monitoring to Michigan's eastern shore and drainage. In addition 'the Stewardship Actions' recommendation calls for strengthening partnerships with other education and outreach efforts to promote the activities necessary to accomplish the following: 1) place special emphasis on preventing the spread of aquatic nuisance species by boat owners; 2) communicate the importance of private efforts in habitat preservation on both public and privately owned land; and 3) develop an Areas of Stewardship program for local communities and watersheds.

Based on the above discussion, the following recommendations are suggested:

- Development of a water quality monitoring plan for the national lakeshore should look to the LaMP for guidance, especially on ecosystem indicators. The importance of water resource issues and information gaps for the national lakeshore is borne out in the list of proposed indicators in the LaMP.
- Similarly, the development of the lakeshore's water quality monitoring plan should take into account the water quality monitoring plan for Lake Michigan, thereby increasing sampling efficiencies and reducing duplicative efforts. In particular the national lakeshore should consider NAWQA methods and protocols in the development of its water quality monitoring plan.
- The NPS should be represented on the Lake Michigan Monitoring Coordinating Council as an avenue to NPS involvement in the lake-wide management planning process and program structure.
- The national lakeshore should work with the Platte River Watershed Project and local agencies, communities and groups in forming a Platte River Area of Stewardship. The Project has recently developed a comprehensive watershed management plan (Benzie Conservation District 2002) which will aid in the formation of the Platte River as an Area of Stewardship. This Water Resources Management Plan will be an important addendum to the comprehensive watershed plan.

Participate in Local Land Use Decisions

Most of the important land use decisions made near a protected area involve local elected officials, citizen boards and commissions, and professional planning staffs at the city and county levels, with input from a large number of citizens and other agencies. National Park Service units, overall, have been slow to participate in these planning and decision-making activities in spite of the profound effects that external land use changes are having on their ability to achieve both cultural and natural resource management objectives. With regard to streams and their watersheds, park units whose land does not include the headwater areas are either the conduit or repository of water pollution from upstream sources.

There are a number of ways [listed below after Wallace (1999)] that park staff can legitimately participate in local land use decisions in order to influence the location, extent, type, and spatial patterns of development near Sleeping Bear Dunes National Lakeshore.

- Designate staff to be assigned to work with a variety of local governments, landowners, homeowners' associations, and nonprofit organizations in order to address adjacent land use issues.
- Conduct a GIS-based boundary layer study with the following layers: 1) a base map showing current land use, infrastructure, ownership, and zoning; 2) a theme showing unique ecosystem components that extend beyond

boundaries (e.g. streams and riparian habitats); and, 3) a theme depicting current and potential development activity as indicated by projects under review, ownership characteristics, available infrastructure, quantity of land for sale, and volume of land recently sold.

- A powerful exercise is to model what build-out (the subdivision and development of all adjacent land) on adjacent lands will look like. This can be accomplished by superimposing the infrastructure, development, and use patterns used by built-out developments with similar zoning on top of existing land uses that are not yet built-out.
- Participate in the development or revision of the comprehensive (master) plans for counties and cities adjacent to the park.
- Participate in the development or revision of the land use code for the counties and cities adjacent to the park.
- Propose the creation of an overlay zone near the park. (An overlay zone is a special zone placed over an existing zoning district, part of a district, or a combination of districts. Put another way, the overlay zone includes a set of regulations that is applied to property within the overlay zone in addition to the requirements of the underlying or base zoning district.)
- Participate in the review of development proposals that could affect management objectives.
- Collaborate with local open space programs and efforts to protect agricultural lands.
- Develop a memorandum of understanding with counties and cities that codifies mutual concerns and how to initiate actions such as those above.
- Use these opportunities to be an advocate of land and community health.

LITERATURE CITED

Albert, D. 1992. A survey of lakes, streams, and wetlands of the Sleeping Bear Dunes National Lakeshore. Michigan Natural Features Inventory, Michigan Department of Natural Resources, Lansing, MI.

Albright, J. 2002. Preliminary characterization of hydrology data for Glen Lake and the Crystal River at Sleeping Bear Dunes National Lakeshore, Leelanau County, Michigan. Unpublished Report, National Park Service, Water Resources Division, Fort Collins, Co.

Allen, J. 1995. Stream ecology, structure and function of running waters. Chapman and Hall, New York, NY.

Allen, J. and A. Flecker. 1993. Biodiversity conservation in running waters: identifying the major factors that threaten destruction of riverine species and ecosystems. Bioscience 43(1):32-43.

Bailey, R. and G. Smith.1981. Origin and geography of the fish fauna of the Laurentian Great Lakes. Can. J. Fish. Aqua. Sci. 38:1539-1561.

Barbour, M., J. Stribling, and J. Karr. 1995. Multimetric approach for establishing biocriteria and measuring biological condition. Pages 63-77 *in* W. Davis and T. Simon, eds. Biological assessment and criteria: tools for water resource planning and decision making. Lewis Publishers, Boca Raton, FL.

Benzie Conservation District. 2002. Platte River watershed management plan. Beulah, MI.

Beeson, C. and P. Doyle. 1995. Comparison of bank erosion and vegetated and nonvegetated channel bends. Water Res. Bull. 31:983-990.

Boyle, T. and N. Hoefs. 1993a. Water resources inventory of Sleeping Bear Dunes National Lakeshore. Sleeping Bear Dunes National Lakeshore, Empire, MI.

Boyle, T. and N. Hoefs. 1993b. Manual for monitoring lakes and streams of Sleeping Bear Dunes National Lakeshore. Empire, MI.

Brown, C. and J. Funk 1940. Fisheries survey of Big Platte Lake and Round Lake with some observations on the lower Platter River, Benzie County, Michigan. Michigan Dept. of Conservation, Institute for Fisheries Research Report No. 631. Lansing, MI.

Calver, J. 1946. The glacial and post-glacial history of the Platte and Crystal lake depressions, Benzie County, MI. Michigan Geological Survey, Pub. No. 45, pt. II.

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

Carpenter, S., J. Kitchell, and J. Hodgson. 1985. Trophic cascade and biomanipulations: interface of research and productivity. BioScience 35:634-639.

Carpenter, S. and K. Cottingham. 1997. Resilience and restoration of lakes. Conservation Ecology [on line] 1(1):2. Available at: < http://www.consecol.org/vol1/iss1/art2 >.

Carter, R. and J. Davidian. 1968. General procedures for gaging streams. Chapter A6 *in* Techniques of water-resources investigations of the U.S. Geological Survey. U.S.Geological Survey, Washington, D.C.

Christie, W.1974. Changes in the fish species composition of the Great Lakes. J. Fish. Res. Bd. Canada 31:827-854.

Cornett, R. and F. Rigler. 1979. Hypolimnetic oxygen deficits: their prediction and interpretation. Science 205:580-581.

Cottingham, K. 1996. Phytoplankton reponses to whole-lake manipulations of nutrients and food webs. Ph.D. dissertation. U. of Wisconsin, Madison, WI.

Coulter, S. 1904. An ecological comparison of some typical swamp areas. Miss. Bot. Gard. Ann. Rept. 15:38-71.

Cowardin, L., V. Carter, F. Golet, and E. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service. FWS/OBS 79/31. Washington, D.C.

Cummings, K. and C. Mayer. 1992. Field guide to freshwater mussels of the Midwest. Illinois Natural History Survey Manual No. 5.

Cummings , T. 1980. Chemical and physical characteristics of natural ground water in Michigan – a preliminary report. U.S. Geological Survey Open-File Report 80-953.

Curry, K. 1977. Species structure of midge communities in Crystal River Drainage basin, Leelanau County, Michigan 1972. M.S. thesis, Central Michigan University, Mt. Pleasant, MI.

Davis, M., C. Douglas, R. Calcote, K. Cole, M. Winkler, and R. Flakne. 2000. Holocene climate in the western Great Lakes national parks and lakeshores: implications for future climate change. Conservation Biol. 14(4):968-983.

Davis, W. and T. Simon. 1995. Biological assessment and criteria: tools for water resource planning and decision making. Lewis Publishers, Boca Raton, FL.

Decamps. H. 1993. River margins and environmental change. Ecol. Appl. 3:441-445.

Delta Institute. 2000. Atmospheric deposition of toxics to the Great Lakes. Delta Institute, Chicago, IL.

D'Eon, R. and many others. 1995. The beaver handbook: a guide to understanding and coping with beaver activity. Northeast Science and Technology.

Deshon, J. 1995. Development and application of the invertebrate community index (ICI). Pages 217-243 *in* W. Davis and T. Simon, eds. Biological assessment and criteria: tools for water resource planning and decision making. Lewis Publishers, Boca Raton, FL.

Doppelt, B. M. Scurlock, C. Frissell, and J. Karr. 1993. Entering the watershed, a new approach to save America's river ecosystems. Island Press, Washington, D.C.

Drexler, C. 1974. Geologic report on Sleeping Bear Dunes National Lakeshore. *In* Natural History Report for Sleeping Bear Dunes National Lakeshore by U. of Michigan. Sleeping Bear Dunes National Lakeshore, Empire, MI.

Driscoll, C., C. Yan, C. Schofield, R. Munson, and J. Holsapple. 1994. The mercury cycle in fish in Adirondack lakes. Environ. Sci. Tech. 28:137-143.

Edsall, T., E. Mills, and J. Leach.1995. Exotic species in the Great Lakes. Pages 442-444 *in* E. LaRoe, G. Farris, C. Puckett, P. Doran, and M. Mac, eds. Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. U.S. Department of Interior, National Biological Service, Washington, D.C.

Edsall, T. and M. Charlton. 1996. Nearshore waters of the Great Lakes. State of the Lakes Ecosystem Conference 1996, Working Paper. United States Environmental Protection Agency, EPA 905-D-96-001b, Chicago, IL.

Environmental Resources Management. 1985. Platte River corridor study. Sleeping Bear Dunes National Lakeshore, Empire, MI.

Enviroscience. 1995. Phase 1 Environmental Site Assessment Tucker Lake Dump, Glen Arbor Township, Michigan. Sleeping Bear Dunes National Lakeshore, Empire, MI.

Enviroscience. 1996. Phase 2 Environmental Site Assessment Tucker Lake

Dump, Glen Arbor Township, Michigan. Sleeping Bear Dunes National Lakeshore, Empire, MI.

Fausch, K. J. Karr, and P. Yant. 1984. Regional application of an index of biotic integrity based on stream fish communities. Trans. Am. Fish. Soc. 113:39-55.

Fausch, K. J. Lyons, J. Karr, and P. Angermeir. 1990. Fish communities as indicators of environmental degradation. Am. Fish. Soc. Symposium 8:123-144.

Flint, R. 1957. Glacial and Pleistocene geology. John Wiley and Sons, Inc., New York, NY.

Flower, H. and B. Walker. 1999. Crystal River Biosurvey, September 1998, Leelanau County. Interoffice Communication dated May 27, 1999 to Mike Stifler, Michigan Department of Environmental Quality, Cadillac District Office, Surface Water Quality Division.

Fore, L., J. Karr, and R. Wisseman. 1996. Assessing invertebrate responses to human activities: evaluating alternative approaches. J. North. Am. Benthological Soc. 15:212-231.

Frost, T. S. Carpenter, A. Ives, and T. Kratz. 1995. Species compensation and complementarity in ecosystem function. Pages 224-239 *in* C. Jones and J. Lawton, eds. Linking species and ecosystems. Chapman and Hall, London, England.

Gannon, J. and J. Stockwell. 1978. Limnological investigations of Florence Lake, South Manitou Island, Michigan. U. of Michigan Biological Station, Tech. Rept. No. 5, Pellston, MI.

Granneman, N., R. Hunt, J. Nicholas, T. Reilly and T. Winter. 2000. The importance of ground water in the Great Lakes Region. U.S. Geological Survey, Water Resources Investigations Report 00-4008, Lansing, MI.

Grant , J. 1979. Water quality and phosphorus loading analysis of Platter Lake 1970-1978. Water Quality Division, Michigan Dept. of Natural Res. Pub. No. 4833-9792. Lansing, MI.

Great Lakes Commission.1999. Living with the lakes. Available at: > http://www.glc.org >.

Hammerson, G. 1994. Beaver: ecosystem alterations, management, and monitoring. Natural Areas J. 14(1):44-57.

Handy, A. and J. Stark. 1984. Water Resources of Sleeping Bear Dunes National Lakeshore, Michigan. U.S. Geological Survey, Water-Resources Investigations Report 83-4253, Lansing, MI.

Hazlett, B. 1986. The terrestrial vegetation and flora of the mainland portion of Sleeping Bear Dunes National Lakeshore, Benzie and Leelanau counties, Michigan. University of Michigan Biologial Station Tech. Rept. No. 11, Douglas Lake, MI.

Hazlett, B. 1991. Flora of Sleeping Bear. The Michigan Botanist 30(4):139-202.

Hazlett, B. 1988. The aquatic vegetation and flora of Sleeping Bear Dunes National Lakeshore, Benzie and Leelanau counties, Michigan. University of Michigan Biological Station, Tech. Rept. No. 15, Douglas Lake, MI.

Heck, K. and L. Crowder. 1991. Habitat structure and predator-prey interactions in vegetated aquatic systems. Pages 281-299 *in* S. Ball, E. McCoy, and H. Mushinsky, eds. Habitat structure: the physical arrangement of objects in space. Chapman and Hall, London, England.

Heuschele, A. 1999. Invertebrate fauna of Aral Springs. Sleeping Bear Dunes National Lakeshore, Empire, MI.

Heuschele, A. 2000. Sponges of Sleeping Bear Dunes National Lakeshore. Empire, MI.

Hildebrand, S. 1971. The effects of coho spawning on the benthic invertebrates of the Platte River, Benzie County, Michigan. Trans. Amer. Fish. Soc. 100:61-68.

Hillery, B., M. Simick, I. Basu, R. Hoff, W. Strachan, D. Burinston, C. Chan, K. Brice, C. Sweet, and R. Hites. 1998. Atmospheric deposition of toxic pollutants to the Great Lakes as measured by the Integrated Atmospheric Deposition Network. Environ. Sci. Tech. 32:2216-2221.

Holtschlag, D. and J. Nicholas. 1998. Indirect ground-water discharge to the Great Lakes. U.S. Geological Survey, Open-File Report 98-579.

Hough, J. 1958. Geology of the Great Lakes. Univ. of Illinois Press, Urbana.

Hynes, H. 1970. The ecology of running waters. Univ. of Toronto Press, Toronto, Canada.

Irwin, R. 2001(draft). Vital signs long-term aquatic monitoring: Part B – A detailed study plan that includes a quality assurance project plan (QAPP) and monitoring protocols (standard operating procedures). Available at: < http://www.nature.nps.gov/im/monitor/rirwinwq.doc >.

Jude, D., J. Janssen, and G. Crawford. 1995. Ecology, distribution, and impact of the newly introduced round and tubenose gobies on the biota of the Saint Clair and Detroit rivers. Pages 447-460 *in* M. Munawar, T. Edsall, and J. Leach, eds. The Lake Huron ecosystem: ecology, fisheries, and management. Ecovision World Monograph Series, S.P.B. Academic Publishing, The Netherlands.

Karamanski , T. 2000. A nationalized lakeshore: the creation and administration of Sleeping Bear Dunes National Lakeshore. Available at: < http://www.cr.nps.gov/history/online_books/slbe/adhi_3f.htm >.

Karr, J. 1981. Assessment of biotic integrity using fish communities. Fisheries 6:21-27.

Karr, J. 1990. Biological integrity and the goal of environmental legislation: lessons from conservation biology. Conservation Biology 4:244-250.

Karr, J. 1991. Biological integrity: a long-neglected aspect of water resource management. Ecol. Appl. 1:66-84.

Karr, J. 1992. Measuring biological integrity: lessons from streams. Pages 83-104 *In* P. Schulze, editor. Engineering within ecological constraints. National Academy Press, Washington, D.C.

Karr, J., K. Fausch, P. Angermeir, P. Yant, and I. Schlosser. 1986. Assessment of biological integrity in running water: a method and its rationale. Special Publ. No. 5, Illinois Natural History Survey, Champaign, IL.

Keeler. G. 1994. Project summary: Lake Michigan air toxics study. EPA/SR-94/191, U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC.

Kelly, T. and B. Price. 1979. Fishes of the Sleeping Bear Dunes National Lakeshore. Sleeping Bear Dunes National Lakeshore, Empire, MI.

Kenaga, D. and E. Evans.1982. The effect of the Platte River Anadromous Fish Hatchery on fish , benthic macroinvertebrates and nutrients in Platte Lake. Water Quality Division, Michigan Dept. of Natural Resources. Unpublished Rept., Lansing, MI.

Kennedy, E. 1984. Discharge ratings at gaging stations. Chapter A10 *in* Techniques of water-resources investigations of the U.S. Geological Survey, Book 3. U.S. Geological Survey, Washington, D.C.

Kerans, B. and J. Karr. 1994. A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. Ecol. Appl. 4:768-785.

Kratzer, C. and P. Brezonik. 1981. A Carlson type trophic state index for nitrogen in Florida lakes. Water Res. Bull. 17:713-715.

Kwon, H. 2000. The return of the beaver. Available at:< http://www.pipelilne.com/~mrrunoff/beaver.html >.

Last, L., R. Whitman, and P. Gerovac. 1995. Limnological variation of selected lakes of Sleeping Bear Dunes National Lakeshore, Michigan. Presented at the 1995 Michigan Academy of Science, Arts and Letters annual meeting. U. S. Geological Survey, Lake Michigan Ecological Station, Porter, IN.

Last, L. and R. Whitman. 1996. Maintaining a water quality monitoring program at Sleeping Bear Dunes. Park Science 16 (3):19-21.

Lee, D., C. Gilbert, C. Hocutt, R. Jenkins, D. McAllister, and J. Stauffer, Jr. 1980 *et seq*. Atlas of North American freshwater fishes. N.C. State Mus. Nat. His., Raleigh, NC.

Linton, M. 1987. Analysis of habitat for invertebrates in the stream systems of Sleeping Bear Dunes National Lakeshore. Sleeping Bear Dunes National Lakeshore, Empire, MI.

Livermore, B.1992. Amphibian alarm: just where have all the frogs gone? Smithsonian Magazine 1992(10):113-120.

Lodge, D. 1993. Biological invasions: lessons for ecology. Trends in Ecology and Evolution 8:133-137.

Lowe, R. 2000. Investigations into blooms of *Cladophora glomerata* in Platte Bay, Michigan and the waters of Sleeping Bear Dunes National Lakeshore. Empire, MI.

Lyons, J., S. Navarro-Perez, P. Cochran, E. Santana-C., and M. Guzman-Arroyo. 1995. Index of biotic integrity based on fish assemblages for the conservation of streams and rivers in west central Mexico. Conserv. Biol. 9:569-594.

Macdonald, L., A. Smart, and R. Wissmar. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. EPA 910/9-91-001. U. S. Environmental Protection Agency, Seattle, WA.

Magnuson, J. and eleven others. 1997. Potential effects of climate changes on aquatic systems: Laurentian Great Lakes and Precambrian Shield region. Hydrological Processes 11:825-871.

Malanson, G. 1993. Riparian landscapes. Cambridge Univ. Press, Cambridge, UK.

Maret, J., M. Parker, and T. Fanny. 1987. The effect of beaver ponds on the nonpoint source quality of a stream in southwestern Wyoming. Water Res. 21:263-268.

Maser, C. and J. Sedell. 1994. From the forest to the sea: the ecology of wood instreams, rivers, estuaries, and oceans. St. Lucie Press, Delray Beach, FL.

McDiarmid, R. 1994. Ampibian diversity and natural history: an overview. *In* W. Heyer, M. Donnelly, R. McDiarmid, L. Hayek and M. Foster, eds. Measuring and monitoring biological diversity: standard methods for amphibians. Smithsonian Institution Press, Washington, D.C.

Medin, D. and W. Cleary. 1990. Bird populations in and adjacent to a beaver pond ecosystem and adjacent riparian habitat in Idaho. Intermountain Forest and Range Experiment Station. U.S. Dept. of Agriculture, Ogden, UT.

Meyer, J., M. Sale, PI Mulholland, and N. LeRoy Poff. 1999. Impacts of climate change on aquatic ecosystem functioning health. J. Am. Water Resources Assoc. 35:1373-1386.

Michigan Cooperative Lakes Monitoring Program. 1999. Annual summary report, 1999. Michigan's Citizen Volunteer Lakes Monitoring Program. Michigan Department of Environmental Quality, Lansing, MI.

Michigan Department of Environmental Quality. 2002. Michigan's 305(b) water quality report. Lansing, MI.

Michigan Department of Natural Resources. 1983. Clean Lakes Program Platte Lake Benzie County, Michigan. Phase I Final Report. Lansing, MI.

Michigan Department of Natural Resources, 1991, Great Lakes and Environmental Assessment Section (GLEAS) procedure 51, revised June 1991 - Qualitative biological and habitat survey protocols for wadable streams and rivers: Surface Water Quality Division, Lansing, MI.

Michigan Natural Features Inventory. ND. Wooded dune and swale complex. Community Abstract, Michigan Natural Features Inventory, Lansing, MI.

Miller, D. and seventeen others. 1988. Regional applications of an index of biotic integrity for use in water resource management. Fisheries 13:12-20.

Mills, E., J. Leach, J. Carlton, and C. Secor. 1993. Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. J. Great Lakes Res. 19:1-54.

Montgomery, D., J. Buffington, and G. Pess. 1995. Pool spacing in forest channels. Wat. Res. Research 31:1097-1105.

Muller-Schwarze. D. 1979. Final report on a study of the behavioral and population ecology of the Canadian beaver at Acadia National Park. National Park Service Cooperative Res. Unit, State U. of New York, College of Environmental Science and Forestry, Syracuse, NY. Contract CX-1600-7-0030.

Naiman, R., H. Decamps, and M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecol. Appl. 3:209-212.

Naiman, R. J. Magnuson, D. McKnight, and J. Stanford. 1995. The freshwater imperative. Island Press, Washington, D.C.

Naiman, R. and H. Decamps. 1997. The ecology of interfaces: riparian zones. Ann. Rev. Ecol. Syst. 28:621-658.

National Park Service. 1961. A proposed Sleeping Bear National Lakeshore, natural history report. National Park Service, Washington, D.C.

National Park Service. 1979. Resource information base, Sleeping Bear Dunes National Lakeshore. National Park Service, Denver Service Center, Denver, CO.

National Park Service. 1997. Baseline water quality data inventory and analysis for Sleeping Bear Dunes National Lakeshore, Vols. I and II. Water Resources Division, National Park Service, Tech. Rept. NPS/NRWRD/NRTR-97/106, Fort Collins, CO.

National Park Service. 1999. Reference Manual to Director's Order 83 – Public Health. National Park Service, Washington, D.C. Appendix D (Bathing Beaches).

National Park Service. 2001. Preliminary draft – General Management Plan for Sleeping Bear Dunes National Lakeshore. Empire, MI.

National Research Council 1992. Restoration of aquatic ecosystems. National Academy Press, Washington, D.C.

National Resources Conservation Service. 1996. Final report for soil digitatization of Sleeping Bear Dunes National Lakeshore. On file at Sleeping Bear Dunes National Lakeshore, Empire, MI.

Nichols, S. 2000. Inventory and status of unionid mussel populations in five midwestern national parks: potential refugia for native unionid mussels. Sleeping Bear Dunes National Lakeshore, Empire, MI.

Offenberg, J. and J. Baker. 1997. Polychlorinated biphenyls in Chicago precipitation: enhanced wet deposition of nearshore Lake Michigan. Environ. Sci. Tech. 31:1534-1538.

Ohio Environmental Protection Agency. 1988. Biological criteria for the protection of aquatic life, volumes 1-3. Ecological Assessment Section, Division of Water Quality Monitoring and Assessment, Columbus, OH.

Olson, R. and W. Hubert. 1994. Beaver: water resources and riparian habitat management. U. of Wyoming, Laramie, WY.

Omernik, J. and A. Gallant. 1988. Ecoregions of the upper Midwest states. Map (scale 1:2,500,000) EPA/600/3-88/037. U.S. Environmental Protection Agency, Corvallis, OR.

Osborne, L. and D. Kovacic. 1993. Riparian vegetated buffer strips in water quality restoration and stream management. Freshwater Biology 29:243-258.

Pearson, R., D. Swackhamer, S. Eisenreich, and D. Long. 1997. Concentrations, accumulations, and inventories of toxaphene in sediments in the Great Lakes. Environ. Sci. Tech. 32:1629-1635.

Pflakin, J., M. Barbour, K. Porter, S. Gross, and R. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish. EPA/440/4-89-001. U.S. Environmental Protection Agency, Washington, D.C.

Pirrone, N., I. Allegrini, G. Keeler, J. Nriagu, R. Rossman, and J. Robbins. 1998. Historical atomospheric mercury emissions and depositions in North America compared to mercury accumulations in sedimentary records. Atmospheric Env. 32:929-940.

Platts, W. 1981. Influence of forest and rangeland management on anadromous fish habitat in western North America: effects of livestock grazing. U.S. Forest Service, General Technical Report No. PNW-124.

Poff, N. 1996. A hydrogeography of unregulated streams in the United States and an examination of scale-dependence in some hydrological descriptors. Freshwater Biology 36:71-91.

Postel, S. and S. Carpenter. 1997. Freshwater ecosystem services. Pages 195-214 *in* G.Daily, ed. Nature's services. Island Press, Washington, D.C.

Pranger, H. 2002. Platte River Waterwheel Site Restoration at Sleeping Bear Dunes National Lakeshore. Draft trip report (February 28, 2002) submitted to the Superintendent, Sleeping Bear Dunes National Lakeshore, Empire, MI.

Rygwelski, K., W. Richardson, and D. Endicott. 1999. A screening-level model evaluation of atrazine in the Lake Michigan basin. J. Great Lakes Res. 25:94-106.

Sanders, R., R. Ward, J. Loftis, T. Steele, D. Adrian, and V. Yevjevich. 1987. Design of networks for monitoring water quality. Water Resources Publications, Littleton, CO.

Schindler, D. 1987. Determining ecosystem responses to anthropogenic stress. Can. J. Fish. Aquat. Sci. 44 (Suppl. 1):6-25.

Schindler, D. 1990. Experimental perturbations of whole lakes as tests of hypotheses concerning ecosystem structure and function. Oikos 57:25-41.

Schindler, D., P. Curtis, B. Parker, and M. Stainton.1996. Consequences of climate warming and lake acidification for UV-B penetration in North American boreal lakes. Nature 379:705-708.

Schindler, D. 1997. Widespread effects of climate change on freshwater ecosystems in North America. Hydrological Processes 11:1043-1067.

Shelby, B., T. Brown, and J. Taylor. 1992. Streamflow and recreation. USDA Forest Service, General Tech. Rept. RM-209. Rocky Mountain Forest and Range Experiment Station. Fort Collins, CO.

Simick , M., H. Zhang, S. Eisenreich, and T. Franz. 1997. Urban contamination of the Chicago/coastal Lake Michigan atmosphere by PCBs and PAHs during AEOLOS. Environ. Sci. Tech. 31:2141-2147.

Skovlin, P. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. *In* Developing strategies for rangeland management, National Research Council/National Academy of Sciences, Washington, D.C.

Smith, B. et a. 1991. Modification of stream ecosystem structure and function by beaver. Canadian J. Zool. 69:55-61.

Stockwell, J. and J. Gannon. 1975. Water quality studies in the Sleeping Bear Dunes National Lakeshore region: the lower Platte River System, Michigan. U. of Michigan Biological Station, Pellston, MI.

Stow, C., S. Carpenter, C. Madenjian, L. Eby, and L. Jackson. 1995. Fisheries management to reduce contaminant consumption. BioScience 46:552-758.

Taube, C. 1974. A descriptive and historical account of the Platte River, its surrounding area, and its salmonid fishes. Mich. Dept. Nat. Res., Fisheries Division, Research Rept. No. 1809. Ann Arbor, MI.

Thompson, P. 1967. Vegetation and common plants of Sleeping Bear. Cranbrook Inst. Sci. Bul. 52.

U.S. Environmental Protection Agency and Government of Canada. 1995. The Great Lakes, An Environmental Atlas and Resource Book. Great lakes National Program Office, U.S. Environmental Protection Agency, Chicago, IL.

U.S. Environmental Protection Agency. 1996. Summary of state biological assessment programs for streams and rivers. EPA230-R-96-007. Office of Policy, Planning and Evaluation, U.S. Environmental Protection Agency, Washington, D.C.

U.S. Environmental Protection Agency. 2000. Lake Michigan Lakewide Management Plan. U.S. Environmental Protection Agency, Chicago, IL.

U.S. Geological Survey.1999. Effects of global climate change on Great Lakes wetlands, 1999-2003, primary contact Douglas Wilcox. Available at: < http://www.nrel.colostate.edu/brd_global_change/proj_31_great_lakes.html >.

U.S. Geological Survey. 2000. Ground water atlas of the United States, Iowa, Michigan, Minnesota, Wisconsin HA 730-J. Available at: < http://capp.water.usgs.gov/gwa/ch_j/J-text1.html >.

Wake, M.1991. Declining amphibian populations. Science 253:860.

Wallace, G. 1999. Influencing land use decisions on lands adjacent to your park or protected area: a planning commissioner's point of view. Pages 446-451 *in* D. Herman, ed., On the Frontiers of Conservation: Proceedings of the 10th Conference on Research and Resource Management in Parks and Public Lands. The George Wright Society, Hancock, MI.

Wallbom, T. ;and G. Larson. 1998. Surficial geology of the Glen Haven, Glen Arbor, Good Harbor Bay, Empire, Burdickville, and Beulah 7.5 minute quads, Leelanau and Benzie counties, Michigan. Michigan State University, Lansing, MI.

Ward, J. 1989. Riverine-wetland interactions. Pages 385-400 *in* Freshwater wetlands and wildlife, R. Shartiz and J. Gibbons, eds. U.S. Department of Energy, Oak Ridge, TN.

Waterman, W. 1922. Development of plant communities of a sand ridge region in Michigan. Bot. Gaz. 74:1-31.

Wetzel. R. 1975. Limnology. W.B. Saunders Co., Philadelphia, PN.

Wetzel, R. 1990. Land-water interfaces: metabolic and limnological regulators. Internationale Vereinigung fur Theroetishche und Angewandte Limnology 24:6-24.

Wetzel. R.1992. Gradient-dominated ecosystems: sources and regulatory functions of dissolved organic matter in freshwater ecosystems. Hydrobiologia 229:181-189.

White, D. 1987. Analysis of the limnology of four streams (Platte River, Crystal River, Shalda Creek, Otter Creek) in the Sleeping Bear Dunes National Lakeshore based on macroinvertebrate fauna. Sleeping Bear Dunes National Lakeshore, Empire, MI.

Whitman, R. 1997. Letter to Superintendent, Sleeping Bear Dunes National Lakeshore, November 24, 1997 from Station Chief, Lake Michigan Ecological Research Station, Porter, IN.

Whitman, R. 2000. Inspect, assess and monitor inland lakes of Great Lakes Cluster parks. Sleeping Bear Dunes National Lakeshore, Empire, MI.

Whitman, R., B. Davis, and M. Goodrich. 2002. Study of the application of limnetic zooplankton as a bioassessment tool for lakes of Sleeping Bear Dunes National Lakeshore. U.S. Geological Survey, Lake Michigan Ecological Research Station, Porter, IN. Report on file at Sleeping Bear Dunes National Lakeshore, Empire, MI.

Yoder, C. and E. Rankin. 1995. Biological response signatures and the area of degradation value: new tools for interpreting multimetric data. Pages 263-286 *in* W. Davis and T. Simon, eds. Biological assessment and criteria: tools for water resource planning and decision making. Lewis Publishers, Boca Raton, FL.

APPENDIX

PROJECT STATEMENT SLBE-N-002.006

TITLE : WETLAND INVENTORY, CHARACTERIZATION AND MAPPING of SLEEPING BEAR DUNES NATIONAL LAKESHORE

Funding Status: Funded: 38.00 Unfunded: 72.20

PROBLEM STATEMENT

Sleeping Bear Dunes National Lakeshore (SLBE) is largely known for its lakeshore and for the perched dunes that provide grand vistas of Lake Michigan and the adjacent North and South Manitou Islands. Interdunal wetlands, called "pannes," are integral features of many of the park's dune complexes, adding significant biotic diversity to these defining park resources. Other important wetland resources include extensive lacustrine and riparian wetlands, sphagnum, shrub, and black spruce bogs, white cedar swamps, sedge meadows, and marshes. The characteristic hydrology, water chemistry, landscape position, and soils of each of these wetland types contribute strongly to the variety of vegetation communities and habitats in the park, including habitats for the federally threatened Michigan Monkey-flower (*Mimulus glabratus* var. *michiganensis*) and the state-listed *Mimulus glabratus* var. *jamesii* (state special concern), *Berula erecta* (state threatened), and *Potamogeton hillii* (state threatened) (Albert, 1992). However, despite initial inventory efforts, very little is known about the locations, characteristics, and conditions of the park's wetland resources except for those associated with the larger lakes and streams.

Thompson (1967) and Hazlett (1988; 1991) both developed aquatic plant lists for the park. Hazlett conducted a more complete survey, but a number of species that are common in some park wetlands were missed (Albert 1992; Pavlovic pers. obs.). Hazlett recommended that more quantitative vegetation and phytosociological sampling be conducted in the future. Albert (1992) assessed the vegetation of the corrugated embayments of the park and added several aquatic species to the park list. His data have not been analyzed quantitatively, however. Least studied are interdunal pannes and forested seeps.

Basic wetland inventory information prepared by the U.S. Fish and Wildlife Service's National Wetlands Inventory (NWI) program is available for SLBE, but these maps vary considerably in quality and resolution. The Good Harbor Bay, Burdickville, and Glen Arbor 7.5-minute USGS quadrangles were mapped at the NWI's current standard (based on 1981 1:58,000-scale color infrared photography and plotted on 1:24,000 scale USGS quad maps). Though they meet current NWI minimum standards, these maps are based on high altitude photography with minimal ground-truthing (typically not more than one wetland visited per quadrangle), and tend to omit smaller (< 1 acre) wetlands and wetlands with forest cover (significant in SLBE). Most classification errors are probably related to misclassification of water regimes or rather gross lumping of habitat types due to small scales. The age of the photos could also mean that subsequent fire, drainage, beaver activity, plant growth and succession (including invasion by exotic or nuisance species) or other factors further limit the accuracy of these maps.

NWI maps for the rest of the park, including North and South Manitou Islands and the wetland-rich area from Sleeping Bear Point to the southern park boundary, were developed using sub-standard 1975 1:80,000 scale black-and-white photography and are overlain on 1:62,500 scale USGS topographic maps. These maps undoubtedly contain significant errors of omission and classification due to the serious limitations imposed by use of dated, very high altitude black-and-white photography and minimal ground-truthing (minimum mapping unit is approximately 3 acres). The resulting product tends to generalize the park's diverse wetland resources due to lumping of various classes at this scale. In particular, wetlands within the dune and swale of corrugated plains, including nearshore pannes, remain poorly mapped and largely undescribed. These under-represented types include plains at Platte Bay, Good Harbor Bay, Glen Arbor, Boekeloo Road, and embayments on North and South Manitou Islands.

An additional problem with the existing NWI maps is the lack of information on plant species associations, substrates (e.g., organic vs. mineral soil), and other factors. For example, two wetlands may be classified identically on the maps as "palustrine emergent semi-permanently flooded wetland;" however, without a site visit, park staff may not know that one is a diverse habitat harboring rare species and the other is a near monoculture of cattails.

Acquisition of enhanced wetland inventory and characterization data is an important asset in management and protection of the park's wetland resources. For example:

1. Invasion of exotic or other highly undesirable plant species such as purple loosestrife (*Lythrum salicaria*) or common reed (*Phragmites australis*) can be documented during an enhanced wetland survey. Invasions of such species in interdunal ponds and other wetland habitats appear to be in the early (and therefore controllable) stages at Sleeping Bear Dunes National Lakeshore with the possible exception of common reed invasions. It is of critical importance that exotic plant "hotspots" not become massive (and perhaps irreversible) invasions, which could result in substantial loss of important wetland habitat as has occurred in comparable areas of Indiana Dunes National Lakeshore. An enhanced inventory would help direct very limited resource management money and time toward those "hotspot" locations where control efforts would be most effective.

2. The riverine, lacustrine and nearshore interdunal wetlands of Sleeping Bear are the focus of much recreational activity by boaters, canoeists, rafters and hikers. As recreation pressure increases with suburban development in the Traverse City region, the necessity for high resolution

mapping and quantitative characterization of the wetlands (including identification of rare and threatened species) of the national lakeshore is increasing. Such studies can help park staff manage visitor use and can establish a baseline of vegetation composition against which to evaluate future recreation impacts.

3. Park staff cannot protect important national lakeshore wetland resources from other (i.e., non-recreational) impacts unless data from this project are readily available. For instance, proposals for shallow groundwater pumping or road construction can not be fully evaluated and mitigated unless the potentially affected wetland resources have been identified and characterized. (A recent proposal to pump groundwater for a relocated salmon egg-take station along the Platte River raised concerns that the resulting water table draw down could impact wetlands. Yet the park does not have adequate inventory and characterization information on wetlands to respond to this potential threat in a timely and effective manner.)

4. An enhanced inventory that locates and characterizes wetland habitats would focus other park research, resource management, and interpretation efforts. For example, the search for a rare plant or animal species for study or special protection, or identification of habitats that the park would like to include in its interpretation programs, could use this inventory as a guide.

DESCRIPTION OF RECOMMENDED PROJECT OR ACTIVITY

The proposed project is an enhanced inventory and characterization of the wetlands at Sleeping Bear Dunes National Lakeshore. This will be conducted in three stages:

- Wetlands will be inventoried, classified and mapped on 1:24,000 scale USGS topographic quadrangles within and adjacent to the national lakeshore. Mapping will be completed using standard NWI photointerpretation and cartographic conventions. Wetlands and deepwater habitats will be identified, classified and mapped using the U.S. Fish and Wildlife Service's Classification of Wetlands and Deepwater Habitats of the U.S. (Cowardin et al. 1979). Color infrared, 1:58,000 scale aerial photography available through the U.S. National High Altitude Aerial Photography Program or equivalent imagery will be the primary data source. All discernable wetlands will be mapped with no minimum size limits. Final, digitally based maps will be produced at 1:24,000 scale.
- A more detailed, enhanced inventory of wetlands will be accomplished through field verification (ground truthing) of the NWI maps and classifications. For each wetland subject to field verification, the dominant plant taxa within each vegetation layer (ground, shrub, and tree) and the wetland status of the dominant plant taxa will be determined, and any existing

and potential threats (e.g., alteration of hydrology, blocked drainages, effluent sources, exotic species) will be documented. Additionally, field crews will systematically collect field data on small wetlands (minimum mapping unit 0.02 ha), wetlands covered by an overstory canopy, and seasonal wetlands, all of which are likely to have been missed by any NWI mapping. Areas with potential to support these small wetlands will be identified using topographic maps, soils maps, NWI maps, and field reconnaissance data. This ground truthing will minimize potential errors of omission of the smallest and most ephemeral wetlands. NWI will then use the additional ground truth to produce an enhanced version of the NWI wetland delineation and classification.

- Quantitatively sample the vegetation of randomly selected plots within randomly or subjectively selected wetlands to develop a compositional vegetation classification that can be cross classified with the Cowardin et al. (1979) wetland classification system. Wetlands will be sampled based on their general type (marsh, pond, lake, etc.) substrate, elevation and physiographic position. Since water depth determines wetland zonation, each wetland will be sampled at two depths, at the least, to characterize within wetland variation. Each plot will be either square or rectangular and will be approximately 400 m^2. Plot shape and size will be modified as needed for small or irregularly shaped wetlands. The long axis of non-square plots will be perpendicular to the slope or parallel to the zonational ecotone. Percent cover of each plant taxon will be documented as both an actual pertcentage and as a cover class. Additional data will be taken concerning the abiotic environment of each plot (e.g. depth of water table, position relative to uplands, slope, exposure, substrate, evidence of disturbance and time since last major disturbance). At each plot, tree and shrub species present in a 5-m radius will be recorded using the relative Daubenmire frequency scale. The information gathered would serve as a baseline against which future analyses could detect change in wetland types.

- To maximize efficiencies in field sampling and cost effectiveness, this wetland inventory project should also include the quantitative sampling of faunal groups in addition to the plant community characterizations. Because of the lack of information on amphibians and reptiles in the national lakeshore, this faunal group should be a top priority for sampling; aquatic macroinvertebrates should also be considered a sampling priority. The budget below does not factor in the sampling of these faunal groups; however, the additional cost to sample these two groups would be approximately $50,000 over the 2 years. Both WRD and the Biological Resources Management Division of the National Park Service could provide technical assistance in factoring in the sampling of these faunal groups to this wetland inventory.

LITERATURE CITED

Albert, D. 1992. A survey of lakes, streams, and wetlands of the Sleeping Bear Dunes National Lakeshore. Michigan Natural Features Inventory, Michigan Department of Natural Resources, Lansing, MI.

Cowardin, L., V. Carter, F. Golet, and E. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service. FWS/OBS 79/31. Washington, D.C.

Hazlett, B. 1991. Flora of Sleeping Bear. The Michigan Botanist 30(4):139-202.

Hazlett, B. 1988. The aquatic vegetation and flora of Sleeping Bear Dunes National Lakeshore, Benzie and Leelanau counties, Michigan. University of Michigan Biological Station, Tech. Rept. No. 15, Douglas Lake, MI.

Thompson, P. 1967. Vegetation and common plants of Sleeping Bear. Cranbrook Inst. Sci. Bull. 52.

BUDGET AND FTES

This will be a 2-year, cost share project in which NWI will pay 50% of the wetland vegetation inventory, map and GIS data production. NPS will pay the remaining 50% of the inventory as well as provide: 1) $16,000/year to fund one GS-07 Biological Technician position for a 6-month period; and 2) $1600/year for vehicle and supply costs. Total cost is $110,200 -- $72,200 from NPS ($36,100/year) and $38,000 ($19,000/year) for U.S. Fish and Wildlife Service National Wetland Inventory. The Water Resources Division is being asked to fund $50,000 – this leaves a shortfall of $22,200. This amount will be funded from additional sources, either internal or external.

PROJECT STATEMENT SLBE-N-002.007

TITLE: REVISE EXISTING WATER QUALITY MONITORING PROGRAM THROUGH THE DEVELOPMENT OF A WATER QUALITY MONITORING PLAN

Funding Status: Funded: 00.00 Unfounded: 35.00

PROBLEM STATEMENT

Sleeping Bear Dunes National Lakeshore, 71,189 acres in size, is located in the northwest part of Michigan's Lower Peninsula in Benzie and Leelanau counties and borders Lake Michigan. Two nearby islands, South Manatee and North Manatee, are in the park.

The park contains 64 miles of Lake Michigan shoreline – 31 on the mainland, 13 miles on South Manatee Island and 20 miles on North Manatee Island. It also contains numerous lakes that are primarily shallow and small, ranging in size from 2 to 248 acres. Streams within the lakeshore include all of Otter Creek, parts of Shall Creek and Crystal River, and 4.5 miles of the Platte River. All streams represent the bottom of their respective watersheds.

Congress established Sleeping Bear Dunes National Lakeshore to preserve outstanding natural features, including forests, beaches, dune formations, and ancient glacial phenomena in their natural setting and protect them from developments and uses that would destroy the scenic beauty and natural character of the area.

Significance statements (National Park Service 2001) describe the lakeshore's distinctiveness and help to place it in its regional and national context:

- The lakeshore contains accessible and compactly grouped features of continental glaciating, including post glacial shoreline adjustment, wind formed dunes and examples of plant succession.
- The lakeshore area is one of the most scenic portions of the Lake Michigan shoreline. Its massive glacial headlands, diverse habitats and superb water resources offer a broad range of recreational and inspirational experiences.
- The lakeshore's historic maritime, recreation and agricultural landscapes are of a size and quality that are unique on the Great Lakes and rare elsewhere on the US coastline.
- The lakeshore includes regionally important native flora and fauna that have declined to either an endangered, threatened or rare status in the Great Lakes ecosystem.

Specific management objectives pertaining to water resources and water-dependent environments within Sleeping Bear Dunes National Lakeshore include:

- Manage waters of the lakeshore and water-dependent environments in a manner designed to maintain the highest degree of biological diversity and ecosystem integrity;
- Assure that park development and operations do not adversely affect the lakeshore's water resources and water-dependent environments;
- Acquire sufficient knowledge about water quality to effectively participate in state and local management planning and seek the highest level of protection under state water quality standards appropriate for the lakeshore;
- Acquire appropriate baseline information to adequately understand and manage water resources and meet National Park Service inventory and monitoring requirements;
- Promote public awareness and understanding of current and potential human impacts upon water resources;
- Detect and evaluate external influences that may impact lakeshore water resources and water-related attributes.

Water Resource Threats

The Integrated Atmospheric Deposition Network (IADN) is a joint effort of the US and Canada to measure atmospheric deposition of toxic materials to the Great Lakes. The IADN was mandated by a 1987 amendment of the Great Lakes Water Quality Agreement. The development plan for the network was approved in 1990. There is one master monitoring station on each lake that measures air, rain and particles for a suit of chemicals, including PCBs, Pash (polyaromatic hydrocarbons), chlorinated pesticides (DDT) and trace metals including lead, arsenic and cadmium. The master station on Lake Michigan is located at Sleeping Bear Dunes National Lakeshore.

The impacts of air toxics deposition to the water resources of the national lakeshore are unknown. It behooves the national lakeshore to better understand the ongoing deposition and to measure its effects on water resources, especially with the data available from the IADN master station.

Cultural eutrophication of lakes is an insidious problem attributable primarily to nutrient inputs via nonpoint sources although point sources may also be involved. The national lakeshore has been concerned with the phosphorus inputs of a point source upstream on the Platte River – the State of Michigan's Anadromous Fish Hatchery (see below). These phosphorus inputs were suspected by the Platte Lake Improvement Association as a major source of pollution problems in Platte Lake (just upstream of national lakeshore boundary). This concern became a long-legal battle that eventually resulted in the State complying with court orders to reduce its phosphorus discharges to the Platte River.

Cultural eutrophication can be assessed by a trophic status index (TSI) of lakes through the analysis of several variables: 1) estimation of the transparency of the water as measured by Secchi disk depth; 2) the concentration of the limiting nutrients such as phosphorous or nitrogen; and, 3) the density of the phytoplankton community as measured by chlorophyll *a* (Carlson 1977; Kratzer and Brezonik 1981). The TSI can be used with a number of variables to calculate a value that can be used to compare among years the trophic status of a particular lake. Two studies (Boyle and Hoefs 1993; Whitman et al. 2002) calculated TSIs for several lakes in the national lakeshore. The recent Water Resources Management Plan for the national lakeshore compared values for comparable lakes. The TSIs based on the Secchi disk compared favorably; only two lakes (Tucker and Narada lakes) showed changes in trophic status and those changes were improvements. The TSIs based on total phosphorus and chlorophyll *a* for 1999 are consistently higher than those for 1992. In fact, the 1999 values reflect major changes in trophic state for all lakes – the tendency is for ever-increasing euthropy. It is unclear without further study just what is driving this discrepancy.

Since the 1800s some 139 nonindigenous aquatic organisms have become established in the Great Lakes (Mills et al. 1993; < http://www.g.c.org/ans/modelsmp.htm >). The bulk of these species include plants (59), fish (25), algae (24), mollusks (14) and oligochaetes (7). Most of have come from Europe (55 percent), Asia (14 percent), and the Atlantic Coast (13 percent), and the rate of introduction has increased as the rate of human activity increased. In 1989 more than 1/3 of the organisms had been introduced in the prior 30 years, coincident with the opening of the St. Lawrence Seaway in 1959 (Mills et al. 1991). Although the obvious impacts of some of the most abundant species are being determined, most of the aquatic nuisance species and their direct and indirect impacts are not known.

Given the totality of the exotic species threat, the national lakeshore does not have an adequate handle on the presence or absence of any of these species, except a few. In particular, zebra mussels have recently invaded at least two lakes, one of which was completed inundated by this species within 1 year of detection. *Phragmites* is spreading at an alarming rate through a fragile and unique Great Lakes wetland ecosystem, the ridge and swale systems (interdunal wetlands). A monitoring regime for detection and possible mitigation of exotic species is needed.

Water-based recreation in the form of canoeing, kayaking, and tubing is increasing, especially on some streams in the national lakeshore. The national lakeshore is concerned about the lasting effects of this increasing pressure on resources. The drought conditions of the last few years have exacerbated the situation. For example, flows are so low that canoes and kayaks need to be portaged. This has resulted in obvious riparian area disturbance and in-stream disturbances to habitat. Do these disturbances result in long-term impacts on the structure and function of in-stream aquatic and riparian biological communities?

Retrospective Analysis of Past Water Quality Studies

The National Park Service (1997) conducted surface water quality retrievals for Sleeping Bear Dunes National Lakeshore from six of the U.S. Environmental Protection Agency's national databases, including STORET the national water quality database. The results of these retrievals for the study area (limits include 3 miles upstream and 1 mile downstream of park boundary) covered the years 1962 to 1996 and included 149 water quality monitoring stations, three industrial/municipal discharge sites (only two of which are in the watersheds represented in the national lakeshore), 12 water impoundments (only one of importance to national lakeshore), and four active or inactive U.S. Geological Survey gaging stations (none active within national lakeshore). Of the 149 stations, 10 stations were established but contained no data. Seventy-six stations were located within the national lakeshore boundary. Twenty stations are located in Lake Michigan waters; however, 17 stations have data older than 1985 and three show no data. Presently, there are no active stations on the Lake Michigan waters of the lakeshore to determine existing water quality and water quality trends.

Most of the remaining monitoring stations represent either one-time or intensive single-year sampling efforts by collection entities or discontinued stations. Sixty-two stations represent data collected before January 1985 and are of little use in an assessment of current water quality of the park. Forty-seven, national lakeshore stations show data collected from 1985 to 1996; 23 of these stations each represent less than 10 total water quality observations over this period and are of little use in determining water quality trends; however, parameter values indicate no water quality impairment. Of the remaining 24 stations in the national lakeshore, all represent data collected no later than 1995 and represent not monitoring stations *per se* but several multi-year assessments. The data from these stations are important in establishing the water quality baseline for many of the lakeshore water resources. Of the national lakeshore's lakes only 12 were consistently sampled over a 5-year time frame (1990-1995); however, only 10 remained common between 1991 to 1992 and 1993 to 1995 (Last and Whitman 1996). For all the lakes, the values for the measured parameters are consistent with hard-water lakes and show no obvious indications of impaired water quality. The national lakeshore's streams show that at least one station on each stream was sampled consistently over a 5-year time frame (1990-1995). As with the lakes, no streams show any obvious water quality impairments.

Adequacy of Current Information

Water quality monitoring at Sleeping Bear Dunes National Lakeshore has had a short history – a 3-year, water resources assessment begun in 1990 (Boyle and Hoefs 1993) represents its beginning. Since that time to the present, water quality monitoring at the national lakeshore has had its 'fits and starts', primarily attributable to a lack of park resources and expertise. Recent years have seen marked improvement towards the development of a sustainable, cost-efficient, and consistent monitoring program, because some resources and expertise, albeit limited, infused the program. However, that program is based only on seasonal (summer) sampling of lakes and streams for physicochemical parameters, and lacks adequate rationale for the measuring of those parameters, biological monitoring and stream discharge determinations. In the latter case, the national lakeshore is already seeing the importance of flow measurement (e.g. Crystal River litigation that occurred in 2002). Monitoring is focused only on surface water resources; ground water resource quantity and quality are unknown commodities. An annual water quality monitoring report is produced on a 'catch-as-catch-can' basis, thereby a year or more in arrears, lacking adequate interpretation of data and not timely to national lakeshore management for decision making. The existing monitoring program is structured such that it addresses basic water quality constituents that are unlikely to address such important issues as deposition of persistent organic pollutants and their bioaccumulation, recreational use impacts, biological integrity and the detection of exotic species and the determination of the status of their populations. Another important water resource issue for the national lakeshore is the cultural eutrophication (point and nonpoint source of nutrients) of its lakes and streams. In this regard the current monitoring program is measuring the appropriate variables, but lacks the analysis and interpretation necessary to define the extent of the problem. Consistency remains a problem; parameters are added or deleted without the development of appropriate rationale, including the best sampling frequency for detection of change. These problems are not unique to the national lakeshore; they are common to fledgling water quality monitoring programs, especially ones that lack adequate resources and expertise. One step in the right direction is that national lakeshore staff recognize the importance of partnerships and cooperation in stretching monitoring resources.

Amphibians in many parts of the world have recently declined in number and geographic ranges (Wake 1991; Livermore 1992). The situation is complex, but many believe that a global problem faces amphibians and that this problem is largely the result of habitat modifications by humans. Acid precipitation, shifts in precipitation patterns, intensive agriculture, deforestation, urbanization, highway construction, wetland draining, dam construction, pollution by pesticides and heavy metals, and the introduction of fishes and other predators can all adversely affect amphibians. Baseline information on the status and health of US populations of amphibians and reptiles is scarce (McDiarmid 1994) and there are no long-term quantitative data on amphibians and reptiles in the Great Lakes region. Amphibians in the Midwest do not seem to be experiencing the drastic declines occurring elsewhere, but local declines are apparent for both amphibians and reptiles.

The amphibians and reptiles of the Great Lakes are an interesting and diverse group that includes 83 species – 51 in Michigan (11 salamanders; two toads; 10 frogs; one lizard; nine turtles; and 18 snakes) (< http://biology.usgs.gov/ >). The National Park Service (1979) stated that past studies in the Sleeping Bear Dunes area listed 32 species of herptiles – 17 amphibian and 15 reptiles. A systematic survey of herptiles has yet to be accomplished for the lakeshore; however, distribution records from the University of Michigan's Museum of Zoology (< http://www.ummz.lsa.umich.edu/herps/miherps>) show that a total of 23 herptiles inhabit the lakeshore -- 11 species of frogs and toads; four species of salamanders; one lizard; five snakes; and two turtles.

Without more comprehensive and consistent water resource information and adequate baseline data, any impacts on water resources will remain undetected and changes will be difficult to document. Determining the status of contaminants on water, sediment and the biota in the national lakeshore would serve as a benchmark for future comparisons and would help to identify problem contaminants and/or sites for possible remedial action. At a minimum, waters entering the national lakeshore should be in compliance with state water quality standards. A comprehensive water quality monitoring program for surface and ground waters is essential to develop adequate baseline information and to determine compliance with water quality standards. An important first step in the revision of the water quality monitoring program is the development of a water quality monitoring plan and analysis of water quality information. Presently, Daren Carlisle of the Midwest Regional Office is assisting the national lakeshore with a review of its water quality monitoring program, and the development of a water quality monitoring plan would codify the results and recommendations of that review.

DESCRIPTION OF RECOMMENDED PROJECT OR ACTIVITY

The immediate objective for the national lakeshore is to establish the foundation for future water quality monitoring by designing and initiating a sustainable, long-term program for monitoring water quality. During the first year of the project, a water quality monitoring plan will be developed and implemented by a professional(s) competent in the fields of physicochemical and biological monitoring techniques and methods. This plan will initially develop monitoring objectives. Identifying the objectives and type(s) of monitoring has implications for the type, intensity, and scale of measurements. Additionally, this monitoring plan will discuss management activities, potential monitoring parameters, frequency and cost of monitoring, statistical considerations, number, location and access to monitoring sites, quality assurance/control, data management, the needs for specific studies and the availability of existing data.

An important step in the development of the water quality monitoring plan, is the summarization and interpretation of existing water quality data. Fortunately, available water quality data from monitoring stations both in and adjacent to the park have been summarized (National Park Service 1997). However, this information (and monitoring data collected since this publication) should be interpreted and reviewed by a water quality specialist, who will determine whether park water resources are in compliance with state water quality standards. Basic data observation and integration techniques and statistical analyses will be performed, and their interpretation will form the basis for a water quality monitoring program sufficient to protect the ecological integrity of the park.

Other aspects of this water quality monitoring plan include:

A design that will establish both a physiochemical and biological baseline for the park's water resources. The plan will develop and/or recommend potential biological assessment techniques for implementation in the water quality monitoring program;

Develop a recreational (bacteriological) monitoring scheme;

Development of a monitoring program that is inclusive of the Lake Michigan waters within the national lakeshore;

Review and citation of the literature necessary to support the plan's rationale and/or recommendations;

Identification of potential partnership efforts, e.g. sediment monitoring with the Michigan Department of Environmental Quality and fish flesh analyses with the Michigan Department of Natural Resources;

Determination of the appropriate mix of regular fixed station monitoring versus the need for events-based monitoring;

Identification of ground water recharge areas to the park --ground water monitoring adjacent to potential contamination should be established;

Incorporation of all data into the park's geographic information system for tracking and management purposes; and,

Provision of alternatives to accomplish the objectives of the water quality monitoring program (including envisioned cooperative monitoring efforts). The plan should be coordinated with the Michigan Department of Environmental Quality, U.S. Geological Survey and local entities to optimize a comprehensive monitoring approach.

In the second year, as part of the evaluative process for the monitoring program, some pilot sampling and analysis will be conducted in order to better identify existing conditions, evaluate proposed methodologies for sustainability (cost-effectiveness), evaluate logistical constraints, evaluate procedures for data management and protocols for data evaluation, and design specific criteria that would activate intensive studies of water quality threats. Revisions to the monitoring plan would be based upon the results of this pilot study.

LITERATURE CITED

Boyle, T. and N. Hoefs. 1993. Water resources inventory of Sleeping Bear Dunes National Lakeshore. Sleeping Bear Dunes National Lakeshore, Empire, MI.

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

Kratzer, C. and P. Brezonik. 1981. A Carlson type trophic state index for nitrogen in Florida lakes. Water Res. Bull. 17:713-715.

Last, L. and R. Whitman. 1996. Maintaining a water quality monitoring program at Sleeping Bear Dunes. Park Science 16 (3):19-21.

Livermore, B.1992. Amphibian alarm: just where have all the frogs gone? Smithsonian Magazine 1992(10):113-120.

McDiarmid, R. 1994. Ampibian diversity and natural history: an overview. *In* W. Heyer, M. Donnelly, R. McDiarmid, L. Hayek and M. Foster, eds. Measuring and monitoring biological diversity: standard methods for amphibians. Smithsonian Institution Press, Washington, D.C.

Mills, E., J. Leach, J. Carlton, and C. Secor. 1993. Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. J. Great Lakes Res. 19:1-54.

National Park Service. 1979. Resource information base, Sleeping Bear Dunes National Lakeshore. National Park Service, Denver Service Center, Denver, CO.

National Park Service. 1997. Baseline water quality data inventory and analysis for Sleeping Bear Dunes National Lakeshore, Vols. I and II. Water Resources Division, National Park Service, Tech. Rept. NPS/NRWRD/NRTR-97/106, Fort Collins, CO.

National Park Service. 2001. Preliminary draft – General Management Plan for Sleeping Bear Dunes National Lakeshore. Empire, MI.

Wake, M.1991. Declining amphibian populations. Science 253:860.

Whitman, R. 2001(draft). Study of the application of limnetic zooplankton as a bioassessment tool for lakes of Sleeping Bear Dunes National Lakeshore. U.S. Geological Survey, Lake Michigan Ecological Research Station, Porter, IN.

BUDGET AND FTES

FUNDED				
Source	**Activity**	**Fund Type**	**Budget ($1,000s)**	**FTEs**
			0.00	0.00
		Total	**0.00**	**0.00**
UNFUNDED				
Year 1	MON	One-time	15.00	0.00
Year 2	MON	One-time	20.00	0.00
		Total	**35.00**	**0.00**

PROJECT STATEMENT SLBE-N-002.008

TITLE: BACTERIAL WATER QUALITY MONITORING OF RECREATIONAL WATERS WITHIN SLEEPING BEAR DUNES NATIONAL LAKESHORE

Funding Status: Funded = 0.00 Unfunded = 5.60 to 17.80

PROBLEM STATEMENT

National Park Service Director's Order 83: Public Health (dated August 2, 1999) now directs NPS park managers to reduce the risk of waterborne disease by requiring designated bathing beaches and recommending that other heavily used recreational waters be appropriately monitored. Guidance pertaining to this monitoring is found in Reference Manual 83 (National Park Service 1999) and includes:

- Conducting a sanitary survey
- Preparing a bathing beach monitoring protocol
- Sampling for *Enterococcus* or *E. coli* bacteria levels, and
- Issuing swimming advisories when bathing beach waters exceed the bacterial standards.

While Sleeping Bear Dune National Lakeshore does not contain designated bathing beaches, some swimming, wading, tubing and canoeing are popular at most of the lakeshore's streams and lakes. This being the case, prudent management dictates that a recreational water quality monitoring program be a high park priority.

The national lakeshore has realized the importance of a recreational water monitoring program. Since 2000, the national lakeshore has monitored for *E. coli* at 20 sites – nine on national lakeshore streams, nine on Lake Michigan, and two on inland lakes. Sampling occurred weekly from the end of May to the middle of September. National Lakeshore staff conducted their own laboratory analysis of water samples using the standard membrane filtration technique. However, the staff time needed for sampling and analysis is substantial, and there is a growing need to monitor more sites. In addition there is a greater need to address the national lakeshore's other water resource issues. This project proposes to re-design the ongoing recreational water quality monitoring program at the national lakeshore by basing the program on a relatively new, quantitative and cost-effective monitoring technique called the Idexx Laboratories Quanti-tray 2000 test (Budnick et al. 1996).

DESCRIPTION OF RECOMMENDED ACTIVITY

Data from the above study, national lakeshore monitoring, and from any earlier State or local monitoring programs will be used along with information pertaining to water-based recreational use patterns to design a seasonal recreational water quality monitoring program. Monitoring protocols will be designed in consultation with the US Public Health Service and the Michigan Department of Environmental Quality.

Techniques and protocols for monitoring recreational water quality are changing rapidly with a shift away from the older fecal coliform indicator-based programs to programs based upon *E. coli* and *Enterococci* indicators. Legislation currently in Congress would require states to adopt the new standards that conform with the newer US Environmental Protection Agency recommended criteria within 3.5 years of enactment. Fortunately, the State of Michigan has adopted these newer criteria. It is important for the national lakeshore to develop a MOU with the State and local entities that addresses monitoring, enforcement and management protocols, similar to the one between Glen Canyon NRA and the states of Arizona and Utah. In this MOU the NPS and the states have agreed to utilize a simpler, more cost effective *E. coli* sampling test (Idexx Laboratories Quanti-tray 2000 test) for the weekly screening of swimming areas by NPS personnel (Budnick et al. 1996). When *E. coli* levels exceed 126 colonies/100 ml (geometric mean; U.S. Environmental Protection Agency criterion also suggested for use by National Park Service 1999), sites are re-sampled (in triplicate) by a state certified laboratory using the more complex membrane filtration technique. Should the arithmetic mean of these three samples exceed 200 colonies/100 ml on two consecutive days, the area will be closed to swimming. Daily sampling will continue and a beach will not be re-opened to use until the geometric mean of the most recent daily, 2-day, 3-day, 4-day, and 5-day samples falls below 200 colonies/100 ml (Anderson 1999).

The use of the above criteria for *E. coli* is specific to Glen Canyon NRA and is also 3 years old. Recently, the national lakeshore has been advised to use the Michigan *E. coli* standard of 130 *E. coli* per 100 milliliters based on the geometric mean of all individual samples taken during five or more sampling events representatively spread over a 30-day period. Each sampling event shall consist of three or more samples taken at representative locations within a defined sampling area. At no time shall the waters of the State contain more than a maximum of 300 *E. coli* per 100 milliliters based on the geometric mean of three or more samples taken during the same sampling event at representative locations within a defined sampling area.

Use of the Idexx Laboratories Quanti-tray 2000 test and cooperation between Sleeping Bear Dunes National Lakeshore and the Michigan Department of Environmental Quality (and local entities) is proposed. Other than some initial training, use of the Quanti-tray 2000 test does not require any special expertise to use; sampling is quite simple. In this regard, monitoring duties could be extended to other park staff. For example, park rangers could sample park waters as part of the regular surveillance duties and drop off the trays at their convenience. This would free up the national lakeshore's water resources staff time for addressing other park water resource issues. Additionally, laboratory analysis similar to the complex membrane filtration technique is not needed and this also frees up staff time.

LITERATURE CITED

Anderson, M. 1999. Quality assurance project plan and standard operating procedures for Glen Canyon National Recreation Area water quality lab. Resource Management and Science Division, Glen Canyon National Recreation Area, Page, AZ.

Budnick, G., R. Howard, and D. Mayo. 1996. Evaluation of Enterolert for enumeration of enterococci in recreational waters. Applied Environmental Microbiology 62(10):3881-3884.

National Park Service. 1999. Reference manual for Director's Order 83 – Public Health (Appendix D - Bathing Beaches). National Park Service, Washington, DC.

BUDGET AND FTES

The annual cost of this monitoring program would depend upon the number of sites and the sampling period; if we assume 8 sites sampled weekly for 20 weeks the annual cost would run between $5,588 and $17,846. The basic 'screening' program – assuming that waters always meet water quality criteria for *E. coli* – would cost $5,588 per year. A regulatory program, assuming waters frequently exceeded the screening criteria and were sometimes out of compliance with water quality criteria would cost approximately $17,846 per year.

Screening Program

Idexx Quanti-tray 2000 is a simple and relatively inexpensive quantitative test for *E. coli* that would be adopted as the screening procedure. One-time, start-up costs for capital equipment are around $4,000 (Paul Murphy, pers. comm., Sleeping Bear Dunes National Lakeshore). Sample costs are approximately $7.00 per sample. Thus, a recreational 'screening' program consisting of eight sites sampled weekly for 17 weeks from the end of April to the end of September would incur the following costs:

Seasonal employee (GS-5, 20 weeks at ¼ time)	$2,356
Laboratory equipment	$ 500
Expendable test supplies ($7/sample)	$1,232
Training	$ 500
Vehicle costs	$1,000

Total	$ 5,588 (does not include $4000 start-up costs)

Regulatory Program

Assuming that a significant proportion of the sites failed to meet recreational water quality standards, at least part of the time, the cost of a regulatory monitoring program would include additional staff time (re-sampling and intensified monitoring), use of a state certified lab for *E. coli* membrane filtration analysis, data interpretation and regulatory coordination. Approximate cost estimates (which will vary according to the quality of the water) are:

Seasonal employee (GS-7, 20 weeks at ½ time)	$5,846
State certified lab ($25/sample)	$5,000
Signage/maintenance	$2,000
Data evaluation/interpretation/consultation	$2,500
Regulatory coordination	$2,500
Total	$17,846

Approximate Total Costs for a Recreational Water Screening and Regulatory Program = $23,434/yr

PROJECT STATEMENT SLBE-N-002.009

TITLE: **ASSESS PROPER FUNCTIONING CONDITION OF RIPARIAN AREAS OF SLEEPING BEAR DUNES NATIONAL LAKESHORE**

Funding Status: Funded = 00.00 Unfunded = 45.00

PROBLEM STATEMENT

Natural riparian areas are some of the most diverse, dynamic, and complex biophysical habitats in the terrestrial environment (Naiman et al. 1993). The riparian area encompasses that stream channel between low and high water marks and that portion of the terrestrial landscape from the high water mark toward the uplands where vegetation may be influenced by elevated water tables or flooding and by the ability of the soils to hold water (Naiman and Decamps 1997). Riparian zones are key systems for regulating aquatic-terrestrial linkages (Ward 1989) and they may be early indicators of environmental change (Decamps 1993).

Physically, riparian areas control mass movements of materials and channel morphology (Naiman and Decamps 1997). Material supplied to streams comes from erosion of stream banks, a process influenced by root strength and resilience, as well as from the uplands. Stream banks largely devoid of riparian vegetation are often highly unstable and subject to mass wasting that can widen channels by several to tens of feet annually. Major bank erosion is 30 times more prevalent on unvegetated banks exposed to currents as on vegetated banks (Beeson and Doyle 1995).

Ecologically, riparian areas:

- provide sources of nourishment -- allochthonous inputs to rivers and herbivory;
- control nonpoint sources of pollution, in particular sediment and nutrients, in agricultural watersheds; and,
- create, through variations in flood duration and frequency and concomitant changes in water table depth and plant succession, a complex of shifting habitats at different spatio-temporal scales (Naiman and Decamps 1997).

Riparian habitats have evolved in a cycle of flood and drought, but it is a system in which there is a natural repeating cycle of events. Riparian vegetation (for that matter, all floodplain vegetation), therefore, is adapted to natural flood regimes. Those species found on floodplains are there because they are better adapted to the conditions than nearby upland species.

A delicate balance exists between the flora and fauna of riparian habitats and the annual flood regime. Unusually high summer flows may scour beds of aquatic vegetation reducing cover for young of the year fish, turtles, and invertebrates.

Summer destruction of these plant beds may affect waterfowl food supply and survival the following winter. Ill-timed artificial flows may destroy larvae of amphibians by flushing them from pools and backwaters. Eggs of reptiles buried on sandbars and islands may be inundated and drown. Ground nesting birds in riparian habitats may also experience high mortality of nest and nestlings.

The maintenance of healthy riparian systems is essential in obtaining and sustaining biologically diverse Great Lake ecosystems. Healthy riparian systems can be described as being geologically stable with stream flow and sediment discharges that are in dynamic equilibrium with their upland watersheds, and as having wetland and riparian vegetation that has appropriate structural, age, and species diversity. When these attributes are maintained, riparian systems provide forage and cover for wildlife and improve water quality by filtering sediment and recycling nutrients. If, however, any of the essential attributes are missing or degraded, or if the system becomes geologically unstable, widespread erosion may occur that will degrade water quality and cause damage or loss of wetland and riparian habitats.

Other than a cursory understanding of the presence of plant species (Hazlett 1986; Albert 1992)), the riparian zones (of streams and lakes) in Sleeping Bear Dunes National Lakeshore are unstudied. To properly manage these important resources, park management must be able to assess riparian conditions and take steps to resolve any problems. All too often, however, when we are asked to assess the condition or overall health of our riparian areas we are at a loss to respond with much more than “they look OK to me” or “they look terrible,” without a strong rationale for either conclusion. Giver our critical role in the conservation of soil, water, vegetation, and wildlife resources, it is essential that natural resource managers have proper tools to evaluate the health of the riparian systems under NPS stewardship, especially when multiple competing uses are present.

The U.S. Bureau of Land Management has developed guidelines and procedures to rapidly assess whether a stream riparian area is functioning properly in terms of its hydrology, landform/soils, channel characteristics, and vegetation (Prichard et al. 1993, rev. 1995). This assessment, commonly called Proper Functioning Condition or PFC, is useful as a baseline analysis of stream condition and physical function. The basic goal of this project is to use the PFC process to classify park riparian areas as either "proper functioning condition," "functional-at-risk," or "nonfunctional.” This goal can be met by implementing a coordinated review of existing literature and tactical field investigations. Water Resources Division staff have successfully used this assessment in several park units since 1995 (< http://www1.nature.nps.gov/wrd/chrisrpt.htm >).

DESCRIPTION OF THE RECOMMENDED PROJECT

A riparian assessment tool called Assessing Proper Functioning Condition (Prichard et al., 1993, rev. 1995) will be used to evaluate riparian systems of streams (Prichard et al. 1998) and lakes (Prichard et al. 1999) of Sleeping Bear Dunes National Lakeshore. This technique uses an interdisciplinary team to assess riparian area "functionality" according to 17 hydrological, vegetation, and stream geomorphologic (e.g. erosion, deposition, channel geometry) factors. PFC is not a quantitative field technique. An advantage of this approach is that it is less time-consuming than other techniques because measurements are not required. It provides an initial screening that can separate areas that are functioning well from those in need of more intensive evaluation or management actions. In this way, money and effort can be targeted toward the higher priority issues. Originally developed by the Bureau of Land Management for assessment of riparian areas managed by that agency, the method is now being applied throughout the western U.S. by the U.S. Forest Service and the Natural Resources Conservation Service. Use of this tool on eastern U.S. riparian areas is a logical extension.

PFC is a methodology for assessing the physical functioning of a riparian-wetland area. It provides information critical to determining the health of a riparian ecosystem. PFC considers both abiotic and biotic components as they relate to the physical functioning of riparian areas, but it does not consider the biotic component as it relates to habitat requirements. For habitat analysis, other techniques must be employed.

The "functioning condition" of a riparian area refers to the stability of the physical system, which in turn is dictated by the interaction of geology, soil, water, and vegetation. A healthy or stable stream/riparian area is in dynamic equilibrium with its stream flow forces and channel processes. In a healthy system, the channel adjusts in slope and form to handle larger runoff events with limited perturbation of the channel and associated riparian-wetland plant communities.

It is important to note that evaluation of functioning condition is not simply an assessment of the ecological status or seral stage of the vegetation community. Rather, evaluation is based upon the concept that in order to manage for such things as potential natural vegetation communities the basic elements of physical habitat must first be in place and functioning properly.

Identifying streams and lakes where riparian areas are not in proper functioning condition, and those at risk of losing function, is an important first step in the ultimate goal of restoration. Physical conditions in riparian zones are excellent indicators of what is happening in a stream or drainage above. With the results of PFC analysis, it is possible to begin to determine stream corridor and watershed restoration needs and priorities. PFC results may also be used to identify where gathering more detailed information is needed and where additional data are not needed.

Riparian Functionality Assessment

In accordance with the BLM's protocols (Prichard et al. 1993, rev. 1995) for assessing riparian functionality, an interdisciplinary team with expertise in hydrology, soil science, geology, and riparian vegetation will evaluate the capability and potential of park streams using existing literature and field examinations to obtain information in the following areas:

- look for and describe relic areas;
- review historic photos, survey notes, and other documents that indicate historic condition;
- review floral and faunal species lists;
- determine species habitat needs related to species that are/were present;
- examine soils and determine if they were saturated at one time and are now well drained;
- estimate frequency and duration of flooding on floodplains and terraces;
- identify vegetation that currently exists and determine if they are the same species that occurred historically;
- determine the entire watershed's general condition and identify its major landforms;
- look for limiting factors, both human-caused and natural, and determine if remedial actions are needed.

Based on the evaluation of the above factors, the team will classify park riparian areas into one of the following three categories:

Proper Functioning Condition: Stream/riparian areas are functioning properly when adequate vegetation, landform, or large woody debris is present to:

- dissipate stream energy associated with high water flows, thereby reducing erosion and improving water quality;
- filter sediment, capture bedload, and aid floodplain development;
- improve floodwater retention and ground water recharge;
- develop root masses that stabilize stream banks against cutting action;
- develop diverse ponding and channel characteristics to provide habitat and the water depths, duration, temperature regimes, and substrates necessary for fish production, waterfowl breeding, and other uses, and;
- support greater biodiversity.

Functional-at-Risk: These stream/riparian areas are in function condition, but an existing soil, water, vegetation, or related attribute makes them susceptible to degradation. For example, a stream reach may exhibit attributes of a properly functioning system, but it may be poised to suffer severe erosion during a large storm in the future due to likely migration of a headcut or increased runoff associated with a recent disturbance in the watershed.

Nonfunctional: These are stream/riparian areas that clearly are not providing adequate vegetation, landform, or large woody debris to dissipate stream energy associated with high flows, and thus are not reducing erosion, improving water quality, etc., as already described. The absence of certain physical attributes, such as a floodplain where one should exist, is an indication of nonfunctioning conditions.

The product of this project will be a report containing a compendium of the standard checklist for each riparian area evaluated by the team, and a brief summary describing the teams conclusions regarding the overall condition of the park's riparian areas.

LITERATURE CITED

Albert, D. 1992. A survey of lakes, streams, and wetlands of the Sleeping Bear Dunes National Lakeshore. Michigan Natural Features Inventory, Michigan Department of Natural Resources, Lansing, MI.

Beeson, C. and P. Doyle. 1995. Comparison of bank erosion and vegetated and nonvegetated channel beds. Water Res. Bull. 31:983-990.

Decamps, H. 1993. River margins and environmental change. J. Ecol. Appl. 3:441-445.

Hazlett, B. 1986. The terrestrial vegetation and flora of the mainland portion of Sleeping Bear Dunes National Lakeshore, Benzie and Leelanau counties, Michigan. University of Michigan Biologial Station Tech. Rept. No. 11, Douglas Lake, MI.

Naiman, R., H. Decamps, M. Pollock. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecol. Appl. 3:209-212.

Naiman, R. and H. Decamps. 1997. The ecology of interfaces: riparian zones. Ann. Rev. Ecol. Syst. 28:621-658.

Prichard, D. et al. 1993 rev 1995. Riparian area management -- process for assessing proper functioning condition. BLM Technical Reference TR 1737-9. Denver, CO.

Prichard, D. et al. 1998. A user guide to assessing proper functioning condition and the supporting science for lotic areas. BLM Technical Reference TR 1737-15, Denver, CO.

Prichard, D. et al. 1999. A user guide to assessing proper functioning condition and the supporting science for lentic areas. BLM Technical Reference TR 1737-16, Denver, CO.

Ward, J. 1989. Riverine-wetland interactions. Pages 385-400 *in* R. Sharitz and J. Gibbons, eds. Freshwater wetlands and wildlife. U.S. Department of Energy, Oak Ridge, TN.

BUDGET AND FTEs:

-----------------------------FUNDED-----------------------------

	Activity	Fund Type	Budget ($1000s)	FTEs
	Total:		0.00	0.00

----------------------------UNFUNDED----------------------------

	Activity	Fund Type	Budget ($1000s)	FTEs
Year 1:	MON	One-time	20.00	0.25
Year 2:	MON	One-time	25.00	0.25
	Total:		45.00	0.50

PROJECT STATEMENT: SLBE-N-002.010

TITLE: USE OF BURROWING MAYFLIES (*Hexagenia*) *AS INDICATORS OF AQUATIC ECOSYSTEM HEALTH IN THE PLATTE RIVER SYSTEM*

Funded Status: Funded = 0.00 Unfunded = 25.00

PROBLEM STATEMENT

The National Parks Omnibus Management Act of 1988 encourages the development of monitoring programs to help protect park natural resources, by inventorying and monitoring park system resources and establishing baseline information that can be used to provide status and trend information on the condition of park resources. Various studies have been conducted in recent years that contribute to the information base needed to protect and manage park resources, but the environmental status of most inland waters of the Great Lakes Cluster Parks is still poorly known (Whitman *et al.* 2002). Major external threats to these waters of the Great Lakes Cluster Parks include cultural eutrophication resulting from elevated levels of phosphorus in precipitation and in surface runoff and tributaries entering the parks from the portions of the drainage basin that lie outside park boundaries.

In the Sleeping Bear Dunes National Lakeshore (SLBE), Loon Lake (surface area 38 ha, maximum depth 21.6 m) and the lower Platte River (which passes through Loon Lake) are among the Great Lakes Cluster Parks waters most seriously threatened by cultural eutrophication. These SLBE waters (river miles 0 to about 5; RM 0-5) are at risk because they receive the effluent from a major Michigan Department of Natural Resources (MDNR) Fish Rearing Station in the upper river at about RM 16, and also receive surface runoff and septic tank seepage from summer and year-round dwellings along the river and around Platte Lake (RM 5-8). Loon Lake serves as a nutrient sink within SLBE waters of the Platte River system (Stockwell and Gannon 1975; Boyle and Hoefs 1993) and, as such, is particularly vulnerable to the effects of nutrient additions originating outside the park.

The effects of cultural eutrophication are already highly evident in Platte Lake, as evidenced by lawsuits by property owners directed against the MDNR and intended to reduce the phosphorus loading to the lake from the MDNR Fish Rearing Station. The effects of cultural eutrophication on Loon Lake and in the river below the lake, which meanders through a sand and marl bottomed, drowned river mouth-wetland and dune complex before entering Lake Michigan, are presently less evident than in Platte Lake. *Hexagenia* was present in the epilimnetic waters of Loon Lake, but may be absent in the hypolimnion (Whitman *et al.* 2002), as would be expected if cultural eutrophication was occurring. The level of total phosphorus measured in Loon Lake in 1998 and 1999 (Whitman *et al.* 2002) was consistently low in water (0.03-0.04mg/L), but varied seasonally and was much higher in lake bed sediments (80-478 mg/kg), suggesting cultural eutrophication was occurring. The N:P ratio (31.5) was very near the point (N:P = 29) where the production of undesirable blue-green algae is favored over that of beneficial diatoms and green algae (Wetzel 1975); this provides further evidence to suggest that cultural eutrophication was occurring. The absence of dissolved oxygen in the hypolimnion in August and September 1998 and 1999 (Whitman *et al.* 2002) is additional evidence that cultural eutrophication was occurring in the lake, and suggests that phosphorus mobilization and release from the sediment during episodes of hypoxia presently might be sufficient to periodically lower the N:P ratio in water and trigger the production of blue-green algae. Earlier records describing hypoxia in the hypolimnion of Loon Lake are not available, but, Brown and Funk (1940) reported that conditions in the hypolimnion were adequate to support fish, including cisco *(Coregonus ariedi)* and trout, which are coldwater fishes that would typically occupy the hypolimnion and that require high levels of dissolved oxygen for survival. A more recent survey (Kelly and Price 1979) found only warmwater fishes were present. The apparent loss of ciscos and trout suggests that hypoxia might have developed between the early 1940s and the late 1970s and that cultural eutrophication might have been the responsible agent.

The present proposal addresses cultural eutrophication in Loon Lake and the lower Platte River within SLBE, using an indictor approach recently developed to assess ecosystem health in Great Lakes surface waters. This method uses burrowing mayflies *(Hexagenia)* as the indicator organism. The indicator approach to assessing ecosystem health was promoted by the U.S. Environmental Agency and Environment Canada at State-of-the-Lakes Ecosystem Conferences (SOLEC) in 1996, 1998, and 2000. The resulting indicators (EPA and EC 2001) are being used to inform the governments of the United States and Canada and the public about progress toward restoring and maintaining the chemical, physical, and biological integrity of the Great Lakes Water Quality Agreement. *Hexagenia* was selected as an indicator because it (1) was historically abundant in unpolluted, nearshore, soft-bottomed habitats throughout the Great Lakes; (2) was intolerant of and was extirpated by eutrophication in many of those habitats by the 1940s-1950s; (3) has shown the ability to recover almost completely in one of those habitats (western Lake Erie; Edsall *et al.* 1999) following nutrient reduction; (4) is ecologically important as a trophic integrator that links detritus (which it eats) directly to trout, bass, walleye, yellow perch, lake sturgeon, and other desirable fish, (which preferentially eat *Hexagenia*); and (5) has highly visible mating swarms of winged-adults, that, by their presence can carry the message to an informed public that the water body supporting the nymph population is healthy.

DESCRIPTION OF RECOMMENDED PROJECT OR ACTIVITY

We propose to use the methods detailed in Edsall (2001), Edsall *et al.* (2001) and Edsall *et al.* (unpublished manuscript) to survey the *Hexagenia* population in

Loon Lake and adjacent reference areas in the Platte River system, to assess and document the health of those populations, and to develop baseline status and trend data that can be used to track future changes in those population and in the health of the lower Platte River ecosystem. We will establish sampling stations on the 2-, 5-, 10- and 15-m depth contours on each of five transects around the perimeter of Loon Lake. A mid-lake station will also be established on about the 20-m depth contour. Three additional stations will be established in the Platte River between Loon Lake and Lake Michigan to assess conditions there, and three reference stations will be established across the 2- to 20-m depth contours in Platte Lake to permit comparison of conditions there with those in SLBE. All stations will be located in areas of suitable substrate (silt and soft clay and fine sand) that will support *Hexagenia* burrow development and maintenance. A Ponar grab will be used to collect three samples of sediment at each station in early-mid June 2002 and 2003, prior to the annual emergence of nymphs as winged sub-adults (submagos). Each sample will be washed on a coarse (3.2-mm mesh) screen to extract the large *Hexagenia* nymphs in the segment of the population that is about to emerge as winged adults. These nymphs will be counted and weighed and reported, by station, as mean values with appropriate measures of variance. Regression equations (Edsall 2001; Edsall *et al.* 2001) will be used to translate the data into estimates of mean annual biomass and annual production for direct comparison with other published values for *Hexagenia* populations in Lake Erie, Green Bay, Lake St. Clair, the St. Marys, St. Clair, and Detroit Rivers, and other North American populations in the Midwest and Canada that have been described in the scientific literature. Comparison of the Loon Lake *Hexagenia* population with those other populations will provide a reliable assessment of ecosystem quality in Loon Lake relative to other waters in North America.

Expected results or products

Data collected during this study will be archived in an electronic database and provided to SLBE management. A progress report describing the results of the sampling in 2002 will be submitted to SLBE management in September 2002. A project final report will be submitted in September 2003. The project final report will contain a simplified protocol that can be performed easily 91 day of sampling effort every 2-3 years) by SLBE staff to monitor *Hexagenia* and assess ecosystem health in the lower Platte River system.

Technology/information transfer

The proposed study will employ recently developed technology to quantitatively assess ecosystem health in the lower Platte River. The results of the study will be presented in a manner that will permit them to be easily interpreted by SLBE resource managers, as well as to educate park visitors about the *Hexagenia* as an indicator of ecosystem health. As a collateral benefit, park visitors can be alerted to the fact that the mating swarms of winged-adult *Hexagenia* that occur at dusk in late June are readily observable and are important indictors of ecosystem health of the water body supporting the *Hexagenia* population. Dense swarms of adults are indicative of a healthy habitat whereas their absence in what was historically suitable habitat for *Hexagenia* suggests habitat quality has been degraded.

LITERATURE CITED

Boyle, T.P., and N.J. Hoefs. 1993. Water resources inventory of Sleeping Bear Dunes National Lakeshore. National Park Service and Colorado State University, Fort Collins.

Brown, C.J.D., and J. Funk. 1940. Fisheries survey of Big Platte Lake and Round Lake with some observations on the lower Platte River, Benzie County, Michigan. Report No. 631, Michigan Department of Conservation, Ann Arbor, Michigan.

Edsall, T.A., C.P. Madenjian, and B.A. Manny. 1999. Burrowing mayflies in Lake Erie a review. Pages 219-231 *in* M. Munawar, T. Edsall, and I.F. Munawar (eds.). The state of Lake Erie: past, present, and future. Ecovision World Monograph Series, Backhuys, The Netherlands. 550 pp.

_____. 2001. Burrowing mayflies *(Hexagenia)* as indicators of ecosystem health. *Aquat. Ecosystem Health and Manage.* 4:283-292.

_____. R.C. Haas, and J.V. Adams. 2001. Annual production of burrowing mayfly nymphs *(Hexagenia* spp.*)* in U.S. waters of Lake St. Clair. J. Great Lakes Res. 27:449-456.

_____. M.T. Bur, O.T. Gorman, and J.S. Schaeffer. 2002. Burrowing mayflies (Hexagenia) as indicators of ecosystem health: status of populations in western Lake Erie, Saginaw Bay (Lake Huron), and Green Bay (Lake Michigan*).* Unpublished manuscript, Great Lakes Science Center, Ann Arbor, Michigan. 30 pp.

Kelly, T.K., and B. Price. 1979. Fishes of the Sleeping Bear Dunes National Lakeshore. Final Report, National Park Service and Eastern National Park and Monument Association.

Stockwell, J.E., and J.E. Gannon. 1975. Water quality studies in the Sleeping Bear Dunes National Lakeshore region – the Lower Platte River system and Florence Lake, Michigan*.* Pages 67 *in* M.W. Paddock (ed.). Natural history surveys of Pictured Rocks National Lakeshore and Sleeping Bear Dunes National Lakeshore. University of Michigan Biological Station, Douglas Lake, Pellston and Ann Arbor.

Wetzel, R.G. 1975. *Limnology.* Saunders, Philadelphia. 743 pp.

Whitman, R.L., M.B. Nevers, T.G. Horvath, L.L. Last, M.L. Goodrich, S.M. Mahoney, and J. Nefezyk. 2002. Status and trends of selected inland lakes of the Great Lakes Cluster. Draft report, Great Lakes Science Center, U.S. Geological Survey, Ann Arbor, MI.

BUDGET AND FTES

First Year = $15K
Second Year = $10K

- Equipment – Manual winch and boom system for deploying Ponar grab $ 3K
- Supplies – Sample containers, preservative, sieving buckets, Ponar grab $ 3K
- Salaries for two part-time /contract GS-5 Biotechs $12K
- Field work/travel $7K

PROJECT STATEMENT: SLBE-N-002.011

TITLE: EVALUATION OF THE IMPACT OF INCREASING MULTIPLE-USE ON THE WATER QUALITY AND HABITAT OF THE CRYSTAL RIVER

Funded Status: Funded = 15.00 Unfunded = 252.00

ABSTRACT

Sleeping Bear Dunes National Lakeshore (SLBE) management is concerned that increased visitor use and off-Park water management in headwater areas will degrade the aquatic habitat of the Park's waterways. Of particular concern is the pristine Crystal River where visitor use doubled from 1998 to 1999. In addition, inland lake levels and streamflow in the area surrounding the national lakeshore were at record low levels during the summer of 2000. This study, through biometric assessments and water-quality monitoring, will provide SLBE with the information necessary to measure the present health of the Crystal River aquatic habitat and macroinvertebrate community and to judge future degradation of these resources. It will also provide an opportunity to demonstrate locally derived, in this case Michigan Department of Natural Resources, biometric assessments as a management tool for the NPS.

PROBLEM STATEMENT

Sleeping Bear Dunes National Lakeshore (SLBE) is located in Michigan's northwestern Lower Peninsula, at the base of the Leelanau Peninsula, 25 miles west of Traverse City, Michigan. The national lakeshore encompasses a 32-mile stretch of Lake Michigan's eastern coastline, as well as North and South Manitou Islands. SLBE was established primarily for its outstanding natural features, including forests, beaches, dune formations, and ancient glacial phenomena. The national lakeshore also contains many cultural features including an 1871 lighthouse, three former Life-Saving Service/Coast Guard Stations and an extensive Rural Historic Farm District.

Besides the Lake Michigan shoreline, SLBE contains many inland waterways. Inland lakes contained wholly within the national lakeshore are generally shallow and small. Streams are warm, nutrient rich, hard water, and potentially autotrophic systems (White, 1987). They include the entire Otter Creek watershed, parts of Shalda Creek and the Crystal River, and 4.5 miles of the Platte River from near Platte Lake to its mouth (figure 1). Although establishment of the national lakeshore is relatively recent (1970), the area has long been used for recreation and its popularity continues to grow. In the 1980's, 700,000 visitors per year enjoyed the national lakeshore; that number has increased to close to 1,300,000 per year today.

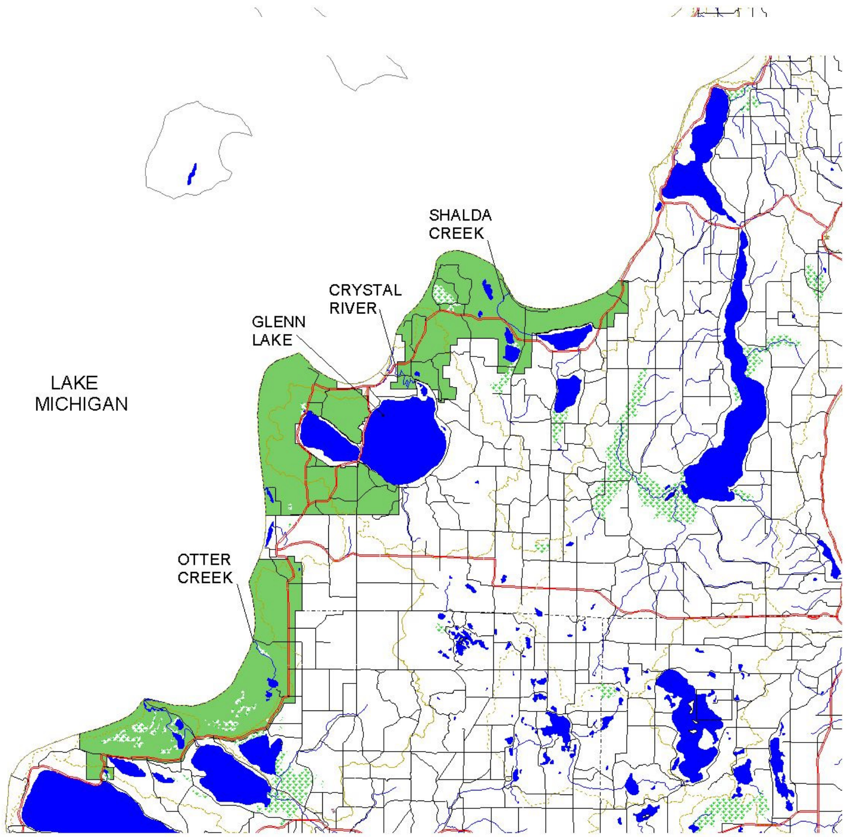


FIGURE 1. -- SLEEPING BEAR DUNES NATIONAL LAKESHORE

The crowded and often-conflicting use of the Platte River at the south end of SLBE has degraded its riverine habitat and driven many visitors to other streams within the national lakeshore. Visitor use of the Crystal River, the second largest river in the national lakeshore, doubled between 1998 and 1999. SLBE management still considers the Crystal River pristine, but is concerned that the increased wading in the channel, bottoming of canoes and kayaks, and disruption of the banks will degrade habitat to the detriment of the aquatic community.

Previous studies reflect management's concern. In an assessment of the macroinvertebrate communities of the four largest rivers in the national lakeshore, White (1987) found the Crystal River community did not reflect pollutants, eutrophication, or severe physical disturbance. Using both the Shannon–Weiner index and Simpson's index, Boyle and Hoefs (1993) found that their lower Crystal River site had the highest consistent pattern of macroinvertebrate diversity among all sites in their water resources inventory of the national lakeshore, whereas their upper Crystal River site showed the lowest pattern of diversity. They attributed this difference as possibly due to sudden changes in streamflow at the upper site due to off-stream management of the dam controlling the elevation of Glen Lake. In a recent study, the Biological Resources Division (BRD) of the USGS found mussel populations decreasing downstream from the dam and in one area downstream of the Park, mussel populations that were found on previous sampling trips had died. BRD attributed the decline in mussel populations to low water levels and increased canoe and human traffic in two ways, (1) the fish carrying young mussels on their gills are spending less time in low water areas because of the increased traffic and (2) people walking and dragging canoes over these areas may be physically affecting the mussels (Nichols, S.J., 2002, oral communication). In addition, the BRD found wavy-rayed lampmussels (*Lampsilis fasciola* Rafinesque), a species of concern in Michigan, in the Crystal River.

The headwaters of the Crystal River are out of SLBE boundaries. Water management and increased development in these headwater areas may threaten water-quality in the national lakeshore. Streamflow in the Crystal River is regulated by discharges from Glen Lake through Fisher Lake (figure 2). Water levels in Glen Lake are regulated within 1945 court mandated guidelines; they are regulated for recreational use of Glen Lake and not for water quality in the Crystal River. In recent years, the Great Lakes area has experienced a drought. During the summer of 2000, lake and stream levels were at record lows. The low water levels are exposing streambeds in places normally not seen. The reduced water levels are adding additional stresses in the form of increased streambed and streambank disturbance during periods of public use. Conservation groups in the area have initiated a lawsuit against the Glen Lake Association claiming that the Association's water management policies are degrading the habitat of the Crystal River. SLBE is not a participant in the lawsuit but expects to be called upon to provide data on the health of the Crystal River habitat.

SLBE management is aggressively pursuing a policy to protect the Crystal River and other national lakeshore waterways from any further degradation. However, decisions to limit visitor use or to seek changes in off-park practices must be made with sound data.

Objectives

1. Provide Sleeping Bear Dunes National Lakeshore with a current assessment of the health of the Crystal River through a multi-discipline study which includes the collection of streamflow, water-quality, macroinvertebrate, and stream-habitat data.
2. Identify any temporal degradation in the habitat of the Crystal River from increasing multiple uses from on-Park visitors and off-Park water management through a comparison with previous studies such as White (1987) and Boyle and Hoefs (1993). Data collected during this study, BRD studies, and previous NPS studies will be examined to identify possible reasons and causes for any identified degradation.

3. Establish baseline data on the habitat of the Crystal River for biometric and water-quality procedures that can be measured by national lakeshore personnel after the completion of this study.

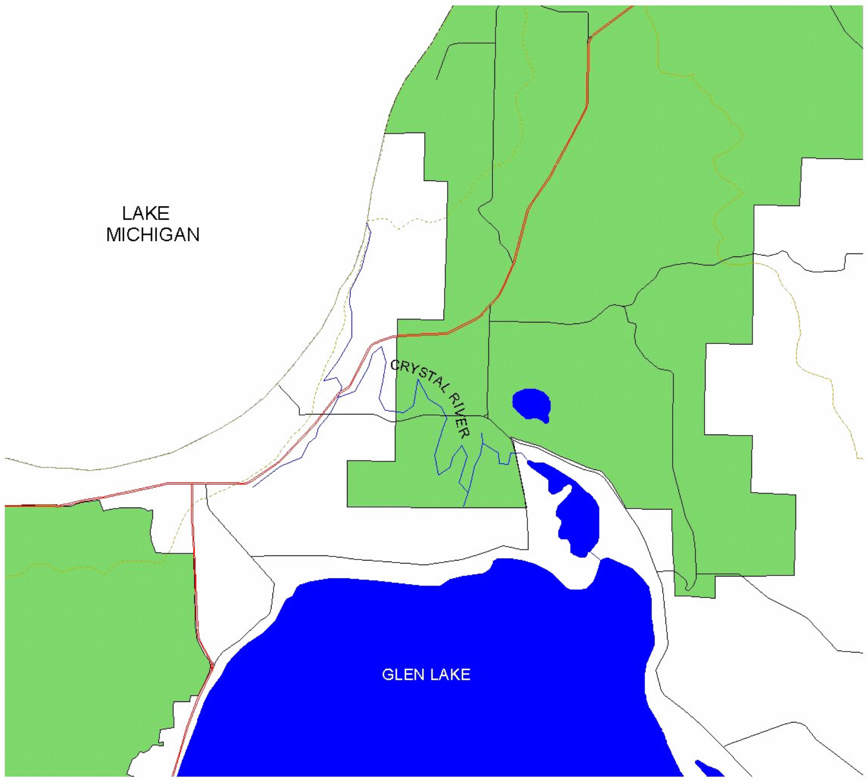


FIGURE 2. -- CRYSTAL RIVERS

DESCRIPTION OF RECOMMENDED PROJECT OR ACTIVITY

The proposed study will use a multi-discipline approach that includes the establishment of a stream gaging and continuous water-quality monitoring station, the collection of discrete water-quality samples, the collection of macroinvetebrate samples for quantification, and macroinvertebrate and habitat surveys that use biometrics to quantify the environmental health of the river.

During October-November 2002, the beginning of the 2003 water year, a streamflow gaging station will be installed on the Crystal River. The station will be operated as part of the USGS Michigan Surface Water Network and a stage-discharge relation developed using standard USGS protocols (Rantz and others, 1982). The station will provide real-time gage height and discharge data that can be disseminated to the public over the USGS Michigan District web page and linked to the national lakeshore's homepage. These data can also be displayed at the Park's visitor centers. The gage will provide information on the daily, weekly, monthly, and seasonal variations in streamflow. Paired discharge measurements at the gage and at a site just downstream of the Glen Lake dam will be used to determine the percentages of surface-water discharge and ground water inflow passing the gage. This is crucial information in relating off-Park water management to water levels in the Crystal River.

A continuous water-quality monitor will be installed at the gaging station to collect hourly data on water temperature, specific conductance, and pH. Additional parameters may be added if they are deemed important to the study. This monitor will provide data on the daily, weekly, monthly, and seasonal variations of the measured parameters and their relations to streamflow. The monitor will also provide data on the impact of specific events such as summer thunderstorms on the water quality of the Crystal River. Procedures and guidelines for the installation and servicing of water-quality monitors can be found in Wagner and others, 2000. Real-time data from this monitor can be provided over the Internet and at the national lakeshore's visitor centers. The gaging station would also be an excellent location for a webcam that shows the daily and seasonal changes of the Crystal River habitat and visitor interaction with that habitat.

Water-quality samples for the analyses of major elements, trace elements, solids, nutrients, bacteria, organic carbon, and other organic chemicals will be collected at two sites on the Crystal River four times a year for the first two years of the study. It is anticipated that the collection sites will be at the gage and at a site downstream of the Glen Lake dam. Low-level sampling and processing protocols that will be followed in this study are detailed in Wilde and others, 1998. Samples will be shipped and analyzed at the USGS National Water-Quality Laboratory. The samples will give an overview of the Crystal River water quality and identify the presence/absence of constituents that may impact the health of the aquatic community. The data will also be compared to data collected during previous studies (Handy and Stark, 1984; Boyle and Hoefs, 1993) to determine if temporal changes in water-quality exist.

Habitat and macroinvertebrate surveys of five reaches along the Crystal River will be conducted in October 2002, 2003, and 2004. During 2002 and 2003, invertebrate samples will be collected and shipped to the U.S. Geological Survey Laboratory in Denver for quantitative sorting and identification by the Standard Taxonomic Assessment, which is comparable to the U.S. Environmental Protection Agency Rapid Bioassessment Protocol III and provides Genus- or species-level taxonomic resolution (Moulton and others, 2000). These data will be compared to previous studies by White (1987) and Boyle and Hoefs (1993) to examine temporal changes in the macroinvertebrate communities.

The habitat and macroinvertebrate surveys will be conducted all three years using Michigan Department of Natural Resources (MDNR) Great Lakes and Environmental Assessment Section (GLEAS) habitat and macroinvertebrate procedure 51 and a modified USGS National Water-Quality Assessment (NAWQA) program cross-section profile protocol to assess current river health at each reach. The GLEAS procedure uses a standard protocol to develop a biometric score for the surveyed reach. The score is then compared to the biometric score for a pristine or non-impacted reference site. An excellent quality reach will score at least 90 percent of the reference site score. A reach with a score of only 60 percent of the reference site is rated poor (Michigan Department of Natural Resources, 1991). Because scores are produced for the studied reaches before the comparison with the reference site, the use of procedure 51 will allow comparisons to sites assessed by the State in the ecoregion surrounding the Park (map 1).

The modified NAWQA cross-section profiles are based on NAWQA protocols that have been proven nationally for ten years (Meador and others, 1993). Second level reach characterization measurements will be made on three to five cross sections for each reach. Flow velocities, bottom profiles, and substrate composition will provide geomorphic and hydraulic information that can be used to evaluate temporal changes for the reach. Streamflow data from the NAWQA protocols can be used with the gage information to determine how streamflow varies longitudinally along the river.

Products

1. U.S. Geological Survey report on findings.
2. Transfer of GLEAS Procedure 51 habitat and macroinvertebrate community assessment and modified NAWQA cross-section profile methods and procedures to Park personnel.
3. During the duration of the study, web-based presentations of data to integrate with SLBE informational and educational systems.

LITERATURE CITED

Arndofer, D. 1985. Platte River Corridor Study. Environmental Resource Management, Bloomington, Minnesota.

Boyle, T.P. and Hoefs, N.J. 1993. Water resources inventory of Sleeping Bear Dunes National Lakeshore. Sleeping Bear Dunes National Lakeshore, Empire, MI.

Cuffney, T.F., Gurtz, M.E., and Meador, M.R. 1993. Methods for collecting invertebrate samples as part of the National Water-Quality Assessment Program. U.S. Geological Survey Open-File Report 93-406.

Handy, A.H. and Stark, J.R. 1984. Water Resources of Sleeping Bear Dunes National Lakeshore, Michigan. U.S. Geological Survey Water Resources-Investigation Report 83-4253, 39 p.

Linton, M.C., 1987, Analysis of habitat for invertebrates in the stream systems of Sleeping Bear Dunes National Lakeshore. A report to the National Park Service, Sleeping Bear Dunes National Lakeshore, Empire, Michigan.

Meador, M.R., Hupp, C.R., Cuffney, T.F., and Gurtz, M.E. 1993. Methods for characterizing stream habitat as part of the National Water-Quality Assessment Program. U.S. Geological Survey Open-File Report 93-408.

Moulton, S.R. II, Carter, J.L., Grotheer, S.A., Cuffney, T.F., and Short, T.M. 2000. Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory-Processing, taxonomy, and quality control of benthic macroinvertebrate samples. U.S. Geological Survey Open-File Report 00-212, 49 p.

National Park Service. 1979. Resources Information Base, Sleeping Bear Dunes National Lakeshore. Empire, MI.

Rantz, S.E. and others. 1982. Measurement and computation of streamflow: volume 1. Measurement of stage and discharge; volume 2. Computation of discharge. U.S. Geological Survey Water-Supply Paper 2175.

Stockwell, J.E. and Gannon, J.E. 1975. Water quality studies in the Sleeping Bear Dunes National Lakeshore Region – The Lower Platte River System, Michigan. Sleeping Bear Dunes National Lakeshore, Empire, MI.

Michigan Department of Natural Resources. 1991. Great Lakes and Environmental Assessment Section (GLEAS) procedure 51, revised June 1991 - Qualitative biological and habitat survey protocols for wadable streams and rivers. Surface Water Quality Division.

Wagner, R. J., Mattraw, H.C., Ritz, G.F., and Smith, B.A., 2000, Guidelines and standard procedures for continuous water-quality monitors: site selection, field operation, calibration, record computation, and reporting: U.S. Geological Survey Water-Resources Investigations Report 00-4252, 53 p.

White, D.S., 1987, Analysis of the limnology of four streams (Platte River, Crystal River, Shalda Creek, Otter Creek) in Sleeping Bear Dunes National Lakeshore based on the macroinvertebrate fauna: A report to the National Park Service, Sleeping Bear Dunes National Lakeshore, Empire, Michigan.

Wilde, F.D., Radtke, D.B., Gibs, J., and Iwatsubo, R.T., 1998, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9.

BUDGET AND FTES:

---FUNDED---

Year	Source Activity	Fund Type	Budget ($1000s)	FTEs
2003:	PKBASE-NR MON	Recurring	5.0	0.1
2004:	PKBASE-NR MON	Recurring	5.0	0.1
2005:	PKBASE-NR MON	Recurring	5.0	0.1
		Total:	15.0	0.3

---UNFUNDED---

Year	Activity	Fund Type	Budget ($1000s)	FTEs
2003:	MON	One-time	85.0	0.0
2004:	MON	One-time	85.0	0.0
2005:	MON	One-time	82.0	0.0
		Total:	252.0	0.0

Alternative Actions/Solutions and Impacts

Without the proposed activities, Sleeping Bear Dunes National Lakeshore management will not have information necessary to make sound decisions to mitigate potential impacts of increased visitor use of the fragile water resources contained in the Park. The current and proposed activities surrounding the Crystal River take place in a highly charged political arena, where speculation and hearsay have no merit. A lawsuit has already been filed over the quality of the Crystal River habitat. Management decisions not based upon sound scientific facts could be easily criticized and not defendable.