WATER RESOURCES OF SLEEPING BEAR DUNES NATIONAL LAKESHORE, MICHIGAN

By A. H. Handy and J. R. Stark

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DEFINITION OF TERMS

Altitude. Vertical distance of a point or line above or below the National Geodetic Vertical Datum of 1929. The National Geodetic Vertical Datum of 1929 (NGVD of 1929) is a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. International Great Lakes Datum of 1955 (IGLD of 1955) is a vertical control datum used on the Great Lakes system.

Aquifer. A formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs. It is also called a ground-water reservoir.

Bedrock. Designates consolidated rocks.

Concentration. The weight of dissolved solids or sediment per unit volume of water expressed in milligrams per liter (mg/L) or micrograms per liter (μg/L).

Contour. An imaginary line connecting points of equal altitude, whether the points are on the land surface, or on a potentiometric or water-table surface.

Ground water. Water that is in the saturated zone from which wells, springs, and ground-water runoff are supplied.

Hydraulic conductivity. The volume of water at the prevailing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. In general terms, hydraulic conductivity is the ability of a porous medium to transmit water.

Hydrograph. A graph showing the variations of stage, flow, velocity, discharge, or other aspect of water with aspect to time.

IGLD of 1955. See altitude.

NGVD of 1929. See altitude.

Potentiometric surface. An imaginary surface representing the levels to which water will rise in tightly cased wells. More than one potentiometric surface is required to describe the distribution of head. The water table is a particular potentiometric surface.

Recharge. The process by which water is infiltrated and is added to the zone of saturation. It is also the quantity of water added to the zone of saturation.

<u>Runoff</u>. That part of precipitation that appears in streams; the water draining from an area. When expressed in inches, it is the depth to which an area would be covered if all the water draining from it in a given period were uniformly distributed on its surface.

<u>Specific capacity</u>. The rate of discharge of water from a well divided by the drawdown of water level within the well.

<u>Specific conductance</u>. A measure of the ability of water to conduct an electric current, expressed in micromhos (μmhos) per centimeter at 25°C. Because the specific conductance is related to amount and type of dissolved material, it is used for approximating the dissolved-solids concentration of water. For most natural waters the ratio of dissolved-solids concentration (in milligrams per liter) to specific conductanc (in micromhos) is in the range 0.5 to 0.8.

<u>Subcrop</u>. Consolidated rock directly underlying glacial deposits; would be exposed if all glacial deposits were removed.

<u>Water table</u>. That surface of an unconfined water body at which the pressure is atmospheric. It is defined by levels at which water stands in wells that barely penetrate the water surface.

CONVERSION FACTORS

The inch-pound units used in this report can be converted to the metric (International) system of units as follows:

Multiply inch-pound unit	By	To obtain metric unit
inch	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
gallon per minute (gal/min)	6.309×10^{-5}	cubic meter per second (m^3/s)
gallon per minute per foot ((gal/min)/ft)	0.2070	liter per second per meter ((L/s)/m)
cubic foot per second (ft^3/s)	0.0283	cubic meter per second (m^3/s)
cubic foot per second per square mile ((ft^3/s)/mi^2)	0.01093	cubic meter per second per square kilometer ((m^3/s)/km^2)
micromho per centimeter (μmho/cm)	1.000	microsiemen per centimeter (μS/cm)
acre-foot (acre-ft)	1.233×10^{-3}	cubic hectometer (hm^3)
degree Fahrenheit (°F)	((°F)-32)/1.8	degree Celsius (°C)

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ABSTRACT

Sleeping Bear Dunes National Lakeshore is a water-rich area. It borders Lake Michigan, and several small streams flow through the park to the lake. Small lakes are numerous within the park and near its boundaries. Ground water is available at most places in park and wells yield as much as 100 gallons per minute.

Water from streams, lakes, wells, and springs is acceptable for most uses. Dissolved solids range from 35 to 180 mg/L in lakes, from 145 to 214 mg/L in streams and from 136 to 468 mg/L in ground water. Analyses of samples for pesticides and trace metals indicate that no pesticides are present in the water, and that concentrations of trace metals do not exceed U.S. Environmental Protection Agency recommended drinking-water standards.

Surface and ground water are available in sufficient quantity in most areas of the park for the development of water supplies for visitor's centers, campgrounds, picnic areas, and other park facilities.

INTRODUCTION

Sleeping Bear Dunes National Lakeshore[1] is in the northwest part of Michigan's Lower Peninsula in Benzie and Leelanau Counties (fig. 1); it borders Lake Michigan. Two nearby islands, South Manitou and North Manitou Islands, are part of the park (fig. 2).

Sleeping Bear Dunes National Lakeshore was authorized by the Congress in 1970. This authorization provided for the establishment of boundaries and the purchase of land. Although establishment of the National Park Lakeshore is relatively recent, the area has long been used for recreation. About 718,000 people will visit the Lakeshore in 1983 and 1,400,000 in the year 2000 according to Park Service estimates (oral communication, 1988).

Figure 1.--Location of Sleeping Bear Dunes National Lakeshore.

The park takes its 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 much of the park the land surface is quite rolling (fig. 3). From an altitude of 579 feet along the shores of Lake Michigan, the surface forms steep 200- to 300-foot bluffs at several places and rises to an altitude of more than 1,000 feet at a few places. Empire Bluffs at Empire reach a height of 390 feet above the lake. These bluffs are also capped by dunes.

The boundary of the park contains 64 miles of Lake Michigan shoreline--31 miles on the mainland, 13 miles on South Manitou Island, and 20 miles on North Manitou Island. In most places, the shoreline is a sand, gravel, or cobble beach.

The park includes inland lakes that are shallow and small. They range in size from 15 acres to 160 acres. Streams include all of Otter Creek, parts of Shalda Creek and Crystal River, and 3 miles of the Platte River from Platte Lake to its mouth.

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[1] Commonly referred to as park in this report.

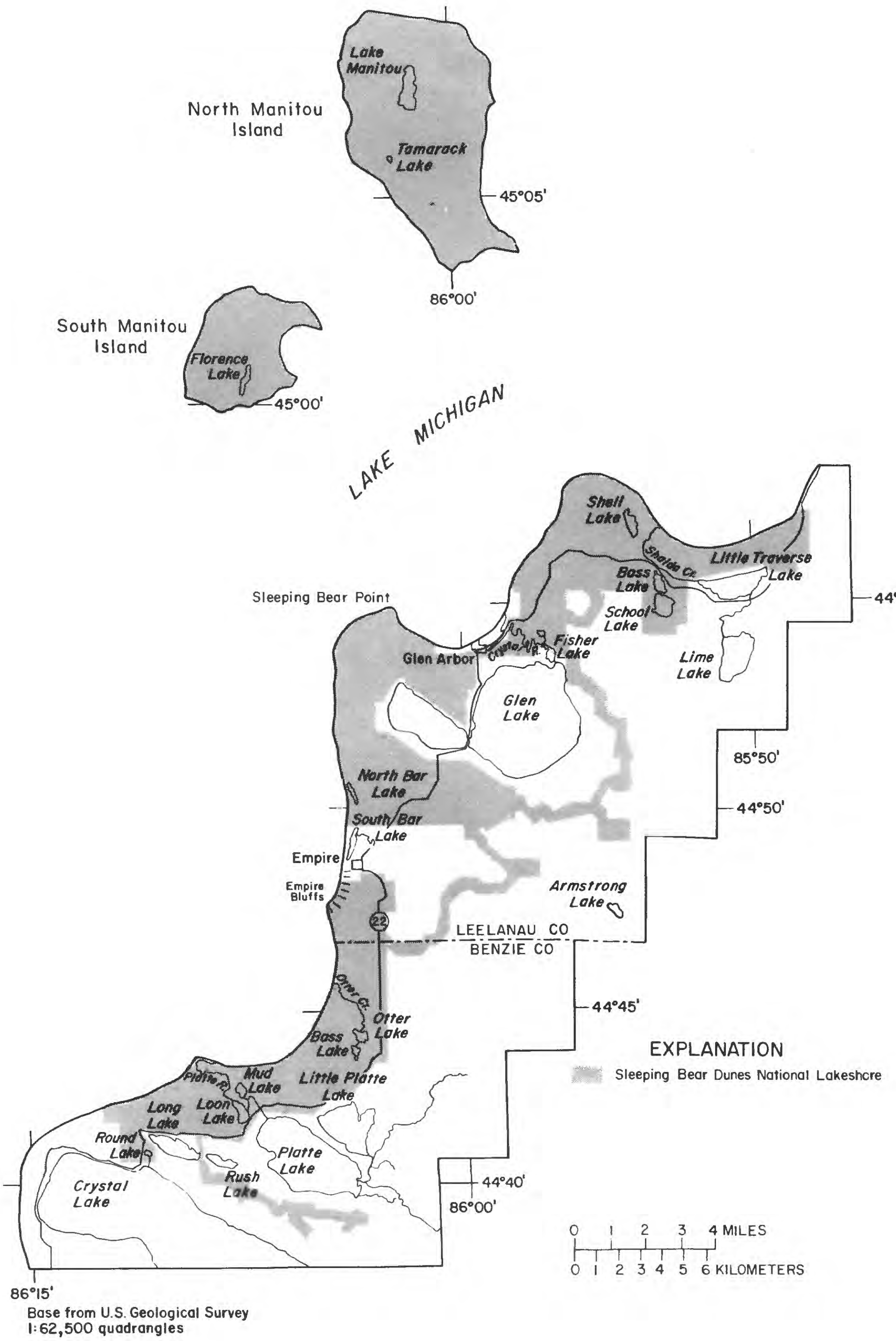

Figure 2.--Park boundary and physical and cultural features.

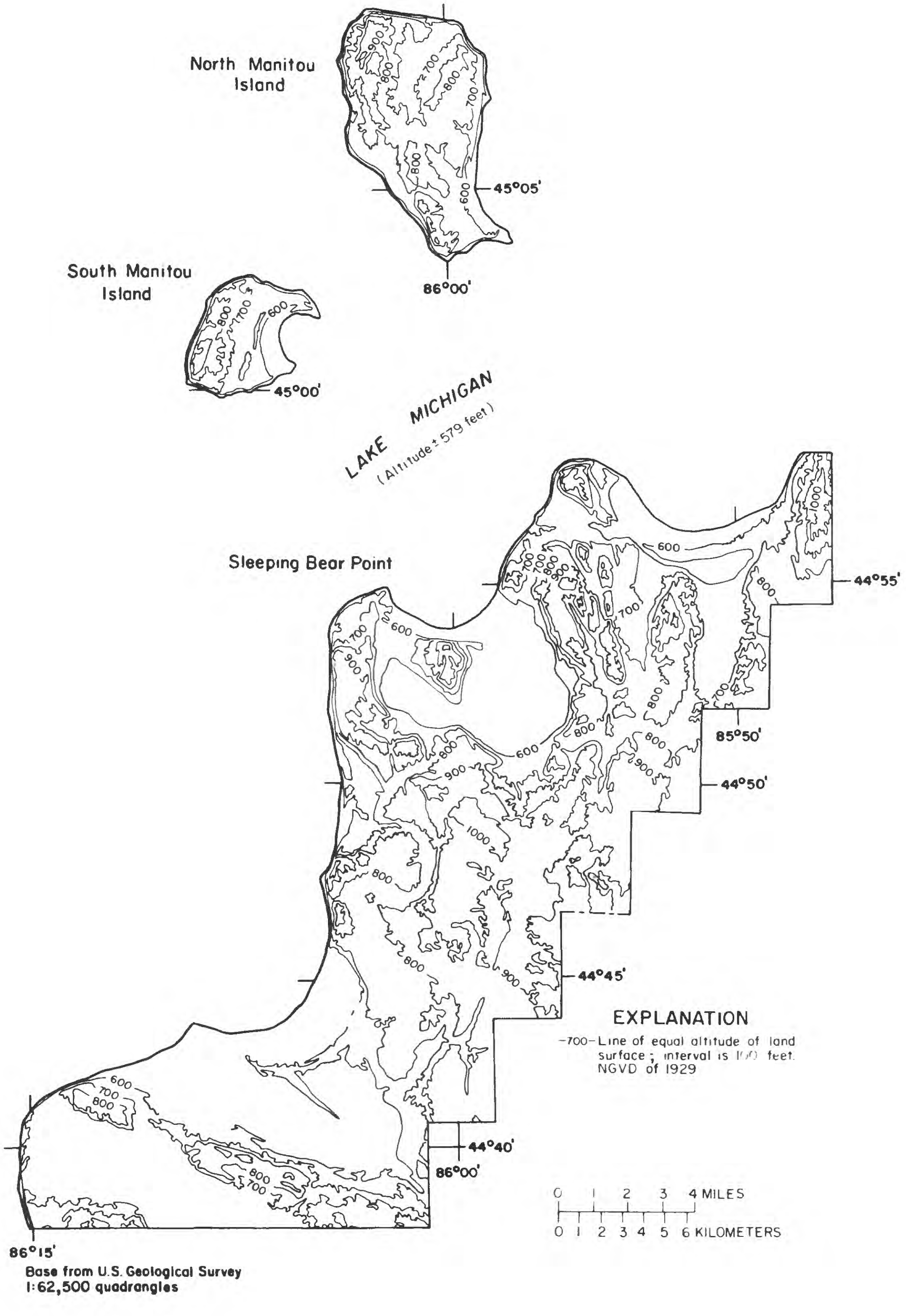

Figure 3.--Topography of the land surface.

The average annual precipitation, about 33 inches[2], is well distributed throughout the year. The period May to October receives an average of 57 percent of the total amount. Summer precipitation is mainly in the form of afternoon showers and thundershowers. The average annual temperature is about 45°F. In 1980, the maximum temperature was 85°F in June; the minimum was -6°F in February. Low temperatures of -5°F and -1°F were recorded in 1977 and 1978 (Fred V. Nurnberger, State Climatologist, written communication, 1981).

Purpose and Scope

The purpose of this investigation was to (1) describe general hydrogeologic conditions in the area, and (2) assess the ground- and surface- water resources of Sleeping Bear Dunes National Lakeshore and their potential for future development.

Acknowledgments

Acknowledgment is made to personnel of the Sleeping Bear Dunes National Lakeshore, National Park Service for their assistance and cooperation. Acknowledgment is also made to R. L. LeuVoy, G. L. Morin, S. J. Rheaume, R. J. Minnerick, and J. C. Failing who assisted in the collection of hydrologic data. Cartographic and art work provided by S. M. Beall.

Methods of Investigation

Ten wells were drilled in the lakeshore area during the project (March 1979 to September 1982). Eight were drilled for public supply and two for monitoring of water levels and water quality. Four of these wells were carefully logged and the geology studied; drillers records are available for the other six wells. Ground water and geologic maps were drawn using data from these and other wells in the area. Water from the new wells, 12 other wells, and 2 springs was analyzed for metals, pesticides, and other constituents. Laboratory analyses of water from lakes and streams were made, as well as field measurements of specific conductance, pH, bicarbonate, carbonate, and dissolved oxygen. Discharge measurements were made each year of the study at the lake outlets and rating curves constructed in order to estimate lowest average 7-day discharge.

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[2] Climatic data are for the period 1979-81 at the Frankfort weather station just southwest of the park.

GEOLOGY

Alluvium and dune sand of Holocene age and glacial deposits of Pleistocene age cover the Sleeping Bear Dunes National Lakeshore area (fig. 4). Because of the relatively great thickness of glacial material, study of the underlying bedrock has been infrequent and only at places where it has been penetrated by deep wells and where geophysical data have been collected.

Recent Alluvium and Dune Sand

Recent alluvium is the unconsolidated material, primarily sand, that forms the flood plains of present-day streams. The deposits of greatest areal extent in the study area are along the Platte River. Minor deposits along other streams are too small to show on figure 4.

Sand dunes occur at two levels in the park; some are at or near the level of Lake Michigan; others are perched high on morainal plateaus 300 feet above the lake. The "dunes" in the park name is derived from the extensive perched dune complex extending south along Lake Michigan from Sleeping Bear Point. Dunes in this complex and other small dunes are still active and are moving to the northeast.

Glacial Deposits

Glacial deposits in the park area are 500 to 700 feet thick and represent many glacial events. Much of the material at land surface and many surficial landforms are the result of events that occurred during the closing phases of the last glacial period, the Wisconsin.

At times during Wisconsin glaciation, all of Michigan lay under several thousand feet of ice. About 16,000 years ago the glaciers began to retreat. Following the last major retreat, two minor advances and retreats of glacial ice occurred. The first, the Port Huron (Leverett and Taylor, 1915), resulted in glacial ice covering all the study area (fig. 5). A range of hills (moraines) in southeast Benzie County marks the terminus of this advance in the Sleeping Bear Dunes area.

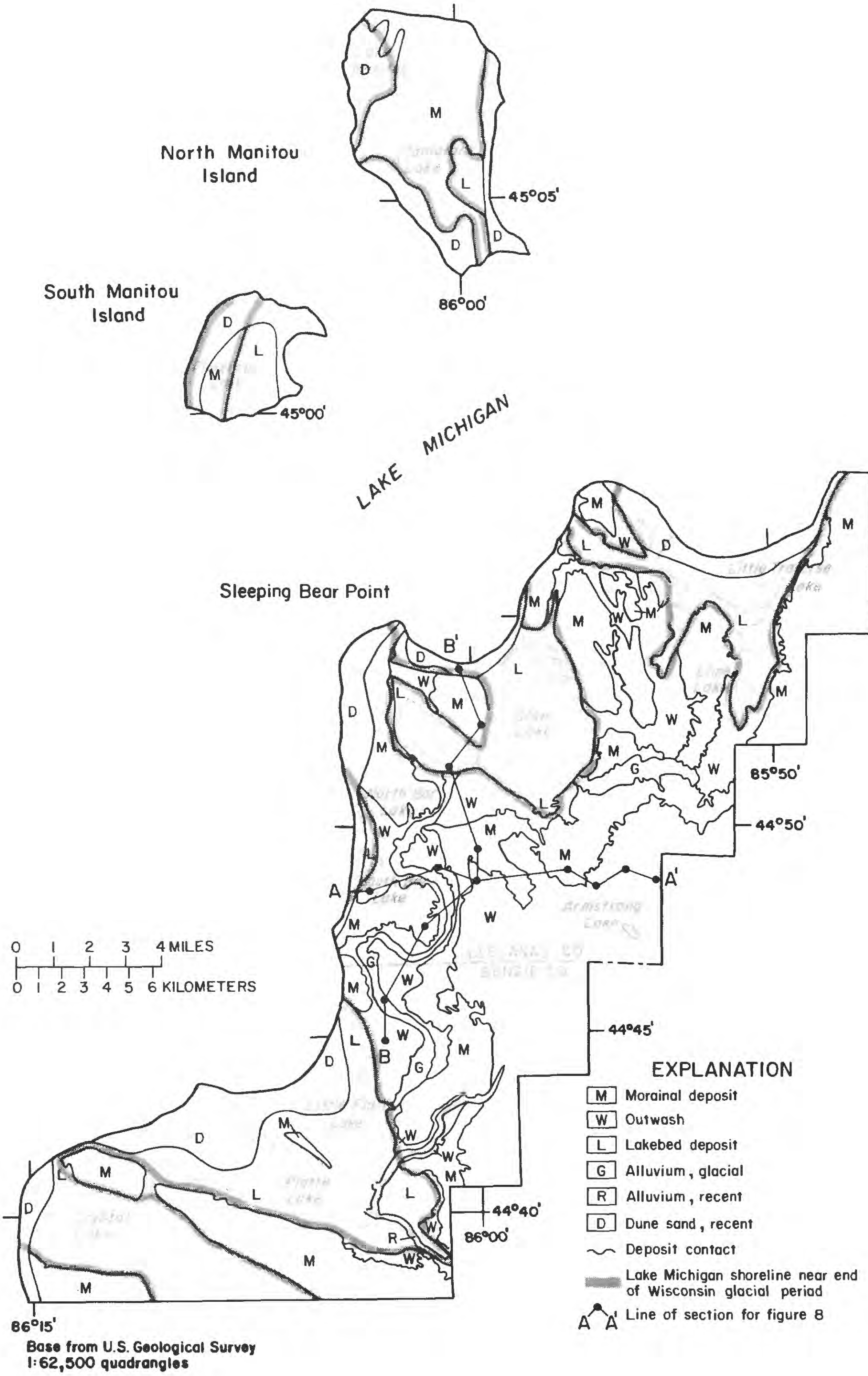

Figure 4.--Distribution of alluvium, dune sand, and glacial deposits.

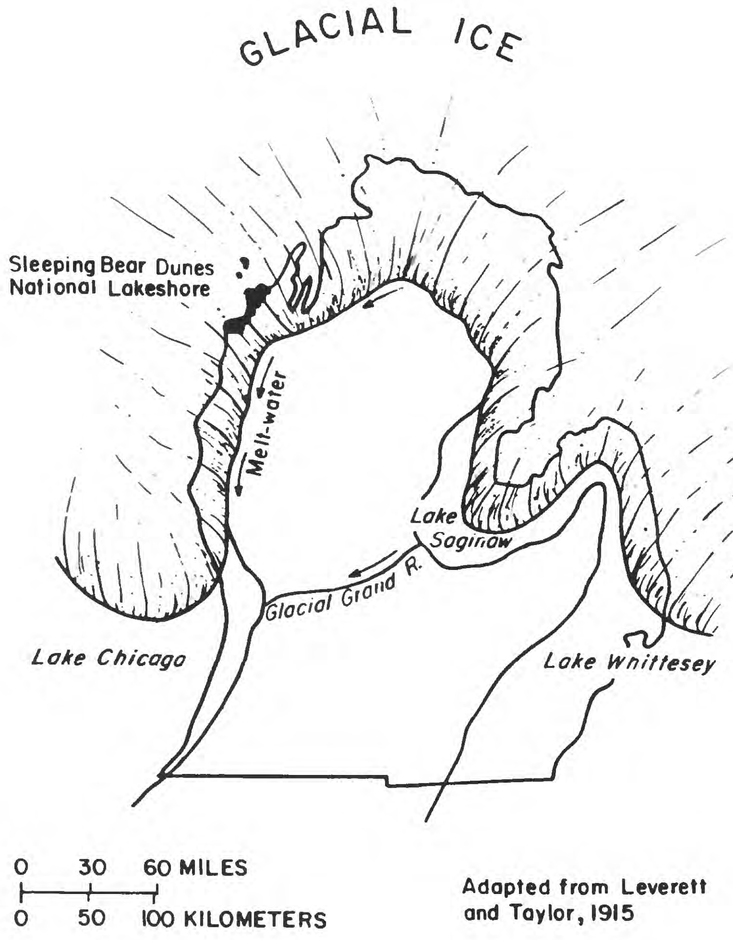

Figure 5.--Extent of Port Huron ice advance.

The second minor advance, Greatlakean (Burgis, 1977 and Martin, 1957), covered much of the study area (fig. 6) and was responsible for reshaping many of the landforms in the immediate vicinity of the park. The ice reached a terminus a few miles east of the present Lake Michigan shore, leaving deposits that form most of the hilly areas. As the Greatlakean ice advanced, small lobes of ice funneled into pre-existing lowlands. Glacial processes in these lobes resulted in erosion in the lowlands and deposition between and at the margins of the lobes (fig. 7). The larger lakes in the park area now occupy the lowlands.

Terminal and recessional moraines form the hills in the park area. These moraines consist of a variety of sediment types. The cores of the moraines probably contain material deposited by glacial ice prior to the last two minor ice advances. Draped over this are red, sandy tills deposited during the Greatlakean or Port Huron glaciations, sand and gravel deposited by superglacial streams, and sand deposited by wind.

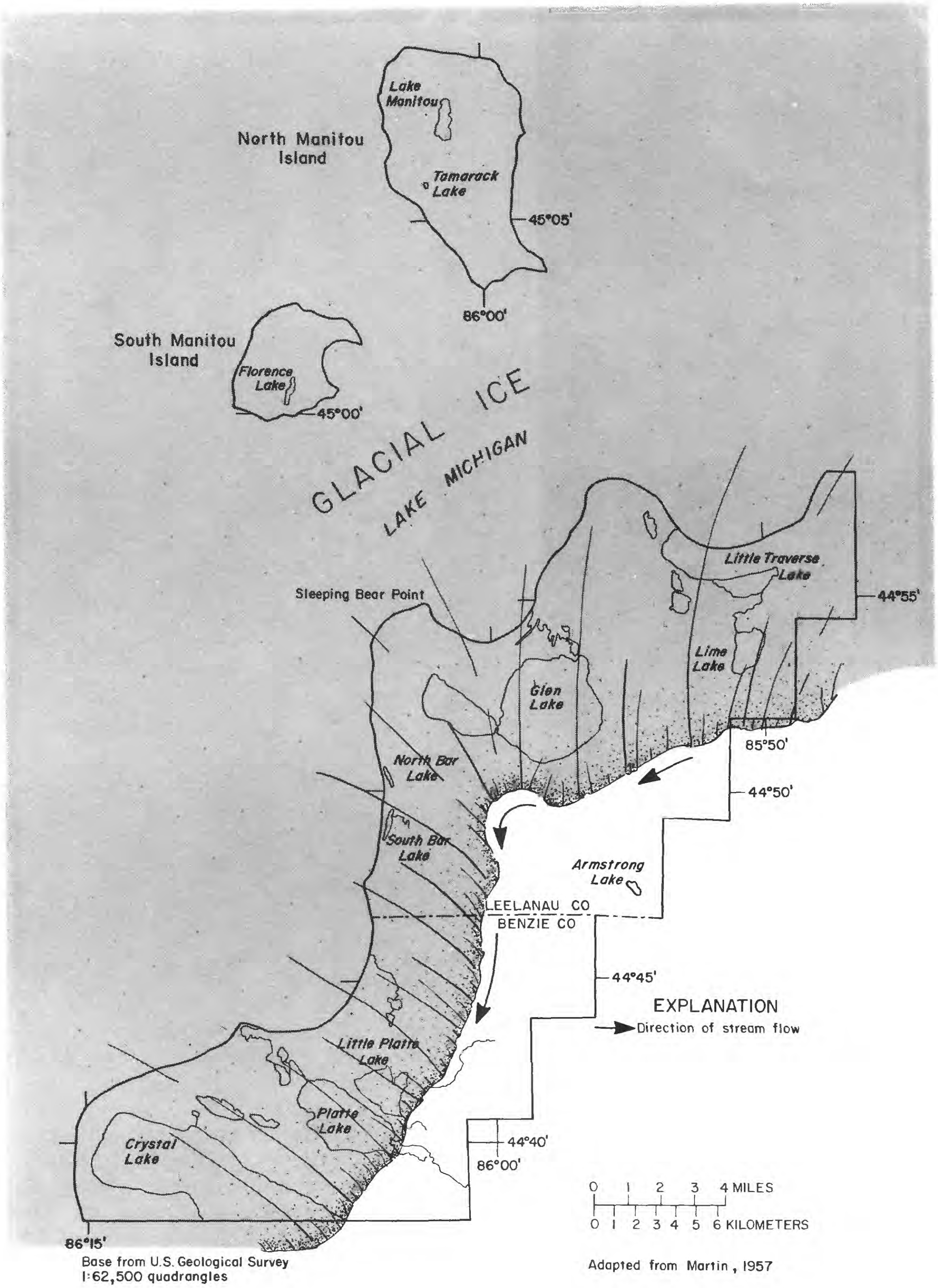

Figure 6.--Extent of Greatlakean ice advance.

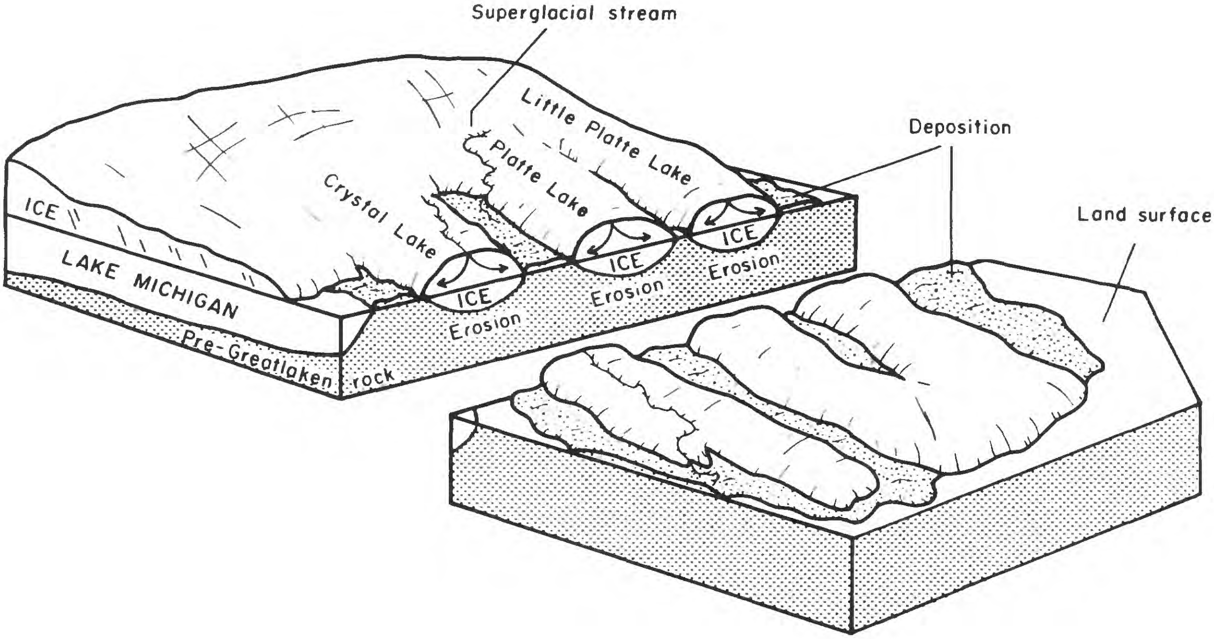

Figure 7.--Glacial processes during Greatlakean advance.

Most of the surface of the morainal complex is covered by well-sorted sand. Coarse sand and gravel are exposed in gravel pits along the crests of the moraine. Clay-rich, red till can be seen in some cuts in the flanks of morainal hills. High bluffs along Lake Michigan, including the bluffs upon which Sleeping Bear Dune rests, are formed by recessional moraines. Moraines border parts of most lakes.

A thick unit of sand and gravel outwash forms a relatively flat area east of the morainal area. This outwash, deposited by melt-water streams flowing from the margin of the glacier ice, is greater than 200 feet thick in some areas and is a primary source of water to wells. The composition and relationship of glacial deposits is shown in figure 8.

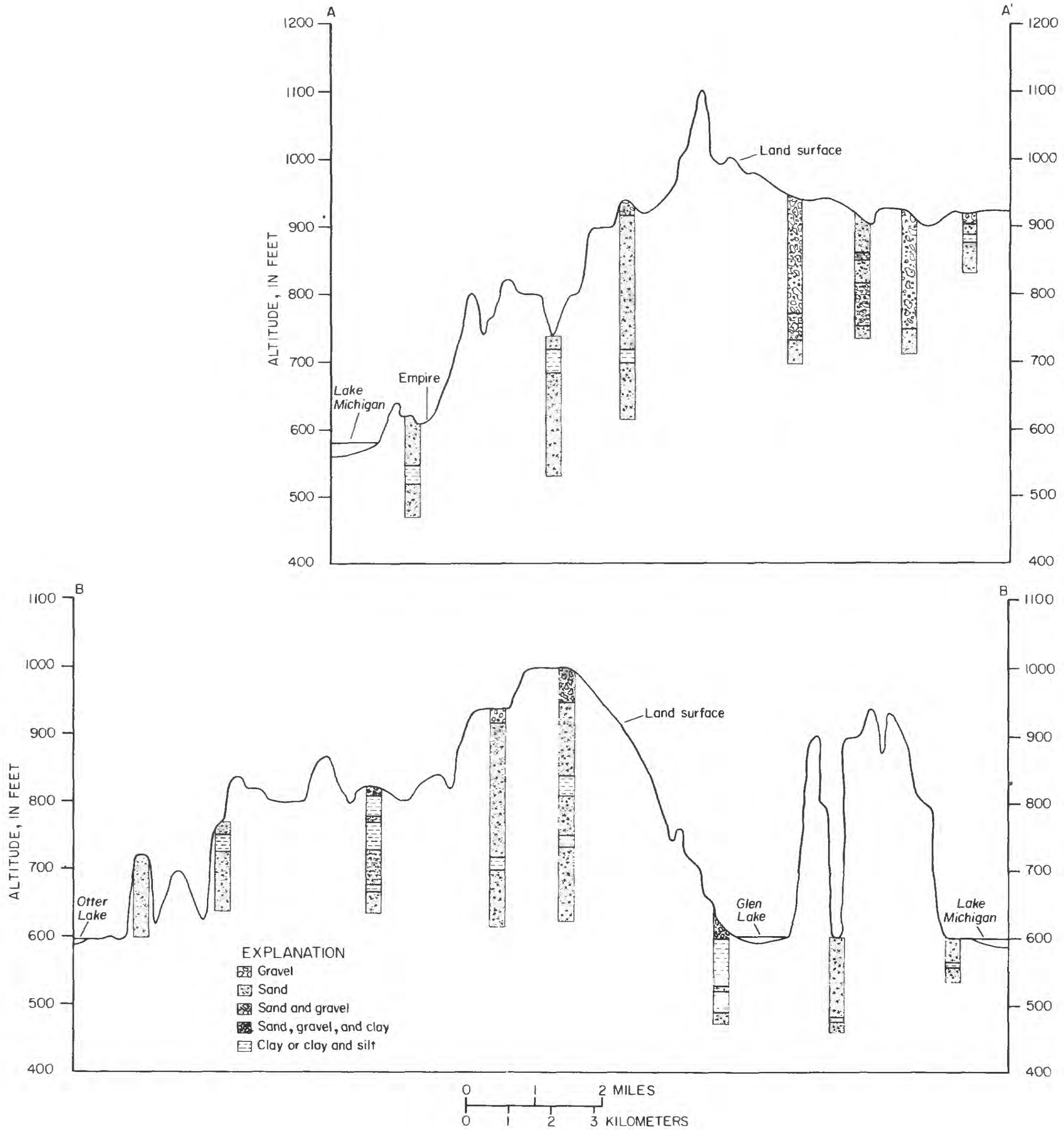

Figure 8.--Cross sections showing composition of glacial deposits (line of section shown on figure 4).

Kettles were produced in areas where stagnant ice masses were covered by sand and gravel. A number of kettles occur in the plateau area 3 to 8 miles east of Empire (fig. 9). Some small lakes, such as Armstrong Lake, are kettles that contain water.

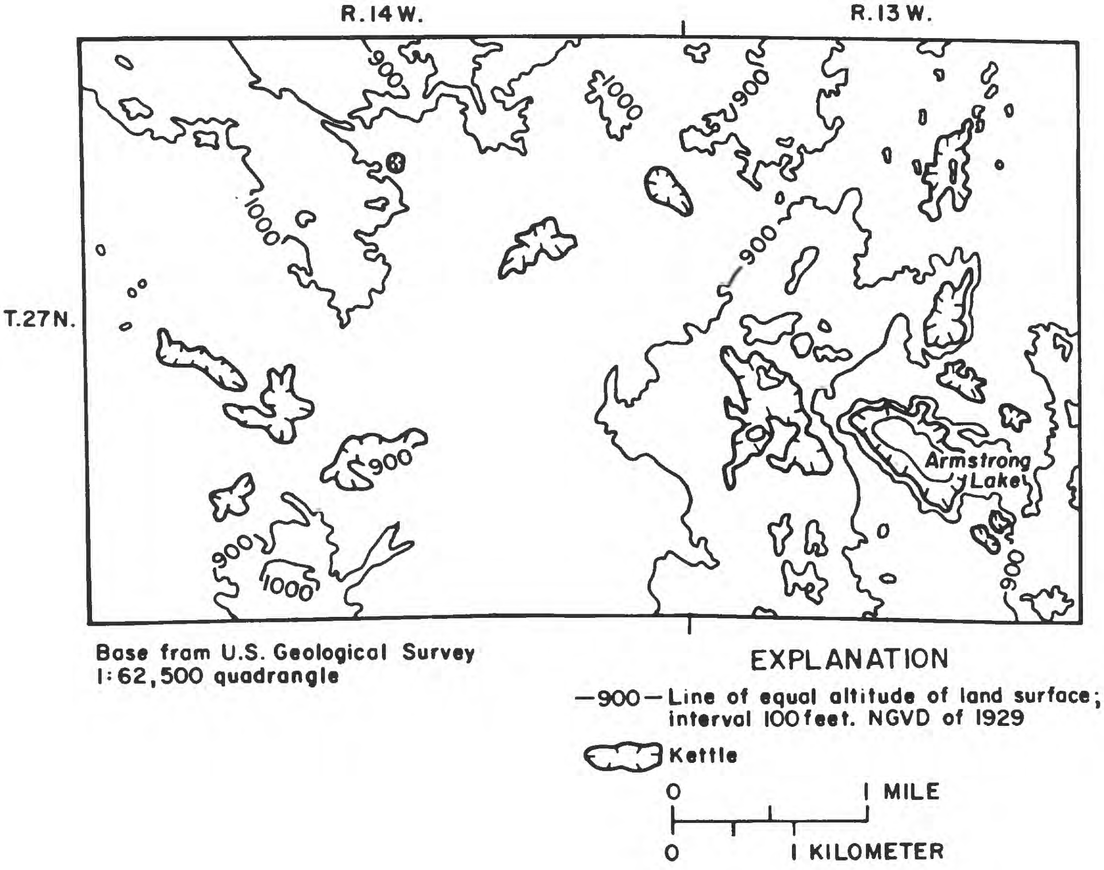

Figure 9.--Kettles east of Empire.

Final retreat of ice resulted in large variations in the level of water in Lake Michigan. At high levels the lake extended inland flooding some of the land. Lakebeds formed in the inundated areas (fig. 4) and wave-cut cliffs formed along the shoreline. During the final stages, bars developed and landlocked the inundated waters (Calver, 1946) to form most of the present-day lakes. Sleeping Bear Dune was deposited when the level of Lake Michigan held steady at an altitude of about 612 feet.

Bedrock

Bedrock is the consolidated rock underlying the glacial deposits. It consists of a thick sequence of layered sedimentary units, primarily sandstone, shale, and limestone. The subcropping bedrock (fig. 10) is the Antrim Shale of Mississippian age and limestone of the Traverse Group of Devonian age (300 to 350 million years old). The eroded bedrock surface is at altitudes ranging from below sea level to 200 feet above.

Little is known about the geologic history of the area during the period between deposition of the Traverse-Antrim formations and the glacial deposits overlying them. The absence of rocks representing this interval suggests that the time was one in which rocks either were not deposited or, if deposited, were subsequently eroded.

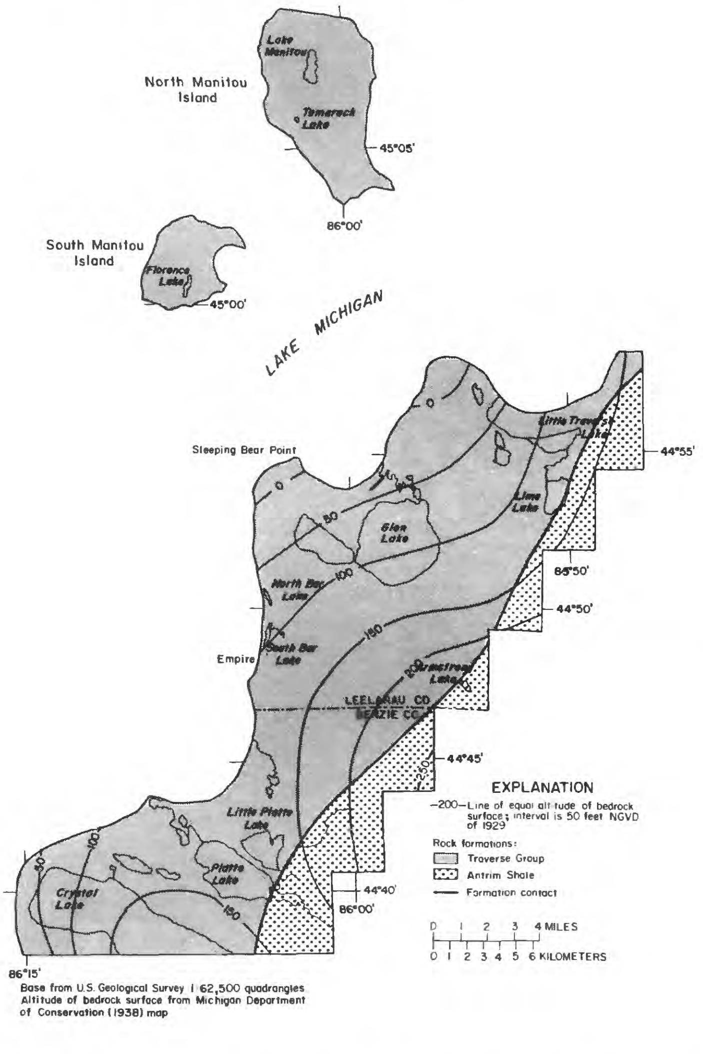

Figure 10.--Subcropping bedrock formation and altitude of bedrock surface.

SURFACE WATER

Lakes

Small lakes are an important aspect of the water resources of Sleeping Bear Dunes Lakeshore; 15 lie within or are adjacent to the park boundary (fig. 2). All lakes are ice covered from January to early April; maximum ice cover occurs in February and March. Ice thicknesses of 20 inches at Crystal Lake and 27 inches at Little Traverse Lake have been recorded (Sleator, 1978). Figure 11 shows sites where water information was collected. Figure 12 shows changes in water levels of selected lakes.

North Bar Lake is unique in that it is separated from Lake Michigan only by a large sand bar. At times, wind and Lake Michigan currents wash out the sand bar and water flows into Lake Michigan. Once flow ceases, the sand bar begins to rebuild. This process was observed near the end of June 1979, during June and July 1980, and near the end of September 1982. The lowest levels in 1980 (fig. 12) occurred during periods when the bar had been washed out. The hydrograph indicates that the sand bar may have washed out at other times during the study. South Bar Lake is similar to North Bar Lake but there is no evidence that the sand bar separating it from Lake Michigan washes out.

The water level of Otter Lake varied only half a foot from spring thaw in May 1979 until it froze over in January 1980. Otter Lake has a small inlet and a small outlet; ground-water inflow is the principal source of water. School Lake has only an outlet and also is ground-water fed. Its level varied about 1 foot during the measurement period 1980-82. Levels of Platte and Glen Lakes varied less than half a foot.

Chemical and physical analyses of water from North Bar, School, and Glen Lakes, and Lake Michigan are shown in table 1 (at back of report). Analyses of water from Manitou and Florence Lakes are shown in table 6 (at back of report). In addition to these analyses, field measurements of specific conductance were made for the lakes listed below.

Lake	Specific conductance (μmhos at 25°C)	Number of measurements
Loon Lake	289-330	3
Bass Lake (nr Otter Lake)	294-300	3
South Bar Lake	310-350	3
Bass Lake (nr School Lake)	210-240	2
Shell Lake	220-240	2
Round Lake	300	1
Rush Lake	350	1

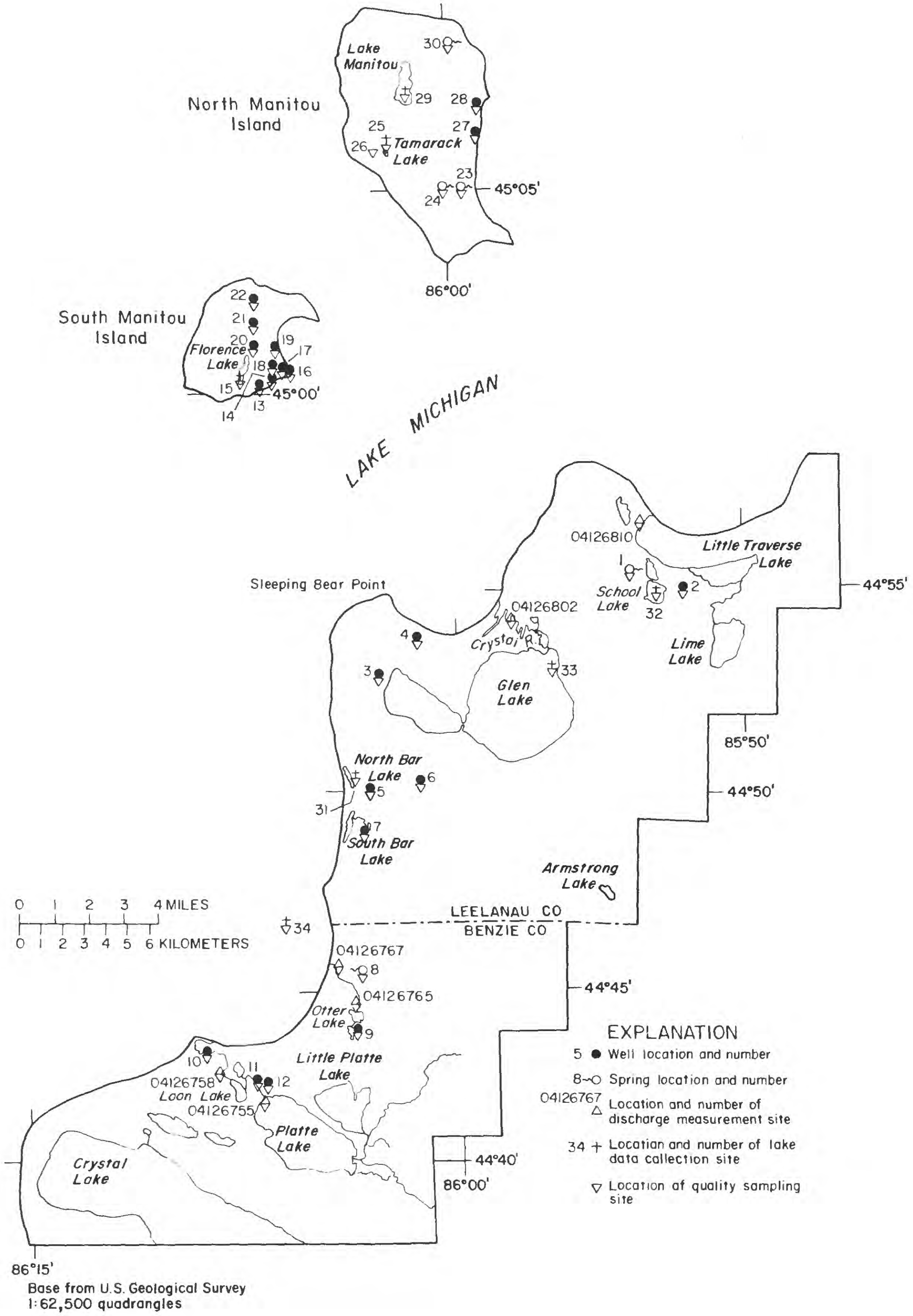

Figure 11.--Location of surface- and ground-water sampling and data-collection sites.

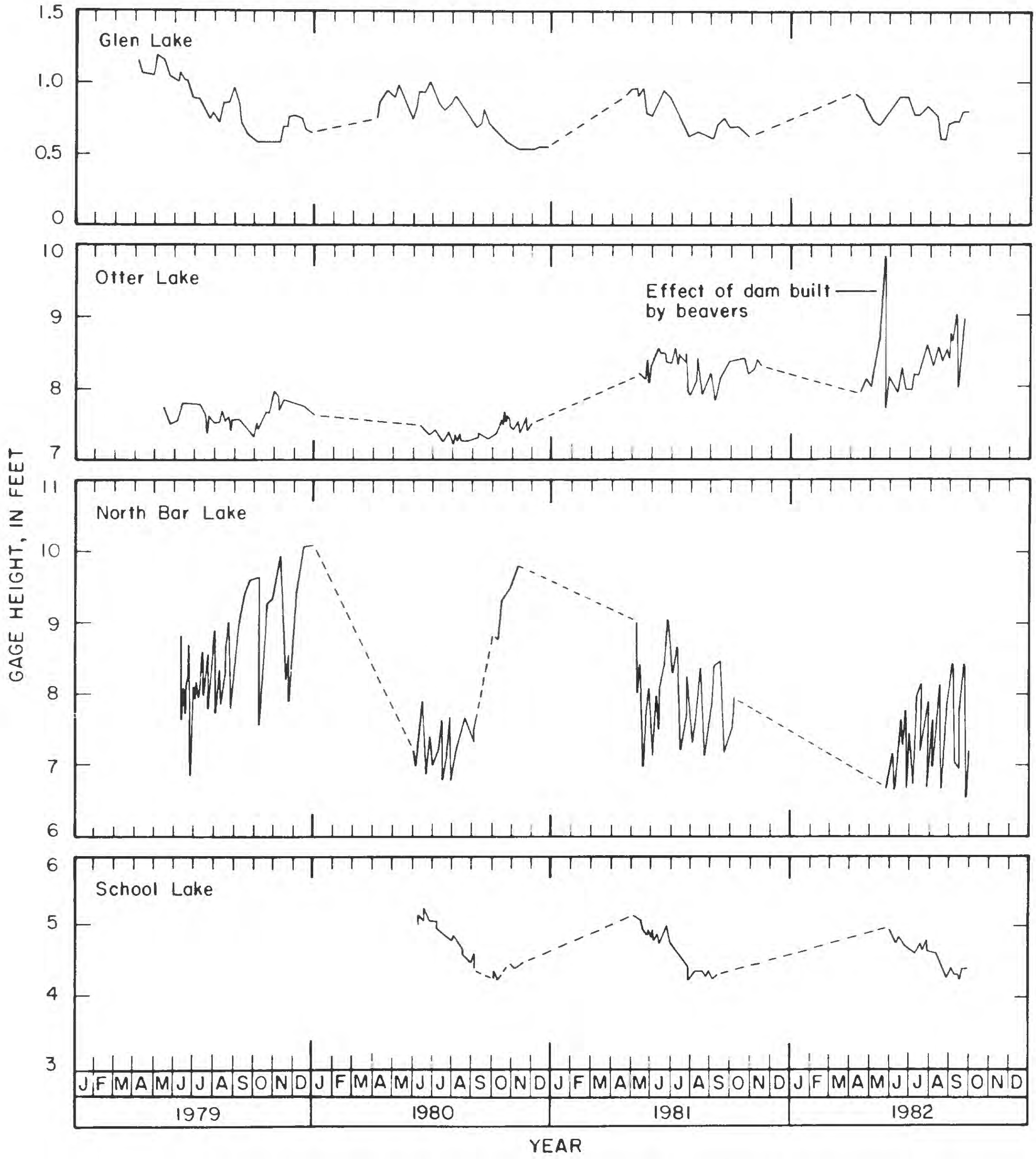

Figure 12.--Lake levels of selected lakes (dashed line indicates missing record).

A comparison of analyses of lake water in table 1 to drinking water standards of the U.S. Environmental Protection Agency (1977a, 1977b) in table 2 indicate that water from lakes is of excellent quality and meets criteria for all constituents in the table. It is frequently hard, however. Concentrations of nutrients and trace metals were low; no pesticides were detected.

Table 2.--Drinking water standards of the U.S. Environmental Protection Agency (1977a, 1977b)

Constituent or property	Maximum contaminant levels for inorganic chemicals	Secondary maximum contaminant levels
Arsenic (As)	50 μg/L	
Barium (Ba)	1,000 μg/L	
Cadmium (Cd)	10 μg/L	
Chloride (Cl)		250 mg/L
Chromium (Cr)	50 μg/L	
Color (Units)		15 units
Fluoride (F)	1.4 to 2.4 mg/L	
Iron (Fe)		300 μg/L
Lead (Pb)	50 μg/L	
Manganese (Mn)		50 μg/L
Mercury (Hg)	2 μg/L	
Nitrate (NO_3 as N)	10 mg/L	
pH (Units)		6.5 to 8.5 units
Selenium (Se)	10 μg/L	
Silver (Ag)	50 μg/L	
Sulfate (SO_4)		250 mg/L
Zinc (Zn)		5,000 μg/L
Total dissolved solids		500 mg/L

Lake Michigan

Lake Michigan, which has a surface area of 22,400 square miles and a maximum depth of 923 feet, influences the climate over an extensive area. From 1900 to 1980, the mean water level of Lake Michigan was 579 feet above IGLD of 1955 (U.S. Army Corps of Engineers, 1981). During this investigation, the level ranged from 578.00 in March 1978 to 579.7 in July 1979. Comprehensive data on levels of Lake Michigan are included in reports by Torrey (1976), Beeton and Chandler (1962) and Bell (1980).

Water was collected for chemical analysis from Lake Michigan at site 34, 1 mile west of the end of Esch Road near Empire, Michigan. Samples were obtained at depths of 20, 40, 60, 80, and 100 feet, and composited. The analysis (table 1, at back of report) indicates that the water is similar in most respects to that of inland lakes and streams.

Streams

Platte River, Otter Creek, Crystal River, and Shalda Creek flow through the park to Lake Michigan. Discharge measurements, made at six locations on these streams (fig. 11), are shown in table 3. The

Table 3.--Discharge of streams flowing through park (in cubic feet per second)

Date	04126755 Platte River at M-22 nr Honor	04126758 Platte River at weir on Loon Lake nr Honor	04126765 Otter Creek at Otter Lake nr Empire	04126767 Otter Creek at Aral Road nr Empire	04126802 Crystal River nr Glen Arbor	04126810 Shalda Creek nr Glen Arbor
May 9, 1979	283	307		21.6		
May 10, 1979			6.84		92.0	54.9
Aug. 14, 1979	179	186				
Aug. 15, 1979			3.86			
Aug. 16, 1979					49.4	20.0
Aug. 17, 1979				21.1		
Oct. 29, 1979	183	190	4.68			
Oct. 30, 1979				17.7	54.9	26.6
May 12, 1980				16.4		
May 13, 1980			6.14			
May 14, 1980					54.1	28.3
May 15, 1980	158	173				
Aug. 26, 1980						17.1
Aug. 27, 1980					23.1	
Aug. 28, 1980	119	122	3.09	14.8		
May 5, 1981	192	209			78.0	37.1
May 7, 1981			1.85	13.6		
Oct. 26, 1981			3.39			
Oct. 27, 1981				14.9	60.2	20.6
Oct. 28, 1981	160	156				
May 24, 1982	144		5.00			
May 25, 1982		140		16.9		
May 26, 1982					34.4	23.1

measurements were used to estimate values for the lowest average 7-day flow for 2- and 10-year recurrence intervals. These low-flow values follow:

Stream	Drainage area (mi^2)	Lowest average 7-day discharge, in ft^3/s, for indicated recurrence interval. (in parentheses, $(ft^3/s)/mi^2$)	
		2-year	10-year
04126755 Platte River at M-22 nr Honor	166	120 (0.72)	100 (0.60)
04126758 Platte River at Weir on Loon Lake nr Honor	169	120 (0.71)	100 (0.59)
04126765 Otter Creek at Otter Lake nr Empire	1.2	3.0 (2.50)	2.5 (2.08)
04126767 Otter Creek at Aral Road nr Empire	9.55	15 (1.57)	14 (1.47)
04126802 Crystal River nr Glen Arbor	42.0	30 (0.71)	24 (0.57)
04126810 Shalda Creek nr Glen Arbor	33.8	17 (0.50)	14 (0.41)

Low-flow values are commonly used by planners and managers as indicators of dependable flows for water supplies without need for storage.

The flow of Otter Creek during low-flow conditions seems to be due largely to ground-water inflow. Seepage along the stream bank is evident at several locations and several springs were found during field reconnaissance. A comparison of chemical characteristics of water at the mouth of Otter Creek (site 04126767, table 4, at back of report) with those of a spring (site 8, table 5, at back of report) further suggests that this is true.

Platte and Crystal Rivers are also in an area characterized by seeps and springs. Ground-water inflow seems to be a significant component of streamflow throughout the year.

Water of streams in the park area is of excellent quality when compared to U.S. Environmental Protection Agency drinking water standards (table 2). Pesticides were not detected and suspended-sediment concentrations were low. On May 24-26, 1982, sediment concentrations ranged from 3 to 11 mg/L. With the exception of Otter Creek, flow was low at the time of sampling.

GROUND WATER

Potentiometric Surface

The potentiometric surface (fig. 13) reflects the altitude of the water surface in wells, lakes, and streams. Because of the variety of sources of water-level data used and the complexity of the geology, the potentiometric surface may reflect several flow systems. Water levels

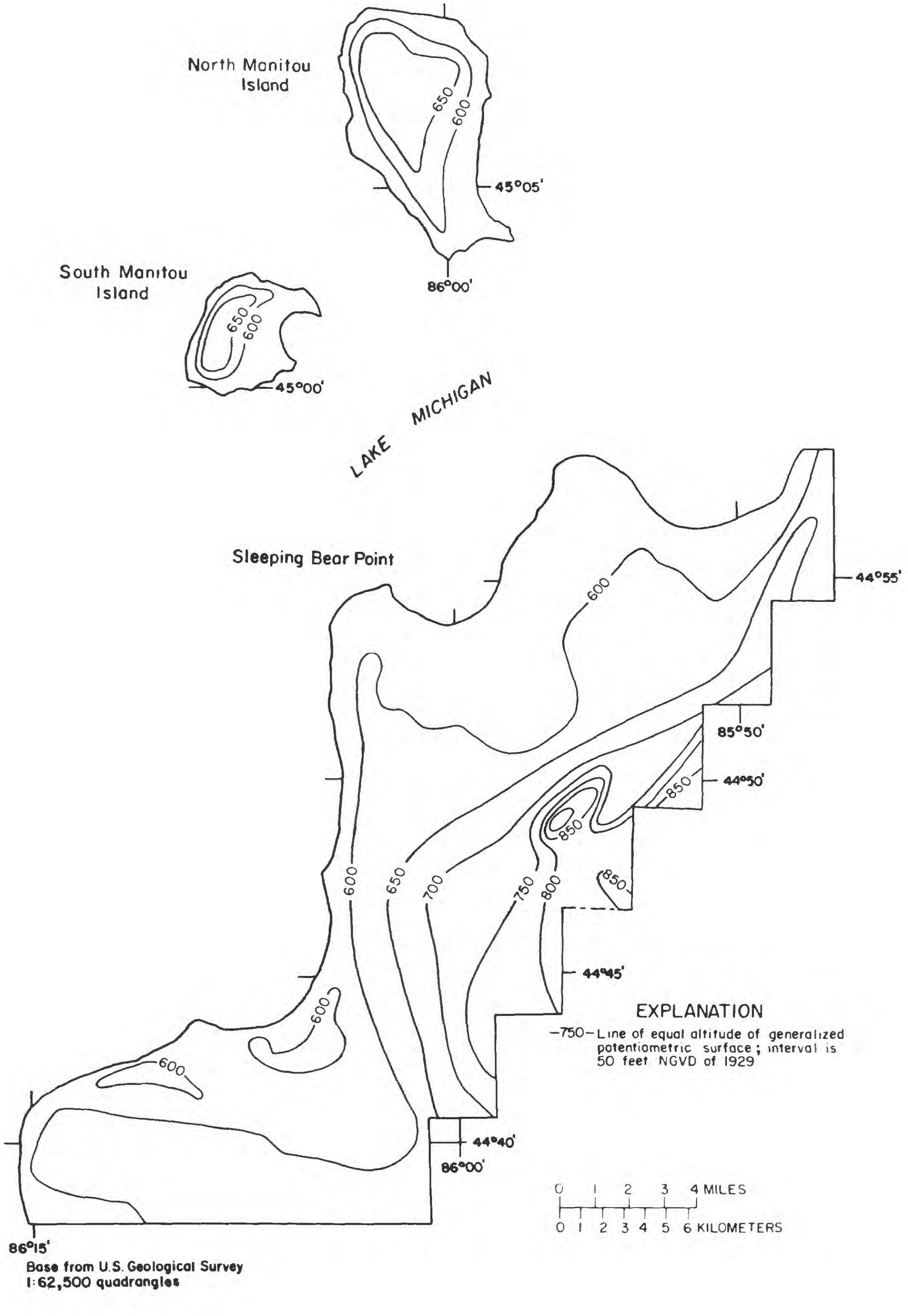

Figure 13.--Potentiometric surface in glacial deposits.

in two wells, shallow well 5 and deep well 6, were measured either monthly or continuously, with an automatic recorder, during this study. Figure 14 shows that levels in the two wells fluctuated less than 2 feet during the period from August 1980 to August 1982. Water levels in the shallow well are affected more by climatic conditions than are those in the deep, as shown by the high levels in spring. Water levels in both wells gradually declined during the period of study indicating, because there is no pumpage in the vicinity, a reduction in recharge.

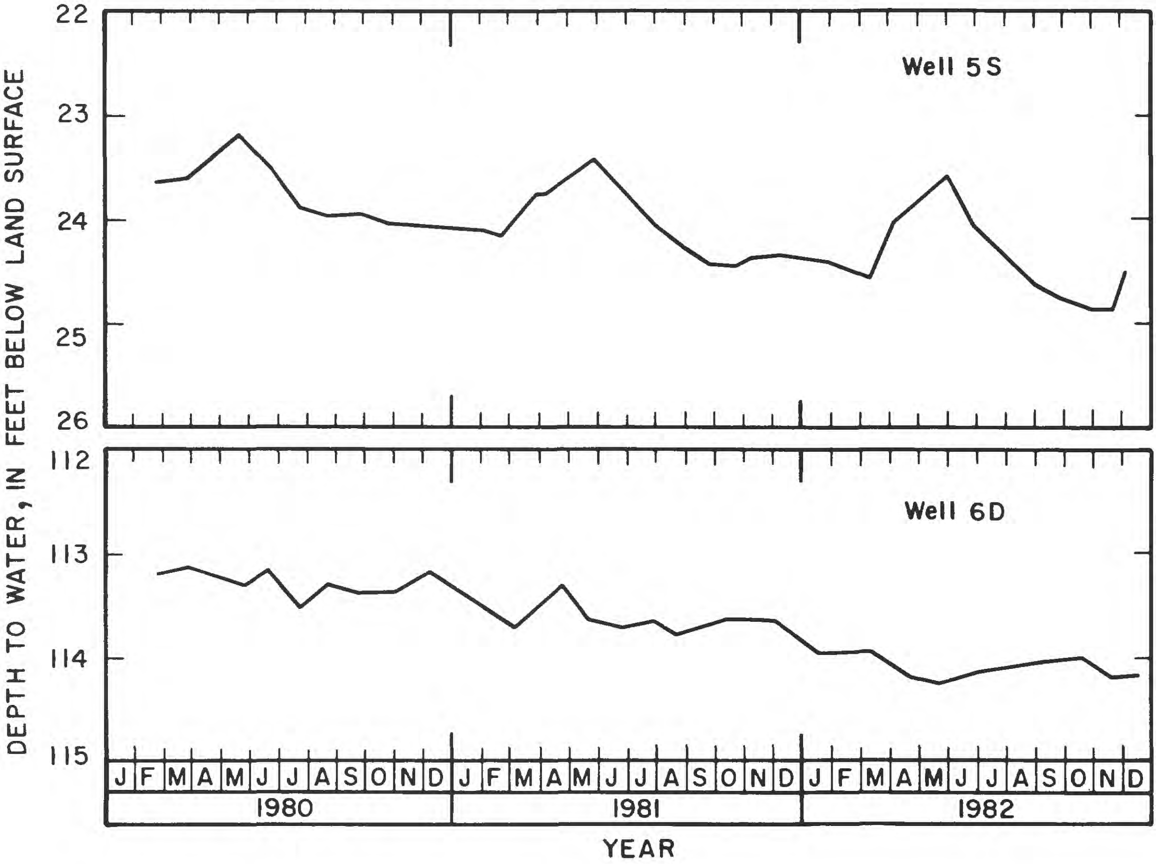

Figure 14.--Water levels in shallow well 5 and deep well 6 near Empire.

The shape of the potentiometric surface is typical of the shape of such surfaces in humid areas with high relief. Ground water flows from recharge areas in the uplands to discharge areas (streams and lakes) in the lowlands. Generally, the depth to water is greater in upland areas than in the lowlands. In the park area the gradient, or slope of the potentiometric surface, ranges from 25 to 50 feet per mile. It is steepest in areas of high surface relief and low hydraulic conductivity (moraines) and is slight in areas of low relief underlain by materials of high hydraulic conductivity (outwash plains).

The potentiometric map (fig. 13), in conjunction with a topographic map (fig. 3) of the area, can be used to estimate the depth to water, by subtracting, at any point, the altitude of the potentiometric surface from the altitude of the land surface.

Potential Yield of Aquifers

The potential water-yielding abilities of aquifers can be estimated from specific capacity--the discharge of a well divided by drawdown of the water level in wells. Values of specific capacity, as derived from data on driller's records, generally ranged from 50 to less than 1 (gal/min)/ft. High values, indicating areas of high potential well yield, as shown in figure 15, generally are in areas underlain by glacial outwash or lakebed deposits. Low values occur in morainal areas.

Wells 11 and 12 (fig. 11), 87 and 85 feet deep, respectively, were installed in a park campground along Platte River in 1981. Depth to water in both wells was about 17 feet, a few feet above the level of nearby lakes. The 6-inch wells have 15-foot screens set at the bottom of the hole and are in glacial deposits consisting primarily of sand and gravel. Well 12 penetrated a 19-foot thick clay unit between 25 and 44 feet below land surface.

Pumping tests at about 100 gal/min were conducted on both wells. Drawdowns were 11.8 ft in well 11 and 13.6 ft in well 12, indicating specific capacities of 7.5 to 8.5 (gal/min)/ft. Because the pumping rate was near the maximum transmitting capacity of the screen, the specific-capacity value may be low. Without nearby observation wells, further evaluation of potential yields was not possible. The data indicate, however, that wells in the sand and gravel aquifers in the park can yield 100 gal/min without difficulty and that wells having larger diameters or longer screens can probably produce 150 gal/min or more.

Water Use

The greatest use of water, excluding recreational use of surface water, is for domestic purposes. This use ranges from 10 to 15 gal/day/person and is greatest during the summer months when travel through the park is greatest. By the year 2000, about 10,000 people will visit the park daily during the busy season and will use 100,000 to 150,000 gallons of water per day. During a 15-hour use period, this is 110 to 165 gal/min total for the park. Known capacity of wells in several places is at least 100 gals/min and indications are that similar quantities can be obtained in many other areas in the park. Several such wells would be more than adequate for the needs of the park in the year 2000.

Water Quality

The chemical and physical characteristics of water from 10 wells and two springs are given in table 5 (at back of report); their locations are shown in figure 11. Analyses suggest that quality of the water is

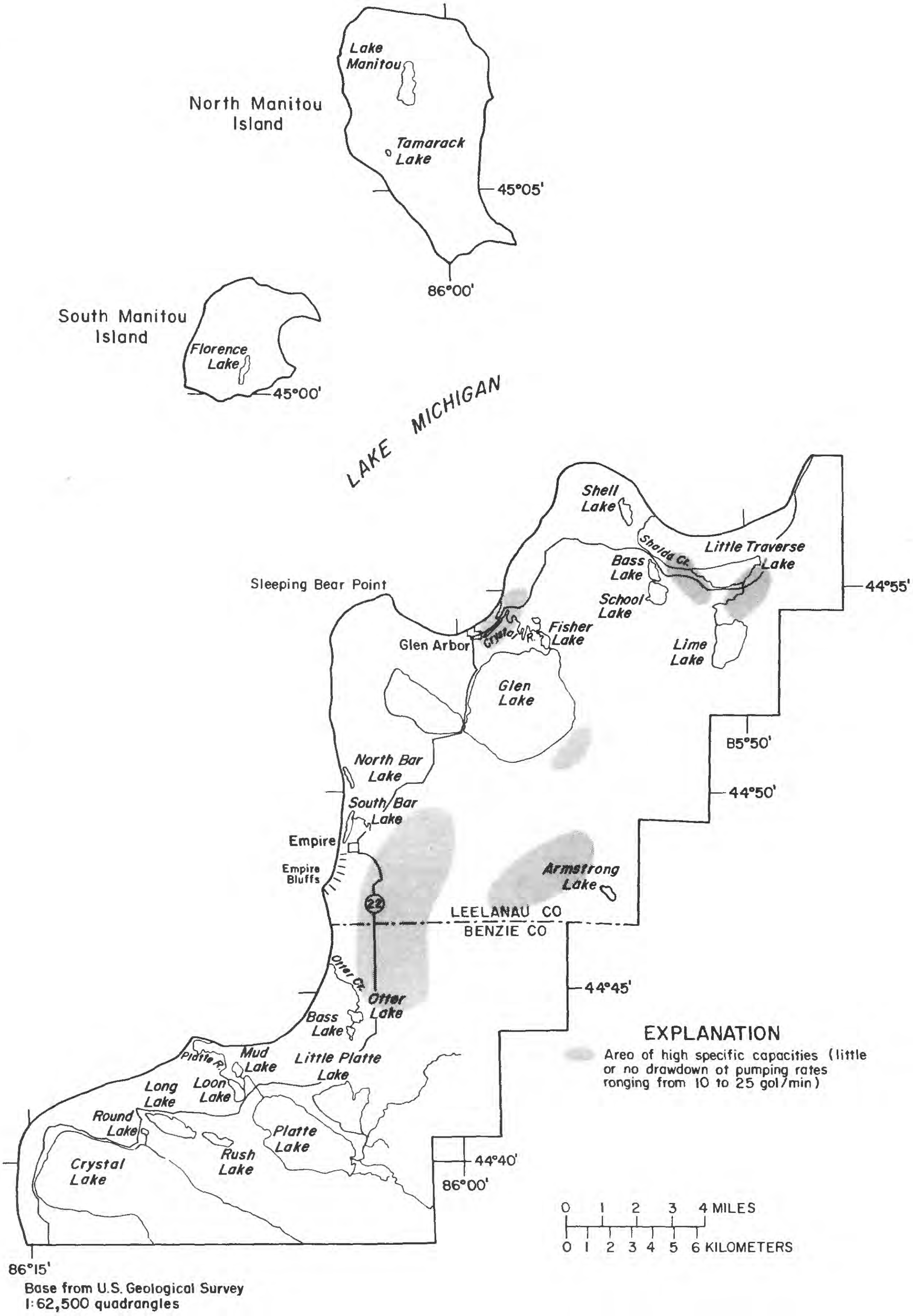

Figure 15.--Specific capacity of wells in glacial deposits.

unrelated to well depth. Water having the lowest dissolved-solids concentration occurred near School and Bass Lakes (spring 1 and well 2), near the Village of Empire (wells 5, 6, and 7), and near Otter Creek (spring 8 and well 9). At most locations water is of a calcium bicarbonate type, although at some places substantial amounts of chloride and sulfate occur. Concentrations of trace metals do not exceed levels common in Michigan ground waters. Pesticides were not detected. With the exception of iron in water from well 4, concentrations do not exceed U.S. Environmental Protection Agency drinking-water standards (table 2).

WATER RESOURCES OF MANITOU ISLANDS

North and South Manitou Islands lie 7 to 8 miles north of the mainland. North Manitou, in recent years, has been a corporate farm and deer hunting preserve. It has been closed to public access for about 40 years. South Manitou is the site of a Coast Guard station and lighthouse. Several small farms and summer homes are on the island. South Manitou is open to the public. Geologically, the islands are similar to the mainland. Glacial deposits, at least 300 ft thick, consist primarily of interbedded sand, gravel, and clay.

North Manitou Island

North Manitou has two small, relatively shallow lakes. Manitou Lake has a surface area of 252 acres. Its bottom is sandy and, at places, aquatic weeds are prevalent. Tamarack Lake has a surface area of 9.9 acres; it is shallow and has a mucky, soft bottom. When the bottom is disturbed, decaying organic compounds give off a noticeable odor of hydrogen sulfide. Growth of aquatic weeds and algae is prolific.

Two small streams drain the island. One, the outlet from Manitou Lake, was not flowing when the island was visited in July 1982, although visual evidence suggests that it does flow for at least part of the year. The other, an unnamed creek, flows from a spring just north of Tamarack Lake. On July 27, 1982, the discharge of the creek was 0.23 ft^3/s--a flow that may have been increased by the 0.07 inch of rain that fell on the island on the same day.

Three springs (fig. 11), The Spring (site 23), Angell Spring (site 24), and an unnamed spring (site 30), were only seeps in July 1982. According to island residents, however, they were larger in the past. The presence of springs suggests that ground water is available for development of small public supplies. As far as is known, only four wells have been installed on North Manitou Island. Wells were dug at the school house and a farm house abandoned by early settlers. Two other wells, drilled during the past 20 years, provided domestic supplies.

Surface and ground water on North Manitou Island is generally hard (table 6, at back of report), but otherwise of excellent chemical quality; concentrations of dissolved substances did not exceed drinking water standards. Some lake water is reported to have objectionable odor, turbidity, and color, however.

South Manitou Island

South Manitou has one lake, Florence Lake, which has no inlet or outlet. It has a surface area of 82.1 acres, a sandy bottom, and a maximum depth of about 26 feet. A comparison of chemical analyses made in 1974-75 by Gannon and Stockwell (1978) with an analysis made during this study (table 6) indicate that the quality of the lake water has not changed appreciably in the past eight years.

Eight wells were installed on South Manitou (fig. 16) in 1982 in an attempt to locate drinking-water supplies. Sand and gravel are abundant (table 7, at back of report) at land surface in the lakebed and dune areas (fig. 4); clay occurs at the surface in the morainal area. Materials in the subsurface vary considerably and in some wells, especially those in or near the morainal area, clay is abundant.

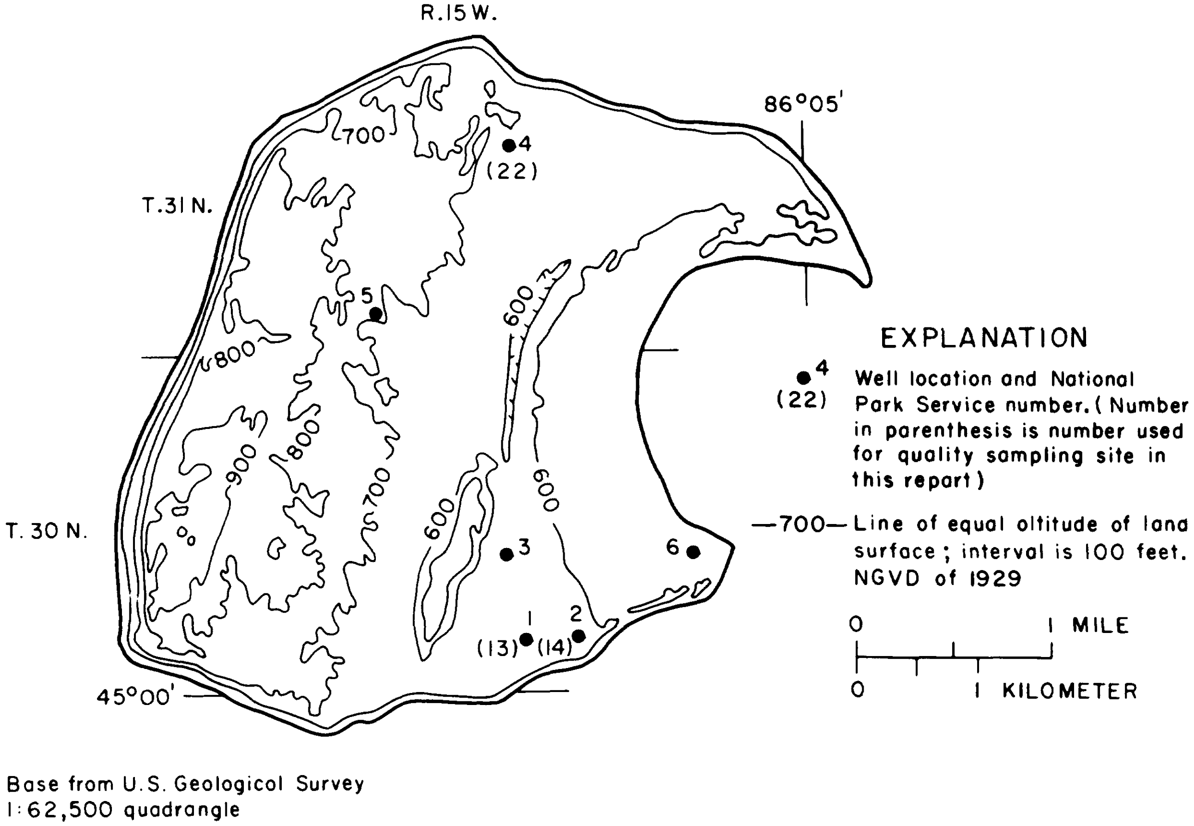

Figure 16.--Location of wells drilled on South Manitou Island in 1982.

Nine wells on the island were sampled (fig. 11). Dissolved-solids concentrations ranged from 136 mg/L in well 22 to 258 mg/L in well 21. These two wells are less than a quarter-mile apart on the north end of the island. Well 22 is newly drilled and 83 feet deep; well 21 is an old dug pit well about 20 feet deep.

Data indicate that ground water on the island is suitable for drinking although it is likely to be hard at some locations. No unusual chemical characteristics were detected, although water from well 16 had a dissolved-phosphorous concentration higher than common in most ground water.

CONCLUSIONS

Sleeping Bear Dunes National Lakeshore has sufficient supplies of water for present campgrounds and other park facilities. These supplies are also adequate for the forseeable future. Much of the park is underlain by sand and gravel aquifers that can yield at least 100 gal/min of good quality water to properly designed wells. Considering the total requirements for the park in the year 2000--probably no more than 165 gal/min--several 100 gal/min wells would be more than adequate. Streams, small lakes, and Lake Michigan provide ample water for recreational needs. Lowest average 7-day discharge of streams ranges from 3 ft^3/s for Otter Creek to 100 ft^3/s for Platte River.

Both surface water and ground water are of good quality and appear to be suitable for most uses. Dissolved solids range from 35 to 180 mg/L in lakes, from 145 to 214 mg/L in streams, and from 136 to 468 mg/L in ground water. Concentrations of most constituents do not exceed the drinking water standards of the U.S. Environmental Protection Agency.

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TABLES

Table 1.--Chemical and physical characteristics of lakes

Date	Sampling depth (ft)	Temperature (deg C)	Turbidity (NTU)	Color (Platinum-cobalt units)	Specific conductance (µmhos)	pH (units)	Carbon dioxide, dissolved (mg/L as CO_2)	Alkalinity, field (mg/L as $CaCO_3$)	Bicarbonate, field (mg/L as HCO_3)	Carbonate, field (mg/L as CO_3)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, nitrate dissolved (mg/L as N)	Phosphorus, dissolved (mg/L as P)
Site 31 - North Bar Lake nr Empire, Michigan (Lat 44°50'07", long 086°03'40")													
Aug. 15, 1979	3.00	18.5	2.0	--	310	8.3	1.5	149	182	0	0.10	0.21	<0.01
May 13, 1980	1.00	10.0	.90	1	335	8.2	1.9	160	190	0	.01	.44	.01
Oct. 27, 1981	--	8.0	1.0	1	304	8.1	--	--	--	--	<.01	--	.03
Site 32 - School Lake nr Glen Arbor, Michigan (Lat 44°55'12", long 085°53'08")													
Aug. 16, 1979	6.00	17.0	1.0	--	210	8.8	0.4	126	105	24	<0.01	0.54	<0.01
May 14, 1980	1.00	11.0	.65	6	248	8.6	.6	120	140	6	.01	.00	.01
Oct. 27, 1981	--	6.0	.50	2	234	8.1	--	--	--	--	<.01	--	<.01
Site 33 - Glen Lake nr Glen Arbor, Michigan (Lat 44°53'31", long 085°56'45")													
Aug. 17, 1979	--	16.0	1.0	--	245	8.3	1.3	133	162	0	0.04	0.10	<0.01
May 14, 1980	--	9.0	1.1	0	273	8.1	2.0	130	160	0	.00	.05	.00
Oct. 27, 1981	--	8.5	.50	1	260	7.9	--	--	--	--	<.01	--	<.01
Site 34 - Lake Michigan 1 mile west of Esch Road, Michigan (Lat 44°46'12", long 086°06'18")													
May 15, 1980	--	7.0	0.80	2	265	8.1	1.8	110	140	0	0.00	0.23	0.01

Date	Cyanide total (mg/L as Cn)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L $CaCO_3$)	Silica, dissolved (mg/L as SiO_2)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Solids, residue at 180 deg. C, dissolved (mg/L)	Solids, sum of constituents, dissolved (mg/L)
Site 31 - North Bar Lake nr Empire, Michigan (Lat 44°50'07", long 086°03'40")													
Aug. 15, 1979	--	160	9	2.9	42	13	2.3	0.8	4.9	13	0.1	185	--
May 13, 1980	0.00	170	14	4.4	45	14	2.4	.7	4.7	13	.1	183	180
Oct. 27, 1981	<.01	170	--	5.3	43	15	2.6	.4	4.5	6.8	.1	174	168
Site 32 - School Lake nr Glen Arbor, Michigan (Lat 44°55'12", long 085°53'08")													
Aug. 16, 1979	--	110	0	5.3	27	9.8	1.5	1.2	3.5	7.2	0.1	130	134
May 14, 1980	0.00	120	0	.3	34	9.6	1.6	1.0	3.4	8.1	.1	141	133
Oct. 27, 1981	<.01	120	--	9.1	28	12	2.4	1.0	4.6	6.2	.1	146	130
Site 33 - Glen Lake nr Glen Arbor, Michigan (Lat 44°53'31", long 085°56'45")													
Aug. 17, 1979	0.00	130	1	5.4	32	13	2.7	0.6	1.8	11	0.4	139	147
May 14, 1980	.00	140	5	4.7	33	13	2.8	.5	1.6	11	.4	148	146
Oct. 27, 1981	<.01	130	--	5.7	32	13	3.2	.2	2.0	7.9	.5	143	143
Site 34 - Lake Michigan 1 mile west of Esch Road, Michigan (Lat 44°46'12", long 086°06'18")													
May 15, 1980	0.00	130	18	0.9	35	11	5.0	1.0	8.3	21	0.1	155	153

Table 1.--Chemical and physical characteristics of lakes--Continued

Date	Arsenic, dis-solved (µg/L as As)	Barium, dis-solved (µg/L as Ba)	Cadmium, dis-solved (µg/L as Cd)	Chro-mium, dis-solved (µg/L as Cr)	Copper, dis-solved (µg/L as Cu)	Iron, dis-solved (µg/L as Fe)	Lead, dis-solved (µg/L as Pb)	Manga-nese, dis-solved (µg/L as Mn)	Mercury, dis-solved (µg/L as Hg)	Sele-nium, dis-solved (µg/L as Se)	Silver, dis-solved (µg/L as Ag)	Zinc, dis-solved (µg/L as Zn)
Site 31 - North Bar Lake nr Empire, Michigan (Lat 44°50'07", long 086°03'40")												
Aug. 15, 1979	1	30	ND	ND	--	11	ND	<10	<0.5	<1	ND	2
May 13, 1980	2	30	0	13	--	0	0	1	<.1	0	0	10
Oct. 27, 1981	2	20	<1	<1	--	7	<1	<1	.2	<1	<1	<4
Site 32 - School Lake nr Glen Arbor, Michigan (Lat 44°55'12", long 085°53'08")												
Aug. 16, 1979	1	10	ND	<2	--	1	5	1	<0.5	<1	ND	20
May 14, 1980	1	20	1	3	--	10	0	2	<.1	0	0	10
Oct. 27, 1981	3	20	<1	<1	--	5	1	<1	<.1	<1	<1	<4
Site 33 - Glen Lake nr Glen Arbor, Michigan (Lat 44°53'31", long 085°56'45")												
Aug. 17, 1979	1	40	ND	ND	--	<10	4	<10	<0.5	<1	ND	3
May 14, 1980	3	30	4	3	--	0	0	0	<.1	3	0	4
Oct. 27, 1981	2	30	<1	<1	--	<3	1	<1	<.1	<1	<1	<4
Site 34 - Lake Michigan 1 mile west of Esch Road, Michigan (Lat 44°46'12", long 086°06'18")												
May 15, 1980	3	30	1	4	4	1	0	0	0.1	1	0	0

Table 4.--Chemical and physical characteristics of streams

Date	Time	Temperature (°C)	Turbidity (NTU)	Streamflow, instantaneous (ft³/s)	Color (platinum-cobalt units)	Specific conductance (μmhos)	pH (units)	Carbon dioxide, dissolved (mg/L as CO_2)	Alkalinity, field (mg/L as $CaCO_3$)	Bicarbonate, field (mg/L as HCO_3)	Carbonate, field (mg/L as CO_3)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, nitrate dissolved (mg/L as N)
04126755 - Platte River at M-22 nr Honor, Michigan (Lat 44°42'39", long 086°07'08")													
Aug. 14, 1979	0845	18.0	2.0	179	--	295	8.3	1.4	143	174	0	<0.01	0.06
May 15, 1980	1130	11.5	1.0	158	4	320	8.3	1.6	160	200	0	.01	.19
Oct. 28, 1981	0930	8.0	1.4	160	3	281	8.2	--	--	--	--	<.01	--
04126758 - Platte River at weir on Loon Lake nr Honor, Michigan (Lat 44°43'12", long 086°08'12")													
Aug. 14, 1979	1430	19.0	3.0	186	--	290	8.3	1.3	--	--	0	0.01	0.09
May 15, 1980	1000	11.0	1.4	173	2	330	8.3	1.6	160	200	0	.01	.18
Oct. 28, 1981	1100	8.0	1.6	156	1	289	8.2	--	--	--	--	<.01	--
04126765 - Otter Creek at Otter Lake nr Empire, Michigan (Lat 44°44'30", long 086°03'40")													
Aug. 15, 1979	0930	18.0	5.0	3.86	--	280	8.2	1.7	138	168	0	<0.01	0.19
May 13, 1980	1030	12.0	1.3	6.14	0	320	8.2	2.0	160	200	0	.01	.43
Oct. 26, 1981	1530	9.5	1.0	3.39	3	293	8.3	--	--	--	--	<.01	--
04126767 - Otter Creek at Aral Road nr Empire, Michigan (Lat 44°45'42", long 086°04'26")													
May 12, 1970	1100	18.0	--	16.4	--	--	--	--	--	--	--	--	--
Aug. 15, 1979	1200	15.0	4.0	--	--	335	7.6	8.4	171	208	0	<0.01	0.38
Aug. 17, 1979	1130	12.0	1.0	21.1	--	345	7.6	8.4	172	210	0	<.01	.01
May 12, 1980	1100	18.0	1.5	16.4	0	330	8.1	2.4	160	190	0	.01	.62
Oct. 27, 1981	0900	4.5	.50	14.9	4	338	7.9	--	--	--	--	<.01	--
04126802 - Crystal River nr Glen Arbor, Michigan (Lat 44°54'10", long 085°57'46")													
Aug. 16, 1979	1410	19.0	1.0	49.4	--	260	8.4	1.0	131	152	4	<0.01	0.02
May 14, 1980	1450	11.0	.40	54.1	0	288	8.2	1.8	150	180	0	.00	.04
Oct. 27, 1981	1315	7.5	.50	59.8	1	254	8.0	--	--	--	--	<.01	--
04126810 - Shalda Creek nr Glen Arbor, Michigan (Lat 44°56'48", long 085°53'07")													
Aug. 16, 1979	1500	16.0	1.0	20.9	--	320	8.1	2.4	153	186	0	<0.01	0.15
May 14, 1980	1000	8.0	.80	28.3	0	360	7.9	4.0	160	200	0	.00	.24
Oct. 27, 1981	1030	6.0	1.0	20.6	1	338	7.9	--	--	--	--	<.01	--

Table 4.--Chemical and physical characteristics of streams--Continued

Date	Phosphorus, dissolved (mg/L as P)	Cyanide, total (mg/L as Cn)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L $CaCO_3$)	Silica, dissolved (mg/L as SiO_2)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Solids, residue at 180 deg. C, dissolved (mg/L)
04126755 - Platte River at M-22 nr Honor, Michigan (Lat 44°42'39", long 086°07'08")													
Aug. 14, 1979	<0.01	--	150	7	2.5	42	11	3.7	0.7	4.4	12	0.2	174
May 15, 1980	.00	0.00	160	0	5.6	46	12	4.2	.6	4.3	11	.2	180
Oct. 28, 1981	<.01	<.01	150	--	3.3	41	12	4.2	.5	4.2	11	.2	179
04126758 - Platte River at Weir on Loon Lake nr Honor, Michigan (Lat 44°43'12", long 086°08'12")													
Aug. 14, 1979	<0.01	--	150	21	2.4	43	11	3.6	0.7	4.4	11	0.2	181
May 15, 1980	.01	0.00	160	0	5.5	46	12	4.1	.6	4.3	11	.2	179
Oct. 28, 1981	<.01	<.01	150	--	3.1	40	12	4.1	.5	4.3	11	.2	181
04126765 - Otter Creek at Otter Lake nr Empire, Michigan (Lat 44°44'30", long 086°03'40")													
Aug. 15, 1979	<0.01	--	140	2	6.7	38	11	1.8	0.7	3.2	11	0.1	168
May 13, 1980	.00	0.00	160	0	6.1	44	12	2.2	.6	3.1	11	.1	173
Oct. 26, 1981	.01	<.01	150	--	7.4	40	13	2.7	.5	3.7	7.3	.2	164
04126767 - Otter Creek at Aral Road nr Empire, Michigan (Lat 44°45'42", long 086°04'26")													
May 12, 1970	--	--	--	--	--	--	--	--	--	--	--	--	--
Aug. 15, 1979	0.01	--	180	5	7.0	49	13	2.2	0.6	2.8	14	0.2	206
Aug. 17, 1979	--	--	170	1	7.2	48	13	2.7	.5	3.0	16	.2	197
May 12, 1980	.03	0.00	170	14	6.9	45	14	2.9	.6	2.8	15	.3	190
Oct. 27, 1981	<.01	<.01	190	--	9.1	50	15	3.5	.3	3.1	12	.3	200
04126802 - Crystal River nr Glen Arbor, Michigan (Lat 44°54'10", long 085°57'46")													
Aug. 16, 1979	<0.01	--	130	0	6.1	31	13	2.5	0.6	1.8	12	0.4	155
May 14, 1980	.00	0.00	140	0	6.0	36	13	2.9	.5	1.7	11	.5	153
Oct. 27, 1981	.02	<.01	140	--	5.6	33	13	3.1	.3	2.0	7.5	.5	145
04126810 - Shalda Creek nr Glen Arbor, Michigan (Lat 44°56'48", long 085°53'07")													
Aug. 16, 1979	<0.01	--	170	17	6.5	45	14	3.3	0.7	3.8	27	0.5	194
May 14, 1980	.01	0.00	180	18	6.9	50	14	3.4	.6	3.7	26	.5	214
Oct. 27, 1981	.13	<.01	180	--	9.2	46	15	4.1	.4	3.9	23	.6	203

Table 4.--Chemical and physical characteristics of streams--Continued

Date	Solids, sum of constituents, dissolved (mg/L)	Arsenic, dissolved (µg/L as As)	Barium, dissolved (µg/L as Ba)	Cadmium, dissolved (µg/L as Cd)	Chromium, dissolved (µg/L as Cr)	Copper, dissolved (µg/L as Cu)	Iron, dissolved (µg/L as Fe)	Lead, dissolved (µg/L as Pb)	Manganese, dissolved (µg/L as Mn)	Mercury, dissolved (µg/L as Hg)	Selenium, dissolved (µg/L as Se)	Silver, dissolved (µg/L as Ag)	Zinc, dissolved (µg/L as Zn)
04126755 - Platte River at M-22 nr Honor, Michigan (Lat 44°42'39", long 086°07'08")													
Aug. 14, 1979	163	1	40	0	0	--	<10	0	1	<0.5	<1	0	2
May 15, 1980	183	3	30	5	3	--	0	0	0	<.1	0	0	0
Oct. 28, 1981	161	1	20	3	<1	--	5	<1	<1	.1	<1	<1	<4
04126758 - Platte River at Weir on Loon Lake nr Honor, Michigan (Lat 44°43'12", long 086°08'12"													
Aug. 14, 1979	--	1	30	0	0	--	<10	0	1	<0.5	<1	0	3
May 15, 1980	183	3	30	3	3	--	0	0	1	.1	0	0	9
Oct. 28, 1981	165	1	20	3	<1	--	6	1	<1	.1	<1	<1	<4
04126765 - Otter Creek at Otter Lake nr Empire, Michigan (Lat 44°44'30", long 086°03'40")													
Aug. 15, 1979	156	2	30	0	<2	--	<10	0	<10	<0.5	<1	0	0
May 13, 1980	180	1	20	3	3	--	1	0	2	<.1	0	0	9
Oct. 26, 1981	159	2	20	<1	<1	--	9	1	1	.1	<1	<1	<4
04126767 - Otter Creek at Aral Road nr Empire, Michigan (Lat 44°45'42", long 086°04'26")													
May 12, 1970	--	--	--	--	--	--	--	--	--	--	--	--	--
Aug. 15, 1979	193	1	40	0	0	--	40	0	4	<0.5	<1	0	3
Aug. 17, 1979	194	--	--	--	--	--	<10	--	3	--	--	--	--
May 12, 1980	184	1	30	0	4	--	10	0	5	<.1	0	0	8
Oct. 27, 1981	196	2	30	<1	<1	--	7	<1	3	.1	<1	<1	<4
04126802 - Crystal River nr Glen Arbor, Michigan (Lat 44°54'10", long 085°57'46")													
Aug. 16, 1979	150	1	20	<2	0	--	<10	5	1	<0.5	--	0	8
May 14, 1980	161	2	40	3	3	--	0	0	3	<.1	0	0	20
Oct. 27, 1981	143	2	30	<1	<1	--	5	1	<1	<.1	<1	<1	<4
04126810 - Shalda Creek nr Glen Arbor, Michigan (Lat 44°56'48", long 085°53'07")													
Aug. 16, 1979	199	1	40	<2	2	--	<10	<2	3	<0.5	<1	0	3
May 14, 1980	205	2	30	1	2	--	20	0	6	<.1	0	0	6
Oct. 27, 1981	192	2	30	<1	<1	--	8	1	2	<.1	<1	<1	<4

Table 5.--Chemical and physical characteristics of ground water (Site number: S, spring; all others are wells)

Site number	Geologic unit	Date of sample	Depth of well, total (feet)	Temperature (deg C)	Turbidity (NTU)	Color (platinum-cobalt units)	Specific conductance (µmhos)	pH (units)	Carbon dioxide, dissolved (mg/L as CO_2)	Alkalinity, field (mg/L as $CaCO_3$)	Bicarbonate, field (mg/L as HCO_3)	Carbonate, field (mg/L as CO_3)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, nitrate dissolved (mg/L as N)
1,S	112GLCL	August 27, 1980	--	14.0	0.50	5	237	7.5	--	--	--	--	0.00	0.00
2	112GLCL	August 26, 1980	--	12.0	.30	6	256	7.7	6.7	172	210	0	.00	.05
3	112GLCL	August 26, 1980	46	11.0	.40	4	806	7.4	12	156	190	0	.01	2.4
4	112GLCL	September 25, 1979	40	9.0	20	5	620	7.2	28	231	282	0	<.01	.00
5	112SAND	May 15, 1980	60	8.0	.20	0	325	7.7	6.7	170	210	0	.00	.82
		August 25, 1980	60	10.0	.20	2	293	7.6	7.8	160	200	0	--	--
6	112SAND	May 15, 1980	138	8.0	.30	0	330	7.5	9.6	160	190	0	.00	1.4
		August 26, 1980	138	10.0	.20	5	286	7.4	10	130	180	0	--	--
7	112GLCL	September 25, 1979	220	8.5	1.0	5	335	7.6	9.5	194	236	0	.01	.01
8,S	112GLCL	September 26, 1979	--	8.0	.00	5	340	7.6	8.8	180	220	0	<.01	.65
9	112GLCL	September 26, 1979	15	10.0	1.0	5	340	7.5	11	180	220	0	<.01	.89
10	112GLCL	September 24, 1979	107	10.0	1.0	2	670	7.5	9.6	160	190	0	<.01	2.0
11	112SAND	September 1, 1981	87	9.0	1.4	1	540	8.1	--	--	--	--	--	--
		November 13, 1981	87	--	--	--	--	--	--	--	--	--	--	--
12	112SAND	August 31, 1981	85	8.5	1.1	<1	520	8.5	--	--	--	--	--	--
		November 12, 1981	85	--	--	--	--	--	--	--	--	--	--	--

Site number	Phosphorus, dissolved (mg/L as P)	Cyanide total (mg/L as Cn)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L $CaCO_3$)	Silica, dissolved (mg/L as SiO_2)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Fluoride, dissolved (mg/L as F)	Solids, residue at 180 deg C dissolved (mg/L)	Solids, sum of constituents, dissolved (mg/L)
1	0.03	0.00	160	--	4.0	43	12	1.6	1.0	3.4	8.3	0.1	156	--
2	.01	.00	170	0	4.5	48	12	.9	.8	1.7	8.8	.1	186	181
3	.03	.01	370	220	5.8	99	31	13	1.4	170	12	.2	672	437
4	.01	.00	290	59	11	79	22	28	1.3	36	150	.6	466	468
5	.01	.00	170	2	7.6	45	15	.9	.4	.8	8.8	.1	179	186
	--	--	180	18	8.2	45	16	.9	.5	1.7	10	.2	190	181
6	.01	.00	160	5	6.4	43	13	2.7	7.5	8.9	11	.1	189	193
	--	--	150	19	6.9	40	12	2.9	8.0	9.1	12	.1	190	180
7	.01	.00	180	0	11	49	13	2.2	.6	.7	8.8	.7	187	224
8	.01	.00	190	12	7.3	54	14	.9	.6	2.6	12	.1	197	203
9	.01	.00	180	0	9.7	48	14	4.0	.6	1.8	7.2	.2	188	198
10	.01	.00	320	170	9.2	83	28	4.2	1.0	62	18	.1	393	308
11	--	<.01	220	--	8.6	68	11	13	1.4	93	3.7	<.1	430	271
	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	--	<.01	200	--	7.0	69	7.8	15	1.8	110	11	<.1	343	266
	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Table 5.--Chemical and physical characteristics of ground water--Continued

Site number	Arsenic, dis- solved (µg/L as As)	Barium, dis- solved (µg/L as Ba)	Cadmium, dis- solved (µg/L as Cd)	Chro- mium, dis- solved (µg/L as Cr)	Iron, dis- solved (µg/L as Fe)	Lead, dis- solved (µg/L as Pb)	Manga- nese, dis- solved (µg/L as Mn)	Mercury, dis- solved (µg/L as Hg)	Mercury, total recov- erable (µg/L as Hg)	Sele- nium, dis- solved (µg/L as Se)	Silver, dis- solved (µg/L as Ag)	Zinc, dis- solved (µg/L as Zn)
1	1	0	0	0	120	2	10	<0.1	--	0	0	0
2	1	0	0	1	70	0	10	<.1	--	0	0	110
3	1	0	0	1	120	0	30	<.1	--	1	0	80
4	4	40	0	0	440	2	100	<.5	--	<1	0	260
5	3	20	5	1	0	0	0	<.1	--	0	0	3
	--	--	--	--	30	--	10	--	<.1	--	--	--
6	3	30	1	1	10	1	4	<.1	--	0	0	120
	--	--	--	--	10	--	0	--	<.1	--	--	--
7	<1	30	0	0	60	0	20	<.5	--	0	0	40
8	1	10	0	0	<10	0	<10	<.5	--	<1	0	30
9	2	20	0	<2	30	0	5	<.5	--	<1	0	9
10	1	20	0	0	60	<2	6	<.5	--	<1	0	250
11	--	--	--	--	<10	--	10	--	.2	--	--	--
	--	--	--	--	--	--	--	--	<.1	--	--	--
12	--	--	--	--	10	--	<10	--	.2	--	--	--
	--	--	--	--	--	--	--	--	<.1	--	--	--

Table 6.--Chemical and physical characteristics of water on North and South Manitou Islands

Site number	Source	Date of Sample	Sampling Depth (ft)	Temperature (deg C)	Specific conductance (µmhos)	pH (units)	Oxygen, dissolved (mg/L)	Oxygen, dissolved (percent saturation)	Nitrogen, NO_2+NO_3 dissolved (mg/L as N)	Phosphorus, dissolved (mg/L as P)
					South Manitou Island					
13	well	July 29, 1982	--	--	322	7.9	--	--	<0.10	0.01
14	well	July 29, 1982	--	--	363	7.8	--	--	<.10	.07
15	Florence Lake	June 2, 1982	2.00	19.0	108	7.6	10.4	113	<.10	.01
16	well	June 3, 1982	--	10.5	352	7.2	--	--	<.10	.35
17	well	July 29, 1982	--	--	351	7.7	--	--	<.10	.05
18	well	June 3, 1982	--	14.0	384	7.0	--	--	<.10	.01
19	well	June 3, 1982	--	10.0	400	6.9	--	--	<.10	.02
20	well	June 3, 1982	--	11.0	369	7.2	--	--	.16	<.01
21	well	June 3, 1982	--	9.5	435	6.9	--	--	.11	<.01
22	well	July 29, 1982	--	--	253	8.0	--	--	.24	<.01
					North Manitou Island					
23	The Spring	July 27, 1982	--	9.5	348	8.4	--	--	.22	<.01
24	Angell Spring	July 27, 1982	--	11.0	313	7.6	--	--	.92	.02
25	Tamarack Lake	July 27, 1982	2.00	24.5	63	8.4	7.0	85	<.10	.03
26	Creek, unnamed	July 27, 1982	--	13.0	376	8.6	10.2	98	1.8	.02
27	well	July 28, 1982	26.0	9.5	343	8.3	--	--	.26	<.01
28	well	July 28, 1982	--	15.0	375	7.3	--	--	.59	.22
29	Manitou Lake	July 26, 1982	--	24.5	240	8.8	9.3	113	<.10	.02
30	Spring, unnamed	July 26, 1982	--	15.0	412	7.7	--	--	.49	.02

Site number	Hardness (mg/L as $CaCO_3$)	Silica, dissolved (mg/L as SiO_2)	Calcium, dissolved (mg/L as Ca)	Magnesium, dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Chloride, dissolved (mg/L as Cl)	Sulfate, dissolved (mg/L as SO_4)	Solids, sum of constituents, dissolved (mg/L)
13	160	11	39	15	4.2	0.5	0.8	2.0	177
14	170	12	42	16	6.2	.4	.7	1.0	199
15	53	.1	13	5.1	.5	.9	.9	6.0	57
16	180	42	48	15	.7	.3	1.0	3.0	228
17	170	19	45	14	.7	.2	1.1	3.0	197
18	210	6.3	52	20	.4	.5	1.2	18	222
19	220	6.7	54	21	.6	.6	1.5	12	229
20	200	10	49	18	1.4	.3	1.2	14	213
21	240	8.0	60	22	1.6	.5	.9	13	258
22	130	5.9	32	11	1.0	.2	.7	10	136
23	200	4.8	49	18	.5	<.1	.8	13	204
24	180	5.7	44	17	.7	.4	1.1	12	182
25	31	.6	[illegible]	2.9	.3	1.0	1.1	8.0	35
26	210	6.4	51	19	.8	.4	1.2	14	215
27	190	5.2	47	18	.6	.1	1.1	13	200
28	190	6.2	48	17	2.9	1.8	1.1	13	210
29	130	.5	28	15	1.4	.4	1.6	10	132
30	240	13	58	22	2.2	.3	1.3	16	249

Table 7.--Logs of wells installed on South Manitou Island in 1982 (from driller's report)

Well 1 (10BCCC)
(Altitude ± 610 ft)

Lithology	Depth (ft)
Sand and gravel	0-16
Clay, hard, sandy	16-105
Clay and sand	105-119
Clay, sandy	119-176
Sand, clean	176-184
Sand, dirty	184-185

(specific capacity = 1.8 gal/ft; pumped at 23 gal/min for 3.5 hr)

Well 2 (10BDCC)
(Altitude ± 610 ft)

Lithology	Depth (ft)
Sand and gravel	0-24
Clay, sandy	24-36
Sand, fine, some pebbles	36-115

(specific capacity = 8.1 gal/ft; pumped at 25 gal/min for 1.4 hr)

Well 3 (9AAAB1)
(Altitude ± 605 ft)

Lithology	Depth (ft)
Sand and gravel	0-17
Clay, sandy	17-21
Sand, fine	21-42
Sand, fine, silty, clay lenses	42-84
Clay	84-99
Sand and gravel	99-103
Clay, sand and gravel	103-119
Clay and sand	119-125
Clay, hard, sandy, silty	125-136
Clay, few sandy lenses	136-303

(well destroyed; well 3a installed nearby)

Well 3a (9AAAB2)
(Altitude ± 605 ft)

Lithology	Depth (ft)
Sand and gravel	0-17
Clay, silty, and sand	17-24
Sand, very fine to fine, trace of clay	24-45
Clay, sandy	45-57
Sand, fine to medium, trace of clay	57-71
Sand and clay	71-82
Clay	82-95
Clay, sandy, some pebbles	95-103
Sand and gravel, cemented	103-109
Sand, fine, silty, some gravel and clay	109-113
Sand, fine to medium, some gravel	113-120
Sand, fine, and gravel, trace of clay	120-125

(specific capacity = 1.3 gal/ft; pumped at 30 gal/min for 3.5 hr)

Well 4 (28DDDD)
(Altitude ± 625 ft)

Lithology	Depth (ft)
Sand and gravel	0-38
Sand, some clay balls	38-43
Sand and gravel	43-77
Sand and gravel, few clay balls	77-83

(specific capacity = 3.8 gal/ft; pumped at 12 gal/min for 3.0 hr)

Table 7.--Logs of wells installed on South Manitou Island in 1982--Continued

Well 5 (33CDBC1)
(Altitude ± 690 ft)

Lithology	Depth (ft)
Clay, sandy	0-69
Clay, sandy and hard	69-196
Clay, soft	196-250
(well destroyed)	

Well 5a (33CDBC2)
(Altitude ± 690 ft)

Lithology	Depth (ft)
Soil	0-10
Sand and gravel	10-14
Clay, sandy	14-106
Clay, sandy; and gravel	106-167
Sand, some clay	167-177
Clay, sandy, hard	177-209
Sand, fine	209-237
Clay	237-238
(specific capacity = 0.2 gal/ft; pumped at 20 gal/min for 4.2 hr)	

Well 6 (10AABA)
(Altitude ± 610 ft)

Lithology	Depth (ft)
Sand	0-5
Sand, fine to medium, silty; and gravel	5-40
Sand, fine to medium	40-52
Sand, fine, silty	52-117
Sand, silty; and clay	117-120
(specific capacity = 5.5 gals/ft; pumped at 60 gal/min for 3.5 hr)	