WATER RESOURCES OF THE APOSTLE ISLANDS NATIONAL LAKESHORE, NORTHERN WISCONSIN

By William J. Rose

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CONVERSION TABLE

For the use of readers who prefer to use metric (International System) units, conversion factors for the inch-pound units used in this report are listed below.

Multiply inch-pound unit	*By*	*To obtain metric unit*
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
ton per square mile (ton/mi^2)	0.3503	megagram per square kilometer (Mg/km^2)
cubic foot per second (ft^3/s)	2.832×10^{2}	cubic meter per second (m^3/s)
degree Fahrenheit (° F)	5/9(° F − 32)	degree Celsius (° C)
pound (lb)	0.4536	kilogram (kg)
gallon per minute per foot [(gal/min)/ft]	12.42	liter per minute per meter [(L/min)/m]

Other units of measurement used in this report are:

cubic foot per second per day ($ft^3/s \cdot d$)	milligrams per liter (mg/L)
microsiemens per centimeter at 25° Celsius (µS/cm)	acre-foot (ac-ft)
micrograms per liter (µg/L)	milligrams per kilogram (mg/kg)
micrograms per kilogram (µg/kg)	milliliter (ml)

Sea level: In this report "*sea level*" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—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 of 1929.*"

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ABSTRACT

The Apostle Islands National Lakeshore consists of 21 islands, part of the Bayfield Peninsula, and the adjacent waters of Lake Superior. Selected water resources of the Apostle Islands National Lakeshore were assessed to aid the National Park Service in developing and managing the Lakeshore and to provide a data base against which future changes can be compared. This summary of water-resources data, collected by the U.S. Geological Survey during 1979–84, provides a qualitative description of selected hydrologic components of the Lakeshore.

Streamflow in the Lakeshore area is characterized by typical seasonal fluctuations. Flow in Sand River at State Highway 13 ranged from 3.9 to 1,630 cubic feet per second. The recurrence interval of the maximum observed discharge was about 4 years. The minimum observed 7-day low flow was 3.86 cubic feet per second.

The greatest concentrations of most chemical constituents in Bayfield Peninsula streams occurred during base flow.

Annual sediment loads in Sand River at State Highway 13 ranged from 977 tons in 1980 water year to 24,600 tons in 1984 water year. The average annual sediment load transported by Bayfield Peninsula streams to the National Lakeshore area of Lake Superior is estimated to be 44,000 tons. Annual phosphorus loads ranged from 1,400 pounds in 1980 water year to 11,100 pounds in 1984 water year. The average annual phosphorus load transported by Bayfield Peninsula streams to the National Lakeshore area of Lake Superior is estimated to be 21,500 pounds.

Few island streams flow perennially, but Oak Island streams generally yield more base-flow runoff than Stockton Island streams. The base flow of Oak Island streams is dominated by ground-water discharge, whereas Stockton Island stream base flow is sustained by seepage from wetlands and beaver ponds.

There are two major lagoons in the Lakeshore, the Outer Island Lagoon's area is 53 acres and its maximum depth is 7 feet. Dominant inflow to the lagoon is from precipitation on its surface and seepage from an adjacent bog. Outflow during open-water periods is dominated by evaporation. Ground-water seepage from the lagoon toward Lake Superior occurs year-round. The lagoon's water is acidic and has low specific conductance and generally small concentrations of most chemical constituents.

The Michigan Island Lagoon is about 4 acres in area and its maximum depth is 6.5 feet. The most significant sources of inflow appear to be precipitation and wave washover from Lake Superior.

Water from four deep-water monitoring sites in Lake Superior revealed concentrations of total phosphorus, organic carbon, and recoverable mercury ranging from <0.01 to 0.02 milligrams per liter, 1.1 to 5.3 milligrams per liter and <0.1 to 0.1 micrograms per liter, respectively. Neither pesticide residues nor fecal coliform bacteria were detected in the water column. Total phosphorus concentrations in bottom sediment ranged from 50 to 470 milligrams per kilogram and were related directly to the percentage of fine-grained (<0.0625 millimeters) sediment particles. Traces of only two pesticide residues—DDE and DDT—were detected in sediment. The most abundant benthic macroinvertebrate was *Pontoporeia*

affinis, which was found in densities of from 960 to 2,100 organisms per square meter.

No adverse affects resulting from visitor use were detected in the shallow-water, heavy-use areas in Presque Isle Bay off Stockton Island or in the waters between Rocky and South Twin Islands. Phosphorus and organic-carbon concentrations were similar to those observed in the deep-water area; mercury was not detected in water from either area.

Ground-water use in the National Lakeshore is primarily for consumption by Lakeshore visitors and employees. Of 14 wells constructed from 1979–84, 4 were finished in glacial sand and gravel, and 10 were finished in sandstone. Specific capacities ranged from 0.63 to 50 gallon per minute per foot. Average concentrations of dissolved solids are moderate and concentrations of heavy metals did not exceed Wisconsin's primary health standard.

INTRODUCTION

Funding for the collection of data and preparation of this report was provided by the U.S. National Park Service.

BACKGROUND

The Apostle Islands National Lakeshore was established in 1970. The National Lakeshore is composed of two units, the Mainland Unit and the Island Unit. The Mainland Unit is a narrow strip of land on the west side of the Bayfield Peninsula, which borders Lake Superior. Twenty of the 22 Apostle Islands compose the Island unit. There are about 42,000 acres of land in the Lakeshore. The Lakeshore extends one-fourth mile into Lake Superior along all shorelines, and includes about 27,000 acres of water. The location of the National Lakeshore is shown in figure 1.

Information on the Lakeshore's water resources is needed for managing and developing the Lakeshore. Baseline water-resources data are also needed as background information against which changes in the character or quality of the water resources can be identified.

PURPOSE AND SCOPE

The purposes of this report are to summarize water-resources data that were collected by the U.S. Geological Survey during the 1979–84 water years[1] and to provide a qualitative description of selected hydrologic components of the Lakeshore.

This report is limited to study and data collection of only those elements that were considered most important to Lakeshore management. The areal scope of the study goes beyond Lakeshore boundaries to include hydrologic elements outside the Lakeshore that could influence the condition of resources within the Lakeshore. Specifically, the report includes (1) a description of the flow and water-quality characteristics of selected mainland streams that discharge to Lake Superior between Squaw Point to the west and the city of Bayfield to the east, and Oak and Stockton Island streams; (2) a hydrologic description of the lagoons on Outer and Michigan Islands; (3) a summary of lake-water and bottom-sediment quality, and benthic macroinvertebrate data from selected shallow- and deep-water sampling sites in Lake Superior; and (4) a brief description of the availability and quality of ground water.

[1] A "water year" begins October 1 and ends September 30 of the following year.

ACKNOWLEDGMENTS

Valuable assistance from National Park Service personnel included providing water transportation to study sites on the islands, collecting water samples from the Sand River, and measuring Lake Superior and lagoon water levels at Outer and Michigan Islands. Merryll Bailey, Lakeshore Ecologist, was especially helpful by providing technical advice and logistical coordination.

PHYSICAL SETTING

TOPOGRAPHY

The Mainland Unit of the Lakeshore slopes steeply toward Lake Superior, except for more level flood plains at the mouths of the rivers. Land altitude within this unit rises 200 to 300 ft (feet) above the level of Lake Superior. The mean altitude of Lake Superior is about 602 ft above sea level. The crest of the Bayfield Peninsula, inland from the Mainland Unit, is about 700 ft above Lake Superior.

Topography and altitude vary considerably from island to island. Gull, Eagle, and Sand Islands are the lowest and they have generally flat to slightly rolling topography. The maximum elevations of Gull, Eagle, and Sand Island are about 8, 20, and 60 ft, respectively, above Lake Superior. Oak Island is the highest of the islands; its peak altitude is about 480 ft above Lake Superior. Peak elevations of the remaining islands range from 100 and 250 ft above Lake Superior.

VEGETATION

Forest covers virtually all the land in the National Lakeshore, however, small clearings from abandoned agricultural fields and small, unforested wetlands are found on the islands. Stands of northern hardwood, hemlock, pine, balsam fir, and aspen compose the forest. The Bayfield Peninsula outside the National Lakeshore probably is 90 to 95 percent forested, the remaining land is cleared for current or past agricultural use.

GEOLOGY AND SOILS

Precambrian sandstone bedrock of unknown thickness underlies the entire National Lakeshore and Bayfield Peninsula. The sandstone is up to

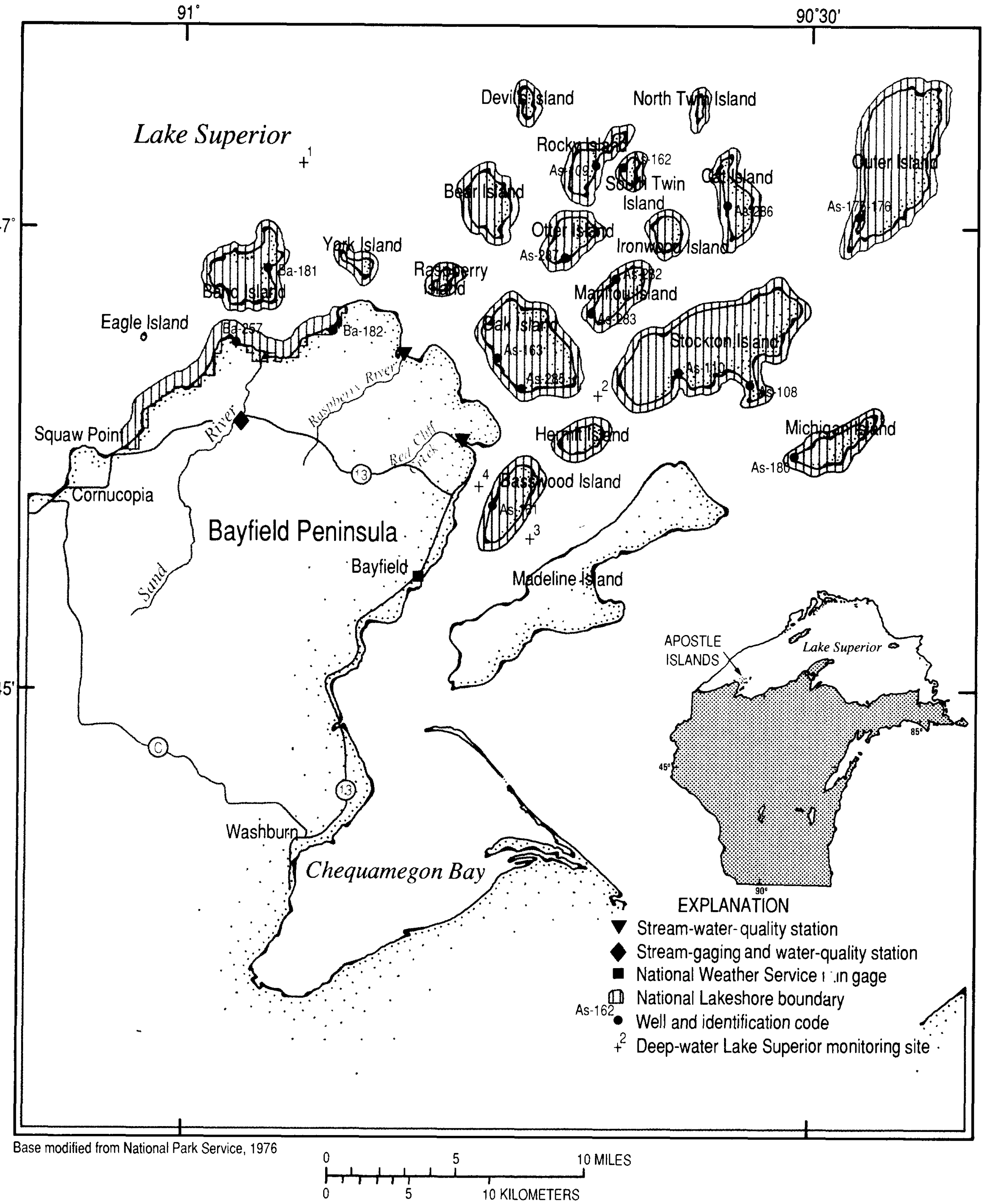

FIGURE 1. Location of Apostle Islands National Lakeshore.

thousands of feet thick (Young and Skinner, 1974). Glacial drift of variable thickness generally covers the sandstone except in local areas along streams and the Lake Superior shoreline where erosion has removed it. Drift is estimated to be up to 400 ft thick in the middle part of the Bayfield Peninsula but is much thinner in the various parts of the Lakeshore. The upper drift is composed of lake clay that was deposited by glacial lakes whose surfaces were as much as 550 ft higher than present Lake Superior (Leverett, 1929, p. 60).

Most of the soils in the Lakeshore and the northeastern end of the Bayfield Peninsula that is included in the study area are silty clay loams developed on the glacial-lake clay. Soil permeability is generally low; it is in the range of 0.05 to 0.8 in/h (inch per hour) range (Young and Skinner, 1974). Local areas covered by beach sand have a much higher soil permeability. Anderson and Milford (1979 and 1980) provide detailed descriptions of various soil types on Outer and Stockton Islands.

WATERSHED AND STREAM-CHANNEL CHARACTERISTICS

The three main streams discharging to the Lakeshore area of Lake Superior from the Bayfield Peninsula are the Sand River, Raspberry River, and Red Cliff Creek. These streams' watersheds constitute 66 percent of the runoff area from the peninsula between Squaw Point to the west and the city of Bayfield to the east. The Sand River has the largest drainage area and flattest channel slope of the three streams. About 2.5 percent of the Sand River watershed is lake and marsh area, whereas lake and marsh area in the Raspberry River and Red Cliff Creek watersheds is almost nonexistent. Watershed characteristics for the Sand River above its mouth and the gaging station at State Highway 13, and for Raspberry River and Red Cliff Creek above their mouths are summarized below.

Watershed	Drainage area (mi^2)	Channel length (mi)	Channel slope (ft/mi)	Lake and marsh area (percentage of total watershed)
Sand River (mouth)	38.1	16.8	24	2.5
Sand River (State Highway 13)	27.4	12.9	26	2.3
Raspberry River (mouth)	14.0	7.49	52	0
Red Cliff River (mouth)	8.19	5.77	61	0

The remaining streams are generally short [<1 mi (mile)] in length, have steep gradients, and, with three exceptions, their drainage areas are less than one-half square mile. About five percent of the area drains to Lake Superior as unchannelized overland flow. The major drainage areas described above are shown in figure 2.

Surface-drainage development differs from island to island and depends mostly on topography, island size, and relief. The smaller islands, such as York, Raspberry, Eagle, Devils, South Twin, North Twin, Gull, and Ironwood, have virtually no drainage channels that are distinguishable on a 10-ft interval topographic-contour map; all other islands have clearly definable intermittently or perennially flowing streams. The natural drainage of Devils Island was somewhat altered by construction of a north-south road that cuts across the island. The most developed surface drainage is on Oak Island; this probably results from the island's great topographic relief (about 480 ft). The largest single drainage basin [2.56 mi^2 (square mile)] is on Stockton Island. Beaver dams impound and retard flow on many of the streams.

Watershed characteristics for selected Oak and Stockton Island streams are summarized in table 1. Oak Island watersheds generally are smaller and have steeper channel slopes than Stockton Island watersheds. Wetland areas and beaver ponds are numerous on Stockton Island, but are absent on Oak Island. The locations of the watersheds are shown in figure 3.

HYDROLOGIC CONDITIONS DURING THE STUDY PERIOD

Total precipitation at Bayfield, Wis., during the October 1979 to September 1984 (water years 1980–84) study period was above normal. Average annual precipitation at Bayfield, Wis., is 31.67 in. (inch). Figure 4 shows that during the first 2 years of the study monthly precipitation was below normal and during the last 3 years of the study monthly precipitation was above normal. "Normal" monthly precipitation values are defined as average values for the 1951–80 period (National Oceanic and Atmospheric Administration, 1985).

Lake Superior water levels generally decreased (disregarding the annual fluctuation cycle) from October 1979 through March 1982 (fig. 4). During 1982, the lake level increased about 1 ft and the increase was sustained through September 1984 (National Oceanic and Atmospheric Administration, 1985).

Streamflow during the 1982–84 water years was above normal and reflects the above normal precipitation for the same period. The White River (drainage area = 301 mi^2), which is about 25 mi south of the National Lakeshore, is used to compare monthly average streamflow during the study period with long-term (1948–84) monthly mean streamflow (fig. 4).

DATA-COLLECTION METHODS

Streamflow monitoring included operating a continuous recording gaging station on the Sand River and making discharge measurements at intermittent intervals at about 20 sites on mainland and island streams. These data were collected following procedures outlined by Rantz and others (1982).

Stream suspended-sediment and chemical quality samples were collected using velocity-weighted depth-integrating samplers. National Park Service personnel collected intermittent samples for sediment

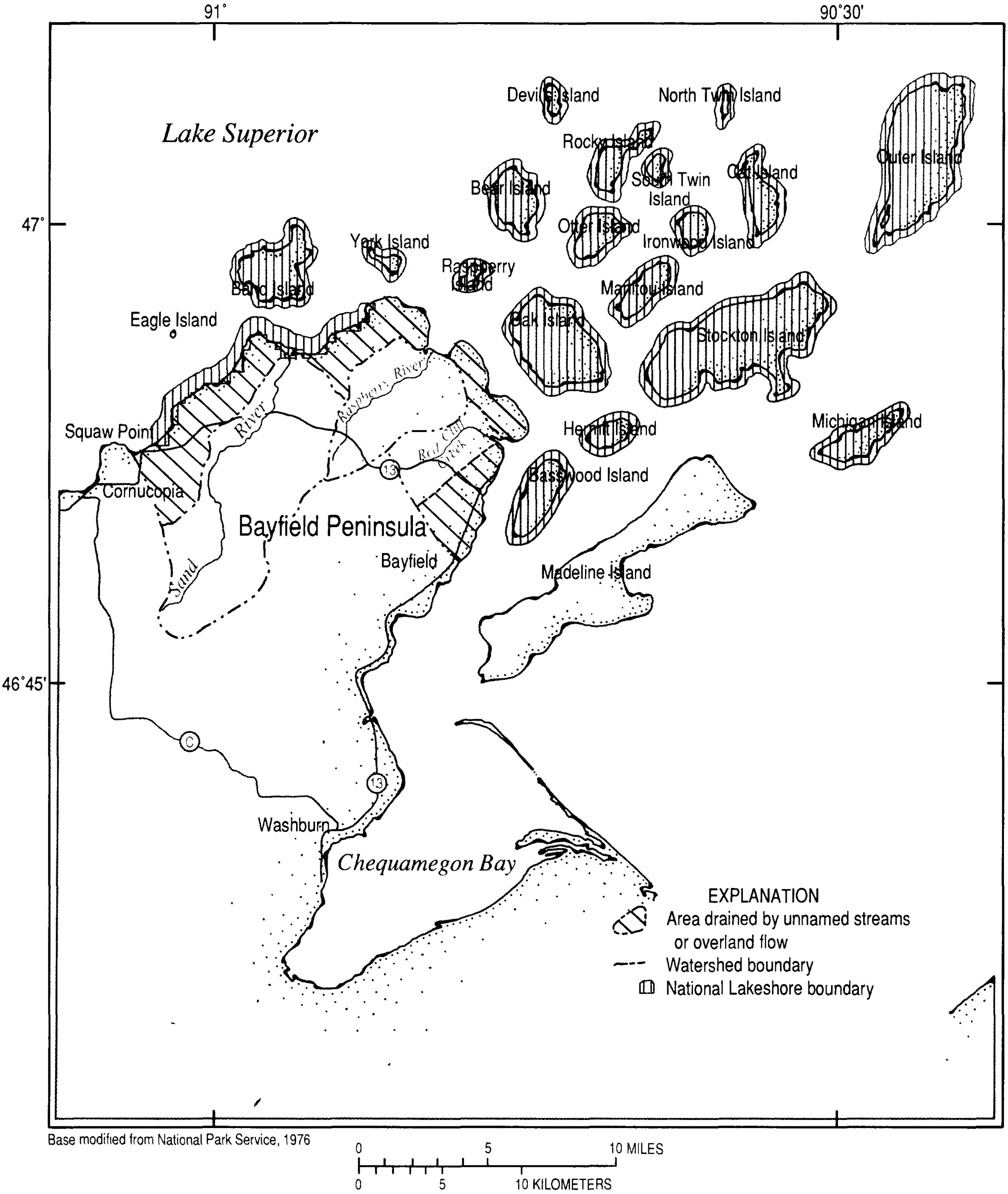

FIGURE 2. Location of Bayfield Peninsula watersheds draining into the National Lakeshore area of Lake Superior.

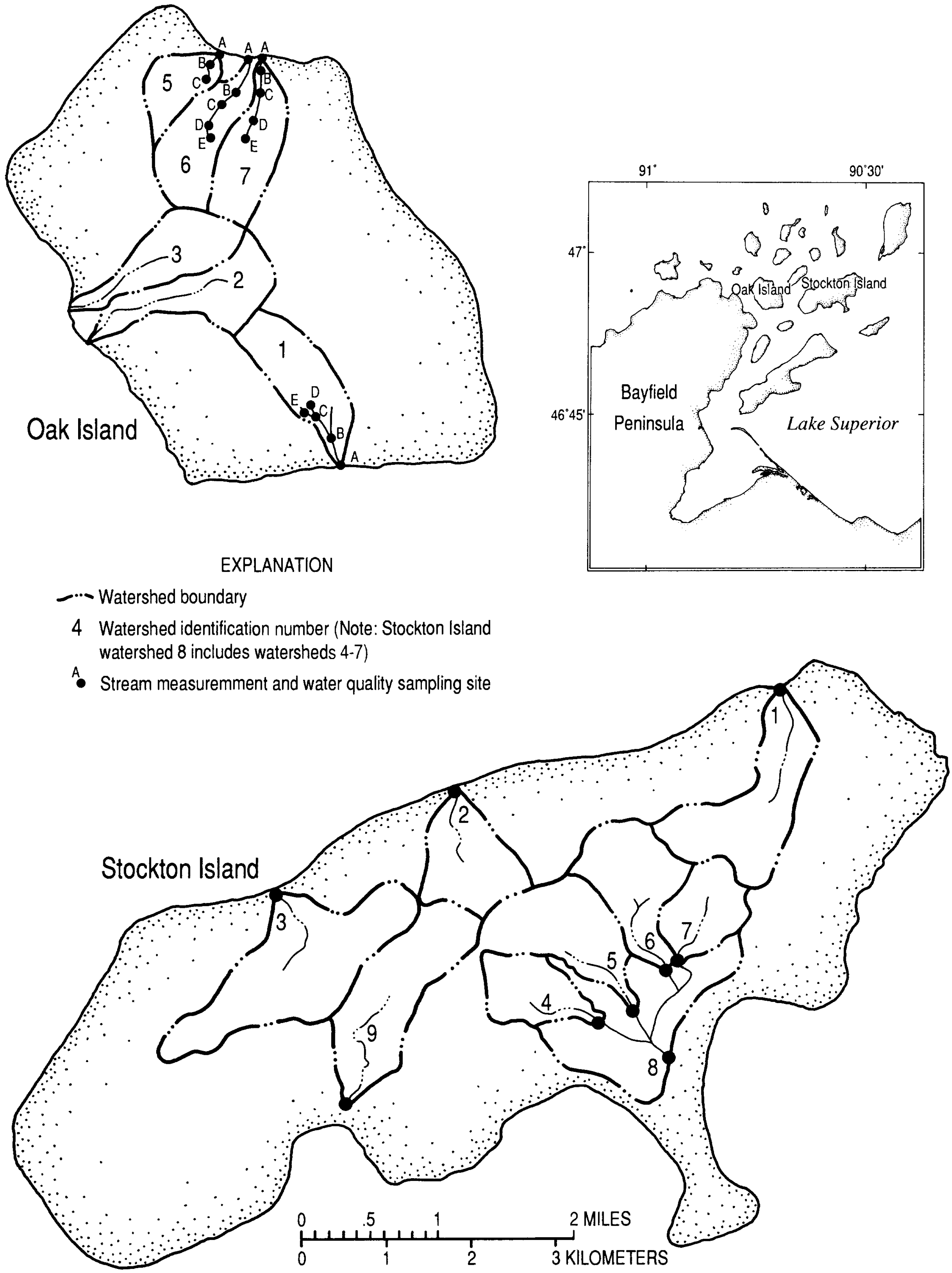

FIGURE 3. **Location of stream watersheds and stream data-collection sites on Oak and Stockton Islands.**

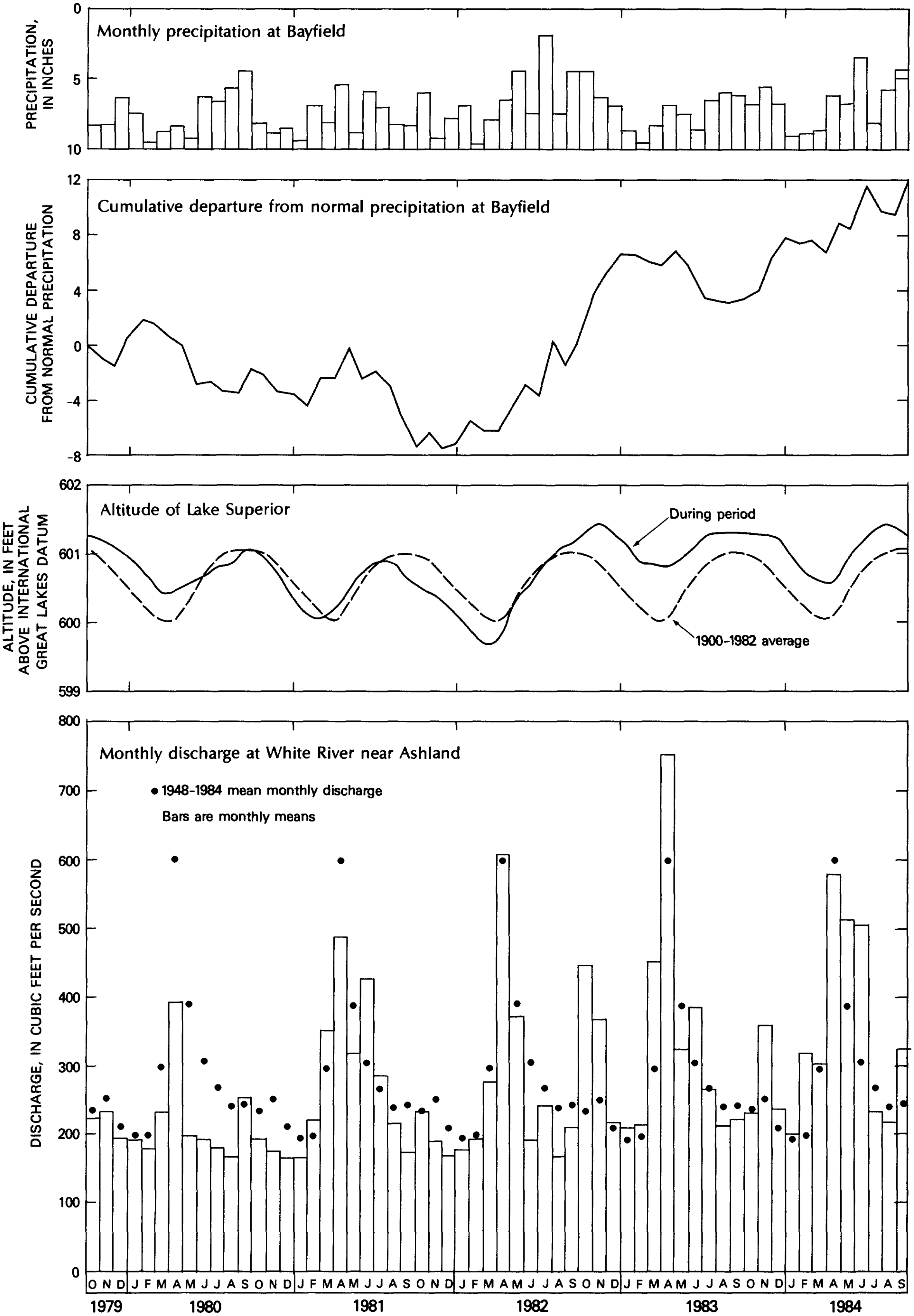

FIGURE 4. Comparison of precipitation, Lake Superior stage, and streamflow during study period with long-term averages, for water years 1980–84.

TABLE 1.—Watershed characteristics for selected Oak and Stockton Island streams

[mi² = square mile; mi = mile; ft/mi = foot per mile; in/h = inch per hour]

Watershed	Drainage area (mi²)	Channel length (mi²)	Channel slope[1] (ft/mi)	Lake and marsh area (percentage of total watershed	Soil permeability (in/h)
Oak Island					
1	0.40	1.43	406	0	
2	.43	1.54	295	0	
3	.38	1.36	348	0	
5	.20	.83	524	0	0.05–0.02
6	.39	1.21	366	0	
7	.36	1.19	384	0	
Stockton Island					
1	.70	1.81	57	24	
2	.46	.99	152	4	
3	1.02	1.93	90	3	
4	.33	1.14	96	4	
5	.57	1.30	102	6	0.2–0.08
6	.53	1.43	74	8	
7	.33	.90	101	2	
8	2.56	2.31	61	16	
9	.73	2.02	48	3	

[1] Channel slope is defined as the slope of the stream between points that are 10 and 85 percent of the distance along the channel from the south to the basin divide, determined from topographic maps.

and phosphorus concentration analyses from a single sampling vertical in the stream cross section at the Sand River gaging station. U.S. Geological Survey personnel collected discharge-weighted cross-section samples by the equal-width increment (EWI) method [previously referred to as the Equal Transit Rate (ETR) method] (Guy and Norman, 1970). The representativeness of the single-vertical samples was verified by comparing the suspended-sediment concentration in concurrently collected single-vertical and EWI samples.

Lake Superior and lagoon water samples were collected with a Kemmerer sampler. Lake Superior was sampled from a vessel equipped with a Loran C navigational system, which was used to find the locations of sampling sites. Field measurements of temperature, pH, specific conductance, and dissolved oxygen were obtained with a Hydrolab Model 4041[2] meter.

Benthic macroinvertebrate samples were collected with a 9-in. × 9-in. Ponar dredge. Replicate samples were collected at each sampling site. Fines were washed from the samples by sieving through a U.S. Standard No. 70 [0.210 mm (millimeter) mesh opening] sieve. Samples were preserved in an ethyl alcohol-water solution and analyzed following methods outlined by Slack and others (1973) by Robert A. Lidwin (U.S. Geological Survey).

[2] The use of brand names in this report is for identification purposes only and does not imply endorsement by the U.S. Geological Survey.

Data for evaluating ground water and aquifer characteristics were obtained by monitoring the construction of eight water-supply wells in the Lakeshore. Drill cuttings were sampled at 5-ft intervals and analyzed to construct stratigraphic logs. Specific-capacity tests were done to estimate well productivity. These wells, along with three hand-driven wells, were sampled for water-quality analyses.

Water samples for chemical analysis were field treated and filtered as required for various constituent analyses, chilled to 4° C, and sent to the U.S. Geological Survey Water Quality Laboratory at Doraville, Ga., for analysis. Samples were analyzed for bacteria in the field by the standard plate count (membrane filter) method (Slack and others, 1973).

Precipitation data were collected at Bayfield by the National Weather Service (National Oceanic and Atmospheric Administration, 1980–85). Lake Superior water-level data were collected by the National Ocean Survey at several locations on the lake (National Oceanic and Atmospheric Administration, 1985).

SURFACE-WATER RESOURCES

MAINLAND STREAMS

Flow Characteristics

The flow characteristics of Bayfield Peninsula streams reflect watershed characteristics that tend

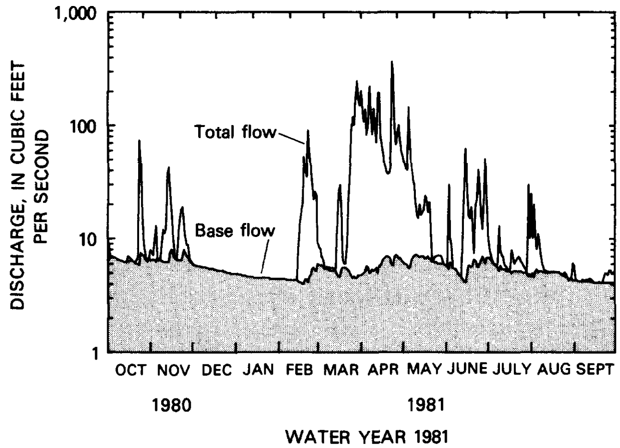

FIGURE 5. Daily mean base and total flow at the Sand River at Highway 13 during water year 1981.

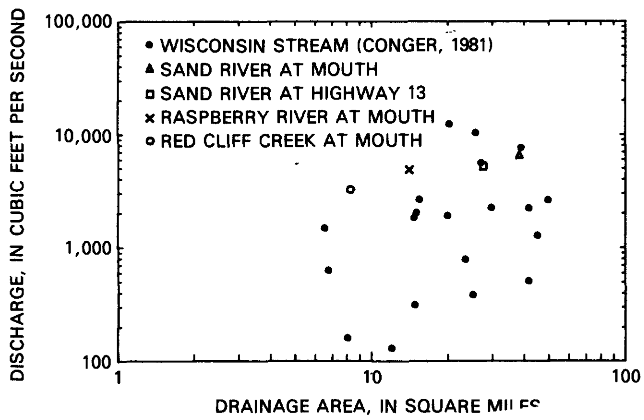

FIGURE 6. Comparison of 100-year recurrence-interval discharges of Sand and Raspberry Rivers and Red Cliff Creek with discharges of other Wisconsin streams having similar-size drainage basins.

to produce high flood flows and low base flows. Steep channel gradient, low soil permeability, and little basin storage favor high flood flows, whereas low soil permeability inhibits ground-water recharge and results in low base flow.

Flow varied from 3.9 to 1,630 ft^3/s (cubic feet per second) at the Sand River at State Highway 13 during the 5-year period (1980–84 water years) during which continuous flow was monitored. Yearly base-flow runoff as a percentage of total yearly runoff varied from 17 to 55 percent in the 5-year period. The hydrograph in figure 5 illustrates the daily variability in flow.

There was considerable variability in annual runoff, as can be seen in the table below.

Water Year	Total runoff volume (ft^3/s•d)[1]	Base-flow runoff (ft^3/s•d)
1980	3,490	1,920
1981	8,210	1,980
1982	12,480	2,190
1983	11,960	2,390
1984	14,580	2,490
Average	10,140	2,190

[1] ft^3/s•d is the volume of water produced by a flow of 1 cubic foot per second for 24 hours. It is the equivalent of 86,400 cubic feet, 1.9835 acre-feet, 646,000 gallons, or 2,447 cubic meters.

Runoff during the 1984 water year, the year of greatest runoff, was about four times greater than 1980, the year of least runoff.

Discharges for 100-year-recurrence interval flood (100-year flood) were calculated using regression equations by Conger (1981). The 100-year flood is one that can be expected to be exceeded at intervals averaging 100 years. The recurrence interval of the maximum observed discharge at the Sand River at State Highway 13 during water years 1980–84 was about 4 years. Figure 6 shows that the 100-year flood discharges of Bayfield Peninsula streams are higher than most other streams of similar size drainage basins in Wisconsin.

Low-flow characteristics for sites on the Sand River, Raspberry River, and Red Cliff Creek were calculated using techniques outlined by Gebert (1979). The annual minimum 7-day mean flow below which the flow will fall on an average of once in 2 years ($Q_{7,2}$) and on an average of once in 10 years ($Q_{7,10}$) are statistics for characterizing the low flows of streams. $Q_{7,2}$ and $Q_{7,10}$ values for the Sand and Raspberry Rivers were determined by Gebert. The low-flow values for these sites also were calculated using additional data obtained from this study, but were the same as the values obtained by Gebert. Low-flow data for the three stream sites are summarized below.

Stream site	Drainage area (mi^2)	$Q_{7,2}$ (ft^3/s)	$Q_{7,10}$ (ft^3/s)	Basis for estimate
Sand River at Highway 13	27.4	4.2	3.8	Correlation with Bois Bois Brule River (Gebert, 1979)
Raspberry River at Road Crossing in sec. 2, T. 51 N., R.4 W.	13.9	.50	.40	Regression equations (Gebert, 1979)
Red Cliff Creek at Road Crossing in sec. 19, T. 51 N., R. 4 W.	7.5	.15	.10	Regression equations (Gebert, 1979)

The minimum 7-day mean flow at the Sand River at Highway 13 during 1980–84 was 3.86 ft^3/s, which was less than the $Q_{7,2}$ but more than the $Q_{7,10}$. The minimum daily flow during 1980–84 was 3.8 ft^3/s.

Water Quality

The quality of water discharging from Bayfield Peninsula streams into Lake Superior influences the quality of the lake in the Apostle Islands area. Hence, an attempt was made to characterize the quality of water in these streams over a range of flow conditions.

CHEMICAL CHARACTERISTICS

Water from the Sand River, Raspberry River, and Red Cliff Creek was collected and analyzed during water years 1982–84 to determine the concentrations of major chemical constituents. The data are summarized in table 2. Concentrations of most constituents were generally highest at low or base flow, which indicates that ground water has generally higher constituent concentration than surface runoff. Concentrations are lower during storm or snowmelt because of the high proportion of direct runoff composing the flow. Phosphorus concentrations increased with increasing stream discharge indicating that phosphorus concentrations are associated with direct runoff.

The constituent proportions of total phosphorus and nitrogen are illustrated in figure 7. The orthophosphorus is the part of total phosphorus that is most readily available to plants as a nutrient for growth.

SEDIMENT LOADING

Sediment loads were estimated for the Sand River at State Highway 13. Most of the sediment concentration data, on which the load calculations were based, were collected during the 1982 water year. These data are summarized in table 3. An equation describing the relation between water discharge and suspended-sediment discharge was determined by regression analysis (fig. 8). Daily suspended-sediment loads were calculated by applying daily mean water discharges to the equation.

Bedload discharge—that part of the total sediment that moves on or very near the streambed—was estimated by applying the modified Einstein procedure (Colby and Hembree, 1955) to hydraulic and sediment data. These calculations indicated that total sediment discharge was comprised of about 88 percent suspended-sediment discharge and 12 percent bedload discharge.

The particle-size distribution of suspended sediment between the sand-, silt-, and clay-size fractions is shown in figure 9. The distribution of these four high-flow samples showed little variation with discharge. The suspended sediment was composed of about one-fourth sand, one-fourth silt, and one-half clay.

Sediment loads and yield estimates for the water years 1980–84 are summarized in table 4. Estimated annual total sediment loads ranged from 977 tons in water year 1980 to 24,600 tons in water year 1984. The estimated average annual load was 13,100 tons. The estimated average annual yield for the 5-year period was 476 tons/mi^2 (tons per square mile). Callahan (1973) estimated an average annual yield of 427 tons/mi^2 for Wisconsin streams tributary to Lake Superior.

The average annual sediment load transported by Bayfield Peninsula runoff to the National Lakeshore area of Lake Superior is estimated to be about 44,000 tons, based on the following assumptions.

1. The limits of the runoff area are bounded by Squaw Point to the west and the city of Bayfield to the east.
2. The average yield at the Sand River during water years 1980–84 is representative of the long-term average annual yield.
3. The yield of the Sand River watershed above State Highway 13 is representative of the yield for the entire Bayfield Peninsula runoff area defined by 1 above.

Precipitation at Bayfield during water years 1980–84 averaged about 3.8 in. above the 1941–80 average, which suggests that the 1980–84 average annual yield may be higher than the long-term average yield. Hence, assumption 2 probably contributes to a high load estimate. The occurrence of delta deposits at the mouths of the Sand and Raspberry Rivers indicates that some of the sediment transported from upstream areas of the watersheds is deposited before reaching the open-water area of Lake Superior. On the other hand, the Sand River watershed is the largest in runoff area under consideration and when all other variables are the same, smaller watersheds generally yield more sediment per unit watershed area than larger watersheds (Chow, 1964).

PHOSPHORUS LOADING

Annual total phosphorus loads were calculated for the Sand River at State Highway 13 in a manner similar to that used for estimating sediment loads. Most of the phosphorus concentration data were collected during the 1982 water year. These data are summarized in table 3.

The equation describing the relation between water discharge and phosphorus discharge was developed by regression analysis, and is shown in figure 10. Daily phosphorus loads were obtained by applying the daily mean water discharge to the equa-

TABLE 2.—Chemical constituent analyses of water taken from Sand and Raspberry Rivers, and Red Cliff Creek at various discharges

[ft³/s = cubic feet per second; μS/cm = microsiemens per centimeter at 25° Celsius; mg/L = milligrams per liter; dash indicates no data available]

Date	Time	Stream-flow, instan-taneous (ft³/s)	Spe-cific con-duct-ance (μS/cm)	pH (stand-ard units)	Temper-ature (°C)	Oxygen, dis-solved (mg/L)	Hard-ness (mg/L as $CaCO_3$)	Hard-ness, noncar-bonate (mg/L as $CaCO_3$)	Calcium, dis-solved (mg/L as Ca)	Magne-sium dis-olved (mg/L as Mg)	Sodium, dis-solved (mg/L as Na)	Potas-sium, dis-solved (mg/L as K)	Alka-linity lab (mg/L as ($CaCO_3$)	Carbon dioxide, dis-solved (mg/L as CO_2)
Sand River at Highway 13														
1982														
Apr. 14	1835	452	—	—	—	—	37	1.0	11	2.3	1.1	1.3	36	—
Apr. 15	1550	912	60	—	0.5	—	34	0	10	2.1	1.0	1.3	43	—
Sept. 15	1150	7.0	162	—	10.0	—	81	0	22	6.4	2.6	6.4	87	—
1983														
June 22	1600	5.5	202	8.0	16.0	9.4	100	0	27	8.6	3.4	1.1	106	2.0
1984														
June 8	1155	528	78	8.2	16.5	—	44	0	14	2.2	.70	1.4	72	.9
July 16	1335	5.1	223	7.9	15.5	9.7	100	0	27	8.5	3.1	1.2	107	2.6
Raspberry River														
1984														
June 8	1400	116	55	7.2	17.0	—	26	4	7.3	1.9	1.2	1.1	22	2.7
July 16	1440	.99	218	7.5	17.5	7.5	100	0	26	8.6	3.2	1.3	104	6.4
Red Cliff Creek														
1984														
June 8	1232	48	72	7.3	16.5	—	34	2	9.6	2.4	1.7	1.4	32	3.1
July 16	1545	.30	215	7.9	19.5	8.7	97	0	27	7.1	3.6	1.9	98	2.4

Date	Sulfate dis-solved (mg/L as SO_4)	Chlo-ride, dis-solved (mg/L as Cl)	Fluo-ride, dis-solved (mg/L as F)	Silica, dis-solved (mg/L as (SiO_2)	Solids, residue at 180°C dis-solved (mg/L)	Solids, sum of consti-tuents dis-solved (mg/L)	Nitro-gen, dis-solved (mg/L as N)	Nitro-gen, nitrite dis-solved (mg/L as N)	Nitro-gen, NO2 + NO3 dis-solved (mg/L as N)	Nitro-gen, ammonia dis-solved (mg/L as N)	Nitro-gen, organic dis-solved (mg/L as N)	Nitro-gen, am-monia organic dis-solved (mg/L as N)	Phos-phorus, total (mg/L) as P)	Phos-phorus, ortho, dis-solved (mg/L as P)
Sand River at Highway 13														
1982														
Apr. 14	3.0	1.5	<0.1	8.5	78	50	0.71	—	0.16	0.160	0.39	0.55	0.19	0.150
Apr. 15	6.0	1.2	< .1	7.0	78	54	.52	—	.10	.060	.36	.42	.19	.050
Sept. 15	5.0	1.7	.2	11	121	108	—	—	< .10	.020	.48	.50	.07	< .010
1983														
June 22	8.0	1.1	.2	12	113	125	—	0.02	< .10	.060	.14	.20	.04	< .010
1984														
June 8	<.2	1.2	< .1	5.3	96	—	—	.01	.17	.050	1.7	1.7	.13	.020
July 16	9.6	1.2	< .1	11	126	130	—	< .01	< .10	< .010	—	< .10	.02	< .010
Raspberry River														
1984														
June 8	<.2	1.7	< .1	6.0	86	—	—	.01	.14	.160	1.1	1.3	.08	< .010
July 16	9.7	1.6	.10	11	120	120	—	< .01	< .10	< .010	—	.20	.02	.010
Red Cliff Creek														
1984														
June 8	<.2	2.2	< .10	7.3	94	—	—	.020	.18	< .010	—	2.8	.08	< .010
July 16	11	4.5	< .10	6.6	133	120	—	< .010	< .10	< .010	—	.20	.02	< .010

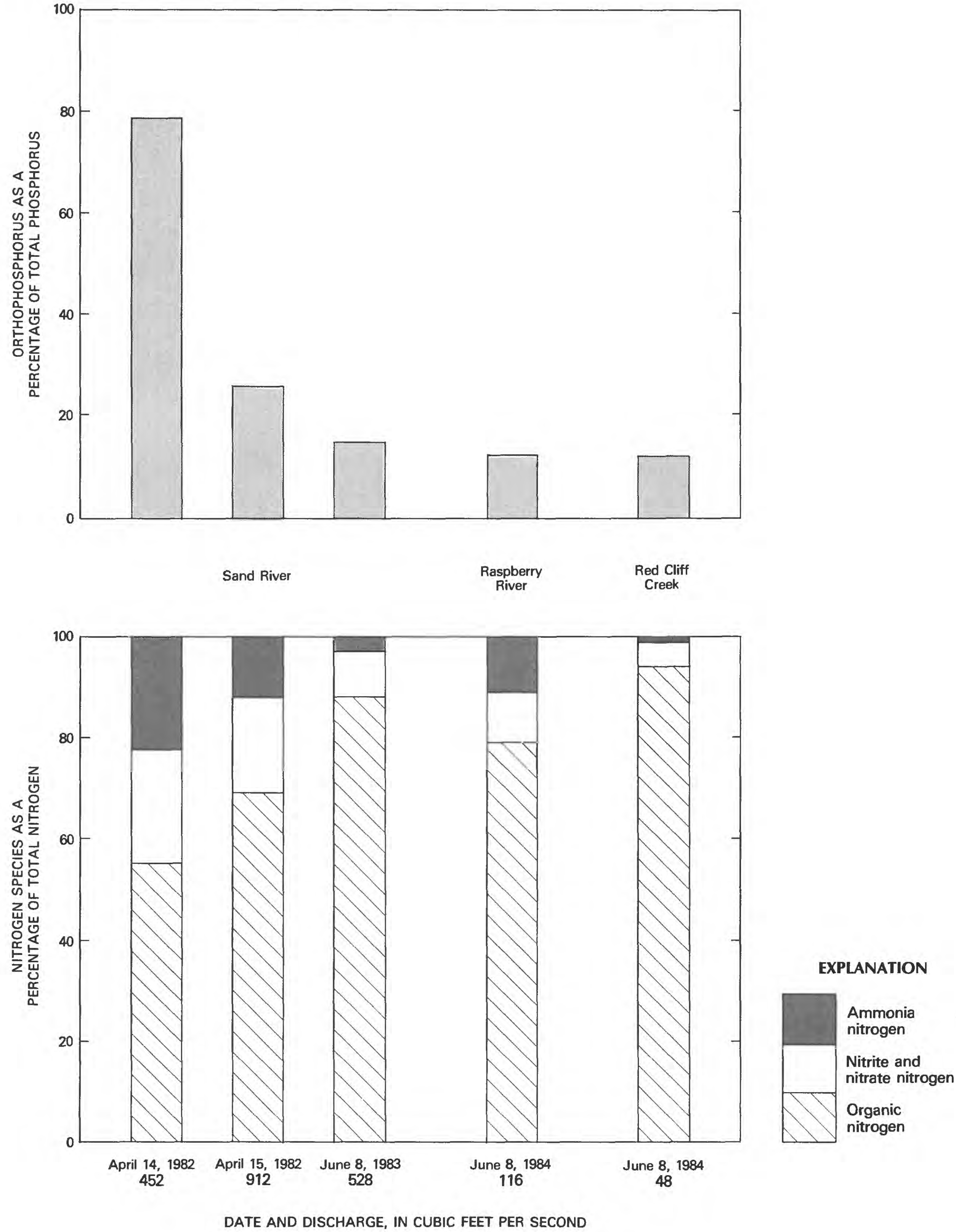

FIGURE 7. Constituent proportions of total phosphorus and nitrogen during storm or snowmelt runoff in Sand and Raspberry Rivers and Red Cliff Creek.

TABLE 3.—Total phosphorus and suspended-sediment concentration data collected during water years 1981–84

Date	Streamflow, instantaneous (cubic feet per second)	Phosphorus, total (milligrams per liter)	Suspended sediment (milligrams per liter)
1981			
Feb. 23	55	—	26
Apr. .1	150	0.18	585
June 17	12	—	22
1982			
Mar. 26	35	.14	44
Mar. 28	31	.09	51
Mar. 29	34	.10	47
Apr. 2	149	—	217
Apr. 10	46	.07	65
Apr. 12	59	.08	105
Apr. 13	195	.09	609
Apr. 14	198	.08	404
Apr. 14	310	—	689
Apr. 14	333	—	688
Apr. 14	352	—	774
Apr. 14	431	—	950
Apr. 14	435	—	1,020
Apr. 14	442	—	978
Apr. 14	452	.19	—
Apr. 15	749	—	1,860
Apr. 15	768	—	1,860
Apr. 15	778	—	1,950
Apr. 15	894	.21	2,070
Apr. 15	916	—	1,810
Apr. 15	923	—	1,790
Apr. 15	927	—	1,870
Apr. 15	912	.19	—
Apr. 16	388	.11	1,100
Apr. 17	435	.11	747
Apr. 18	131	.11	931
Apr. 20	88	.07	2,190
Apr. 21	76	.10	199
Apr. 22	84	.09	277
Apr. 25	51	.08	121
Apr. 26	31	.06	63
Apr. 27	25	.06	74
Apr. 28	19	.07	51
Apr. 29	16	.06	91
May 5	352	.25	1,060
May 7	94	.16	460
May 8	41	.06	70
May 10	47	—	128
May 11	127	.11	411
May 12	48	.12	—
May 13	144	.20	437
May 16	60	.10	102
May 30	6.5	.02	10
June 10	6.0	.08	24
June 15	6.0	.01	13
June 20	4.9	.02	4
June 30	4.3	.02	9
July 3	397	.17	—
July 3	397	—	807
July 3	190	.17	327
July 7	643	.34	1,440
July 8	66	.11	293
July 11	173	.18	417
July 14	36	.07	139
July 28	23	.09	176
Aug. 28	5.1	—	9
Aug. 29	4.9	.03	—
Sept. 15	7.0	.07	14
Sept. 29	9.3	.04	14
1983			
Mar. 16	40	—	37
Apr. 19	56	—	85
June 22	5.5	.04	—
Nov. 22	32	—	28
1984			
Apr. 10	206	—	220
June 8	528	.13	1,960
July 16	5.1	.20	7

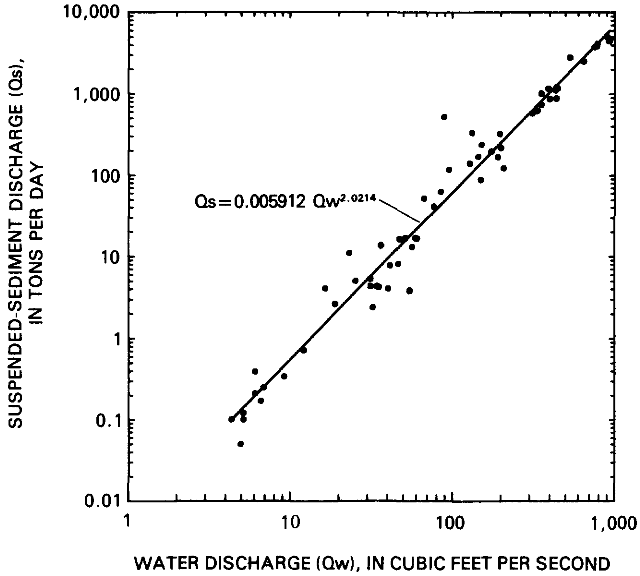

FIGURE 8. Relation of suspended-sediment discharge to water discharge at Sand River at Highway 13.

tion. Annual loads were determined by summing daily loads.

Phosphorus load and yields are summarized in table 3. Estimated annual loads ranged from 1,400 lb (pound) in 1980 water year to 11,100 lb in 1984 water year. The estimated average annual load and yield for the 5-year period were 6,430 lb and 235 lb/mi² (pound per square mile), respectively.

Phosphorus loading fluctuations from year-to-year parallel those of sediment. This close association between phosphorus and sediment is further illustrated in figure 11.

The average annual phosphorus load transported by Bayfield Peninsula runoff to the National Lakeshore area of Lake Superior during water years 1980–84 was estimated to be 21,500 lb. This estimate is based on the same assumptions that were used for calculating sediment loading to Lake Superior. Because of the close relation between sediment and phosphorus concentration, the qualifications that apply to the sediment load estimate also apply to the phosphorus-load estimate.

ISLAND STREAMS

Flow Characteristics

Base-flow measurements were made at selected stream sites on Oak Island during June 1983 and July 1984; similar measurements were made at stream sites on Stockton Island during August 1980 and July 1984. Many of the streams had no flow. The largest observed flow (0.29 ft³/s) was at the mouth of stream 6 (site 6a) on Oak Island. Locations of measuring sites are shown in figure 3.

Measurements were made at three to five sites on each of four Oak Island streams. These flow data are summarized in table 5. The lengths of the channel reaches with flow at time of observation range from about 1,000 ft for stream 5 to about 3,500 ft for stream 6. The maximum altitude at which flow was observed was about 200 ft above Lake Superior.

Of nine stream-measuring sites on Stockton Island, four had measurable flow, four had no flow and one (site 8) had flow, but velocities were too slow

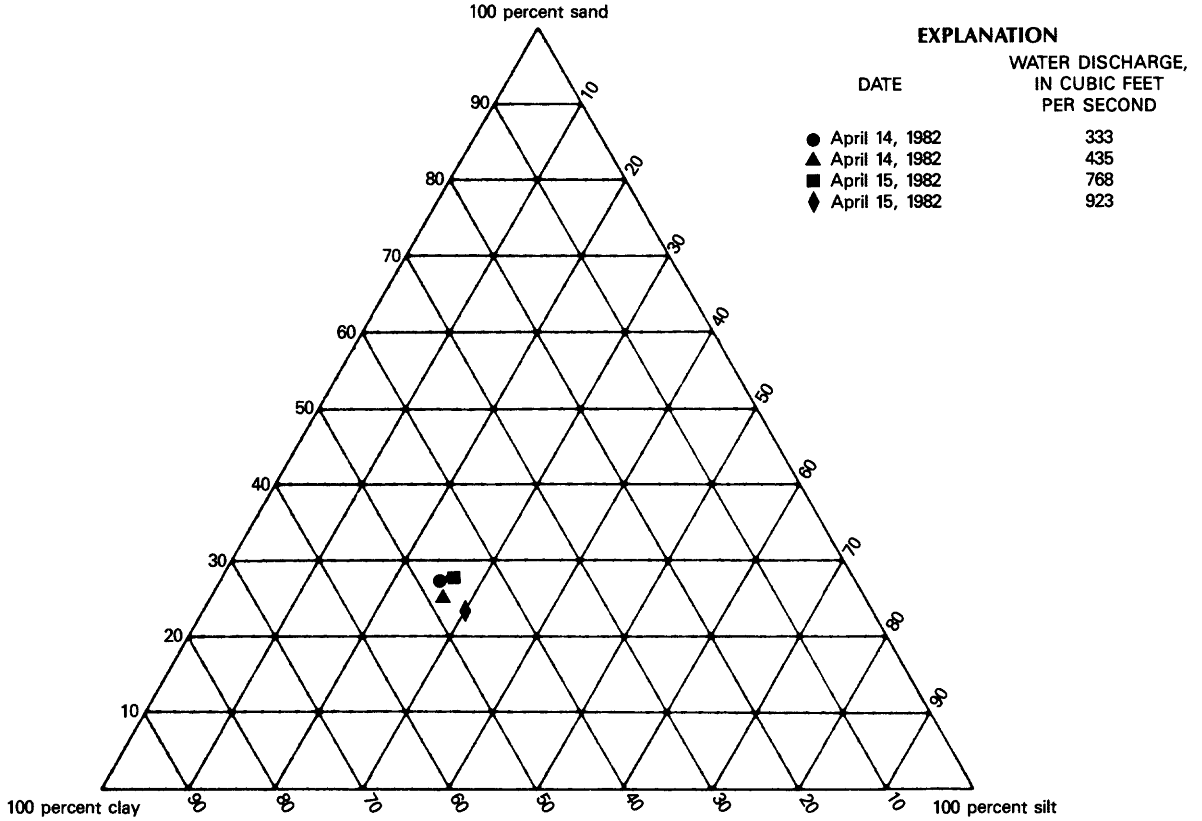

FIGURE 9. Particle-size distribution of suspended sediment at Sand River at Highway 13.

TABLE 4.—Estimated sediment and phosphorus loads and yields for Sand River at Highway 13 for the 1980–84 water years

[$ft^3/s{\cdot}d$ = cubic feet per second day; ton/mi² = ton per square mile; lb = pound; lb/mi² = pound per square mile; in. = inch]

Water year	Runoff volume ($ft^3/s{\cdot}d$)[1]	Suspended sediment load (ton)	Total sediment load (ton)	Total sediment yield (ton/mi^2)	Total phosphorus load (lb)	Total phosphorus yield (lb/mi^2)	Precipitation (in.)
1980	3,490	860	977	36	1,400	51	29.99
1981	8,210	5,540	6,290	230	3,900	142	25.71
1982	12,500	18,100	20,500	749	8,530	311	39.80
1983	12,000	11,300	12,900	469	7,210	263	34.45
1984	14,600	21,700	24,600	899	11,100	406	40.12
Average	10,100	11,500	13,100	476	6,430	235	33.99

[1]$ft^3/s{\cdot}d$ is the volume of water produced by a flow of 1 cubic foot per second for 24 hours. It is the equivalent of 86,400 cubic feet, 1.9835 acre-feet, 646,000 gallons, or 2,2447 cubic meters.

to measure because of backwater from Lake Superior. Stockton Island stream-measurement data are summarized in table 6.

Flood discharges were calculated for six Oak Island and eight Stockton Island stream sites using regression equations by Conger (1981). Peak discharges for the 2-, 10-, 50-, and 100-year recurrence interval floods are summarized in table 7. Oak Island stream basins generally yield flood discharges about twice as great as similar size Stockton Island stream basins (fig. 12); the greater discharge estimates of Oak

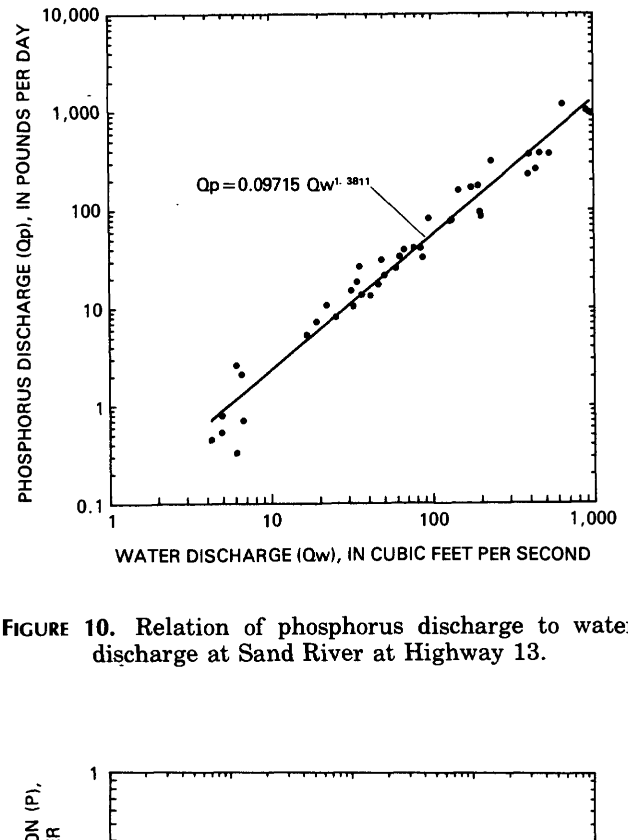

FIGURE 10. Relation of phosphorus discharge to water discharge at Sand River at Highway 13.

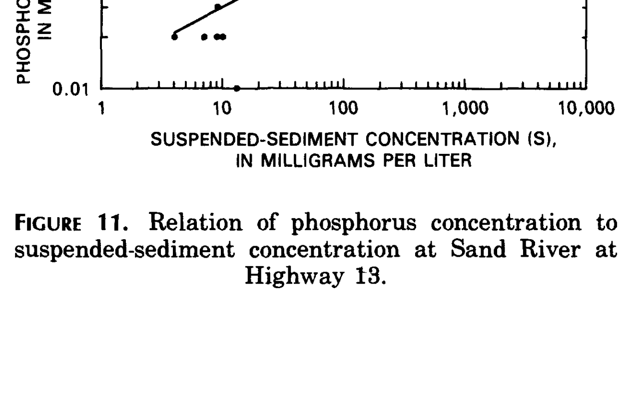

FIGURE 11. Relation of phosphorus concentration to suspended-sediment concentration at Sand River at Highway 13.

Island streams are due to that island's steeper channel slopes, absence of basin storage, and lower soil permeability. Average channel slope and basin storage for Oak Island streams is about 390 ft/mi (feet per mile) and 0 percent, respectively; for Stockton Island streams, average slope and storage are about 90 ft/mi and 7 percent, respectively. Soil permeability is 0.05 to 0.2 in/h on Oak Island compared to 0.2 to 0.8 in/h on Stockton Island (Young and Skinner, 1974).

Water Quality

Water in Oak Island streams during base flow generally contained higher concentrations of dissolved constituents than water in Stockton Island streams. Data from water-quality reconnaissance surveys of selected stream sites at Stockton Island in August 1980 and July 1984 and at Oak Island in June 1983 and July 1984 are summarized in tables 5 and 6.

There was no flow at some of the Stockton Island stream sites at the time of the survey. Water from nearby beaver ponds was sampled and analyzed. Water-quality data for beaver ponds are identified in the remarks column on table 6.

Bacteria analyses were done for some of the Stockton Island sites. Fecal coliform bacteria counts varied from 1 to 118 colonies/100 mL (colonies per 100 milliliters); fecal streptococci ranged from 14 to 5,200 colonies/100 mL.

Water temperatures were generally higher and dissolved oxygen concentrations lower in Stockton Island streams than in Oak Island streams. These differences probably reflect the lower stream gradients and ponded conditions on Stockton Island than on Oak Island.

Specific conductance, pH, and alkalinity values indicate that Oak Island base flow is dominated by ground-water discharge, whereas the Stockton Island base flow is sustained by seepage from wetlands and beaver ponds. Average specific conductance and alkalinity were 61μS/cm (microsiemens per centimeter at 25° Celsius) and 28 mg/L (milligrams per liter), respectively, at Oak Island and 32 μS/cm and 10 mg/L, respectively at Stockton Island. Median pH of Oak and Stockton Island stream water was 6.8 and 6.1, respectively.

Concentrations of major chemical constituents in base flow taken from the mouths of four Oak Island streams are given in table 8. Dominant cations are calcium and magnesium, and the dominant anion is bicarbonate. Sulfate and silica are the two other significant constitutents. These data are graphically illustrated in figure 13.

TABLE 5.—Base flow and water-quality field measurements from selected Oak Island stream sites
[ft^3/s = cubic feet per second; ft = feet; °C = degrees Celsius; μS/cm = microsiemens per centimeter at 25° Celsius; mg/L = milligrams per liter; dash indicates no data available]

Site	Date	Water discharge (ft^3/s)	Altitude (feet above sea level)	Distance from mouth (ft)	pH (standard units)	Temperature (°C)	Specific conductance (μS/cm)	Dissolved oxygen (mg/L)	Alkalinity (mg/L)
1a	6/23/83	0.04	602	0	5.9	12.8	30	9.8	—
	7/18/84	.016	—	—	7.3	14.0	40	9.7	11
1b	6/23/83	.04	660	1,050	5.6	14.5	29	9.3	—
	7/18/84	.04	—	—	7.1	12.5	42	10.2	11
1c	6/23/83	.05	770	2,200	5.5	13.5	29	8.3	—
	7/18/84	0	—	—	—	—	—	—	—
1d	6/23/83	.006	790	2,490	5.8	14.5	28	8.5	—
	7/18/84	0	—	—	—	—	—	—	—
1e	6/23/83	.02	790	2,580	5.6	13.0	29	9.1	—
	7/18/84	0	—	—	—	—	—	—	—
5a	6/23/83	.02	602	0	6.4	14.5	59	9.4	—
	7/18/84	.014	—	—	7.3	13.0	86	9.3	36
5b	6/23/83	.05	630	400	6.4	11.5	94	10.2	—
	7/18/84	.022	—	—	7.3	13.5	85	9.6	36
5c	6/23/83	.003	700	960	5.6	11.9	34	9.3	—
	7/18/84	0	—	—	—	—	—	—	—
6a	6/23/83	.29	603	30	7.0	11.5	111	10.1	—
	7/18/84	.19	—	—	7.6	11.5	145	10.0	65
6b	6/23/83	.16	660	1,450	6.8	11.5	103	10.0	—
	7/18/84	.12	—	—	7.7	11.0	130	10.3	59
6c	6/23/83	.024	700	2,160	6.1	13.0	40	10.0	—
	7/18/84	.037	—	—	7.5	12.5	50	10.0	18
6d	6/23/83	.042	790	3,140	6.1	12.5	38	9.4	—
	7/18/84	.049	—	—	7.3	12.5	48	9.9	15
6e	6/23/83	< .01	840	3,530	5.6	11.5	37	8.1	—
	7/18/84	.019	—	—	7.2	12.0	51	10.1	15
7a	6/23/83	.08	603	0	6.7	14.0	84	9.8	—
	7/18/84	.087	—	—	7.6	13.0	112	10.2	47
7b	6/23/83	.14	640	370	6.7	12.5	67	10.2	—
	7/18/84	.055	—	—	7.5	14.5	82	9.7	34
7c	6/23/83	.09	680	1,300	6.4	13.0	42	10.3	—
	7/18/84	.064	—	—	7.4	14.5	55	9.6	20
7d	6/23/83	.05	740	2,450	6.0	12.5	38	9.5	—
	7/18/84	.034	—	—	7.2	13.0	42	10.0	12
7e	6/23/83	< .05	780	3,150	5.9	13.0	42	8.8	—
	7/18/84	.005	—	—	7.0	14.0	59	9.2	20

TABLE 6.—Base flow and water-quality field measurements from selected Stockton Island stream sites

[ft³/s = cubic feet per second; °C = degrees Celsius; μS/cm = microsiemens per centimeter at 25° Celsius; mg/L = milligram per liter; col/100 ml = colonies per 100 milliliters; dash indicates no data available]

Site	Date	Discharge (ft³/s)	Temperature (°C)	Dissolved oxygen (mg/L)	Specific conductance (μS/cm)	ph	Alkalinity (mg/L)	Fecal coliform (col/100 mL)	Fecal streptococci (col/100 mL)	Remarks
1	Aug. 6, 1980	0.0022	17.5	2.5	17	4.7	—	68	80	
2	Aug. 7, 1980	0	22	4.2	26	5.6	—	10	47	No flow—sampled water in beaver pond
3	Aug. 7, 1980	0	19.5	2.9	52	6.1	—	40	150	No flow—sampled water in beaver pond
4	Aug. 7, 1980	.008	20.5	6.5	42	6.4	—	118	300	
5	Aug. 7, 1980	0	26.0	7.7	20	6.6	—	1	14	No flow—sampled water in beaver pond
6	Aug. 7, 1980	.0006	19.0	6.6	30	6.8	—	43	5,200	
	July 17, 1984	< .005	15.5	2.6	43	6.0	12			
7	Aug. 7, 1980	0	—	—	—	—	—	—	—	No flow
	July 17, 1984	.009	16.0	5.6	28	6.3	8			
8	Aug. 8, 1980	—	22.0	2.4	24	5.6	—	4	114	Channel in backwater—velocity too slow to measure
	July 17, 1980	—	16.7	3.8	28	5.6	4			
9	Aug. 7, 1980	0	—	—	—	—	—	—	—	No flow
	July 17, 1980	0	—	4.2	42	6.4	15	—	—	No flow—sampled water in beaver pond

TABLE 7.—Peak flood discharges at the 2-, 10-, 50-, and 100-year recurrence intervals for selected Oak and Stockton Island streams

Stream	2-year	10-year	50-year	100-year
Oak Island				
1	82	215	381	463
2	82	212	372	450
3	79	205	365	443
5	49	132	238	290
6	81	212	376	456
7	76	200	356	432
Stockton Island				
1	25	61	103	122
2	38	89	148	176
3	73	165	268	316
4	26	60	99	117
5	37	87	143	170
6	29	70	115	136
7	32	73	119	141
9	48	107	170	200

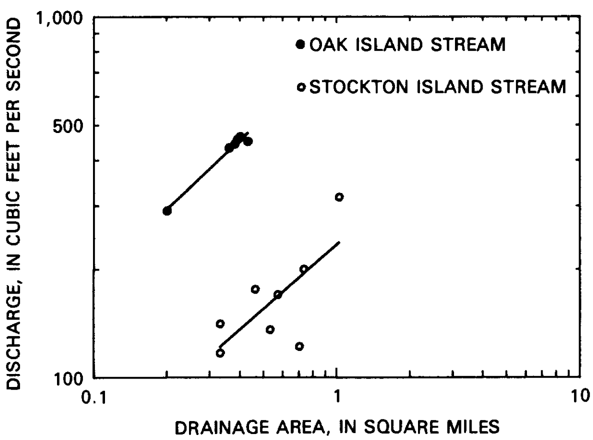

FIGURE 12. Relation of 100-year recurrence-interval discharge to drainage area for selected Oak and Stockton Island streams.

TABLE 8.—Chemical characteristics of base-flow discharge from selected Oak Island streams

[ft^3/s = cubic feet per second; µS/cm = microsiemens per centimeter at 25° Celsius; °C = degrees Celsius; mg/L = milligrams per liter]

Site number	Streamflow, instantaneous (ft^3/s)	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Oxygen, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)
1a	0.04	21	5.8	13.0	9.8	14	3	3.7	1.1	1.1
5a	.02	53	6.4	14.5	9.4	32	6	8.8	2.4	1.3
6a	.29	111	7.0	11.5	10.1	66	5	19	4.6	1.8
7a	.08	84	6.7	14.0	9.8	46	6	13	3.4	1.6

Site number	Potassium, dissolved (mg/L as K)	Alkalinity lab (mg/L as $CaCO_3$)	Carbon dioxide, dissolved (mg/L as CO_2)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Fluoride, dissolved (mg/L as F)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180°C dissolved (mg/L)	Solids, sum of constituents dissolved (mg/L)
1a	0.70	11	34	8.9	0.80	0.20	8.8	36	32
5a	.90	26	20	10	1.3	< .10	11	58	51
6a	.80	61	12	11	.50	< .10	13	84	87
7a	.90	41	16	10	.90	.10	13	77	67

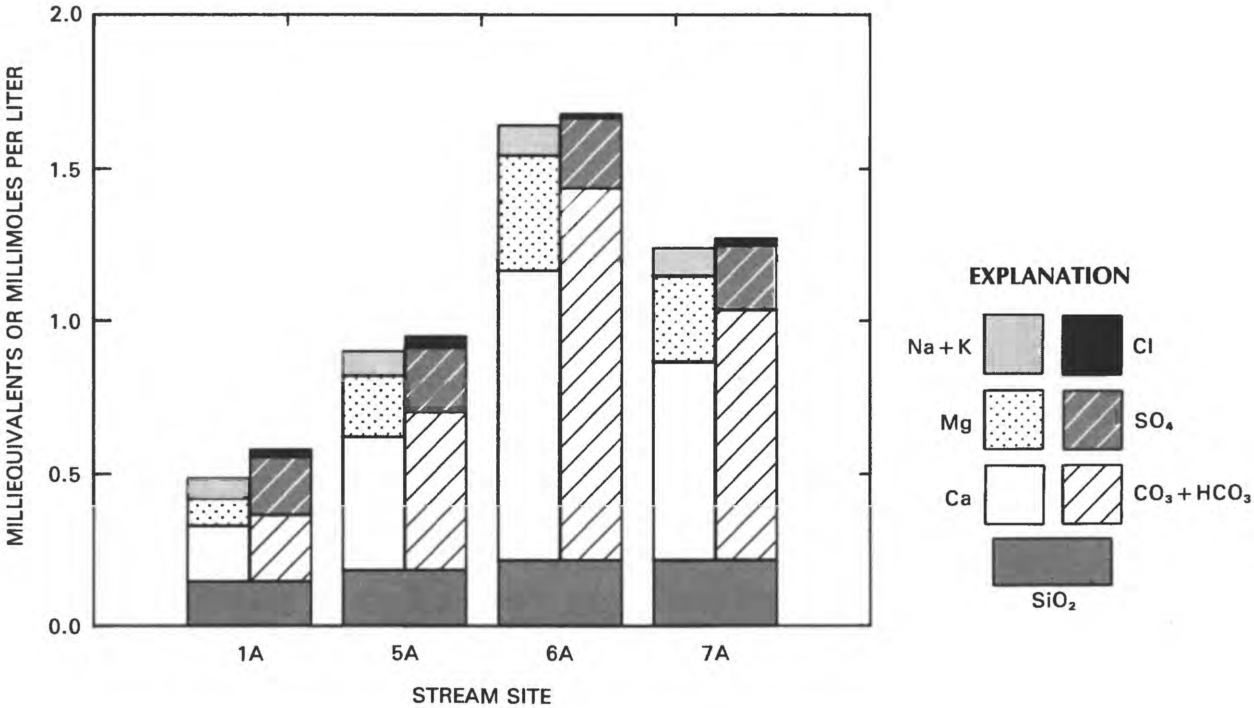

FIGURE 13. Major chemical constituents in base flow of Oak Island streams on June 23, 1983.

ISLAND LAGOONS

Lagoons formed by coastal processes are on several of the islands. Most of the lagoons are behind cuspate bars and forelands that were formed by wave erosion and sediment transport. Morphologic, hydrologic, and water-quality data were collected for the largest lagoon of this type, which is located at the south end of Outer Island, in July 1983; and for the second largest lagoon, which is located on the west end of Michigan Island, in August 1984.

Outer Island Lagoon

DESCRIPTION OF ARBITRARY DATUM

The arbitrary datum to which the altitudes of cross sections and water levels are referenced is at an altitude of approximately 507 ft. Two elevation reference points whose approximate locations are indicated on figure 14 were established. Reference point number one (RP # 1) is a spike in the southwest side of a double-limbed 3-ft diameter pine tree at altitude

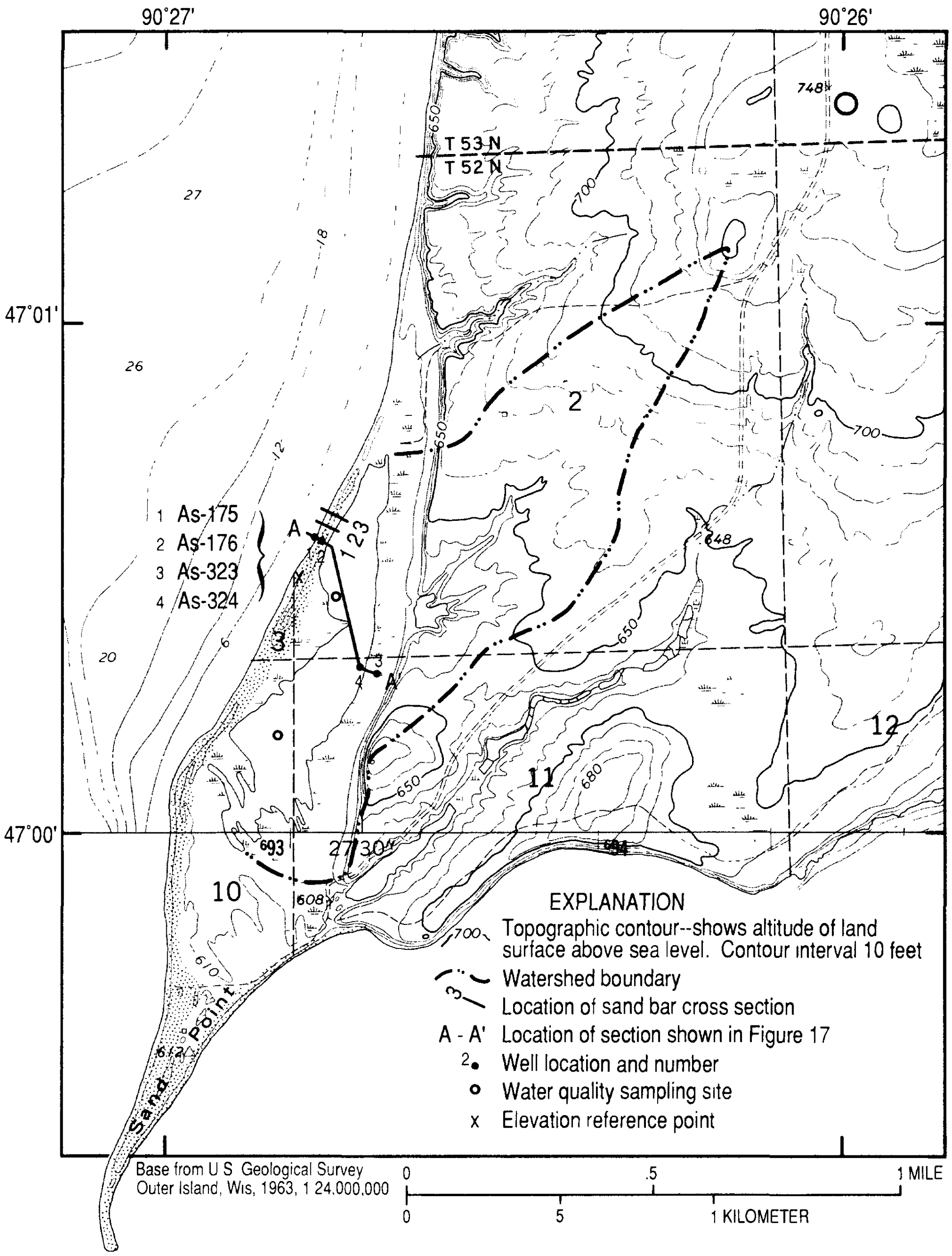

FIGURE 14. Location of Outer Island Lagoon in relation to Lake Superior, watershed, and data-collection points.

100.00 ft above arbitrary datum. RP # 2 is a spike in the northeast side of the northmost limb of a double-limbed pine tree about 25 ft north of RP # 1 at altitude 100.20 ft above arbitrary datum.

PHYSICAL CHARACTERISTICS AND SETTING

The Outer Island Lagoon is about 4,400 ft long and varies in width from about 300 to 1,000 ft. Its surface area is 53 acres; its maximum depth is 7 ft and its average depth is 2.6 ft. Figure 15 is a bathymetric map based on a July 27, 1983, field survey.

The bar separating the lagoon from Lake Superior is narrowest at the lagoon's northern end. The bar's width at the narrowest point was 55 ft on July 27, 1983; the bar crest was about 5 ft above Lake Superior and the lagoon. Figure 16 shows three section views of the bar (locations of the sections are indicated on fig. 14). The bar was reported to have been artificially breached in the past and as recently as the early 1940's. Prior to about 1910, commercial fishermen opened a channel through the bar every spring and anchored their boats in the lagoon where they were sheltered from the waves of Lake Superior (Ernest La-Pointe, retired commercial fisherman, oral commun., Bayfield, Wis., 1986).

The composition of vegetation on the bar is described by Anderson and Milford (1979). The north, east, and south sides of the lagoon are bordered by bog.

A 230-acre watershed to the east drains toward the lagoon. Most of the soils in the watershed consist of 2 to 4 ft of sandy and cobbly beach deposits overlying dense sandy loom till. The primary vegetative cover in the watershed is birch and maple (Anderson and Milford, 1979).

RELATION TO LAKE SUPERIOR AND GROUND WATER

The lagoon water surface varied from 0.04 to 0.38 ft and averaged 0.20 ft higher than the surface of Lake Superior for 12 concurrent measurements. Eleven of the measurements were made during the period July 26 to October 4, 1983; a single set of measurements was made on August 23, 1984. The water surface of Lake Superior generally shows an annual fluctuation of about 1 ft (National Oceanic and Atmospheric Administration, 1985). The annual high-water stages in Lake Superior usually occur from July through September, which is the approximate period when the lagoon and lake measurements were taken. During periods of low Lake Superior stages, it is likely that the lagoon water surface is even higher relative to the Lake than when the concurrent measurements were made.

The altitude of the lagoon water surface relative to the water table and Lake Superior on July 28, 1983, is shown in figure 17. Because the lagoon water surface is generally higher than Lake Superior, the ground-water gradient and movement are generally from the lagoon toward the Lake. The gradient through the bog probably is transient although data are not available to confirm it. Precipitation, runoff and seepage from the watershed to the east probably reverses the gradient so that water, at least intermittently, moves from the bog to the lagoon.

WATER-BUDGET COMPONENTS

There is insufficient information to quantify the lagoon's water-budget components. However, the components can be identified and their relative importance evaluated. The various budget components are shown diagrammatically in figure 18.

The inflow components are precipitation on the water surface, surface discharge from bog, ground-water discharge, and wave washover from Lake Superior. Precipitation and surface discharge from the bog probably compose most of the inflow to the lagoon. Most of the runoff to the bog probably is provided by throughflow from the island watershed. Overland flow and streamflow from the watershed probably are small owing to the sandy soil and dense forest cover. Ground-water discharge likely is small and intermittent from the bog side of the lagoon. The significance of wave washover probably varies considerably from year-to-year. At the time of the July 1983 field study there was no evidence of recent (within past year) wave washover. Washover was confirmed however, during the storm of September 11–12, 1978 (Anderson and Milford, 1979).

The outflow components are evaporation, surface discharge to bog, and ground-water outflow. Evaporation would be most significant during open-water periods. Surface discharge to the bog probably is intermittent and dependent on the relative altitudes of water levels in the lagoon and bog. Evapotranspiration in the bog may induce surface outflow and ground-water outflow on the bog side of the lagoon. Ground-water outflow is the only outflow component during periods of ice cover when there is virtually no evaporation or evapotranspiration.

CHEMICAL QUALITY

The lagoon water can be characterized as acidic, with low specific conductance and generally low concentrations of most chemical constituents. There was no vertical stratification and no significant difference in chemistry between the north and south basins.

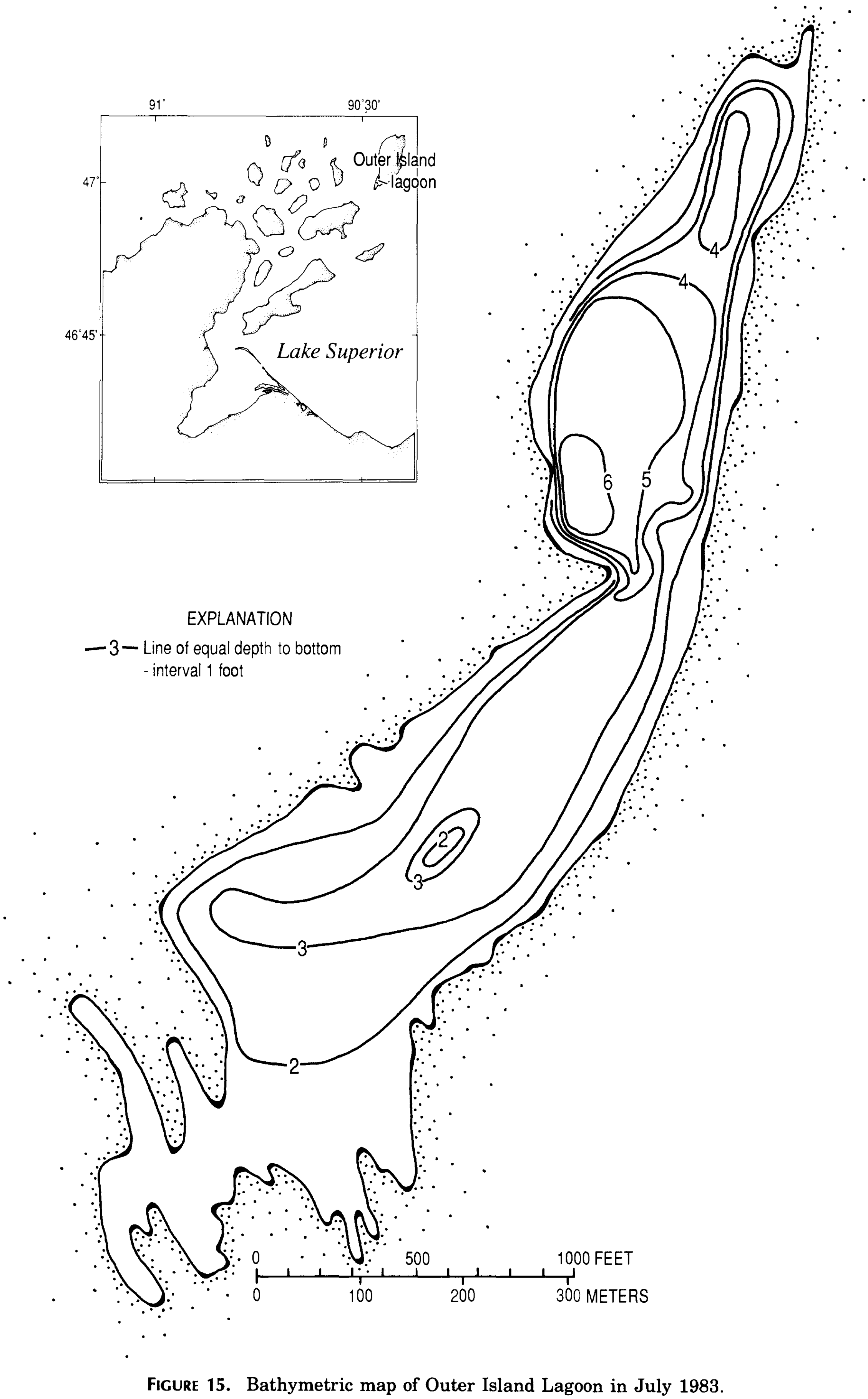

FIGURE 15. Bathymetric map of Outer Island Lagoon in July 1983.

Concentrations of selected chemical constituents are summarized in table 9. Anderson and Milford (1979) reported similar constituent concentrations in samples they collected in August 1978.

The chemical character of the water supports the contention that water inflow to the lagoon is dominated by precipitation and surface flow from the adjacent bog. Specific conductance, an indication of the amount of dissolved solids in water, was greater in both Lake Superior water and ground water adjacent to the lagoon. Average Lake Superior specific conductance was reported to be 97 μS/cm (International Joint Commission, 1977); and specific conductance of shallow ground water from wells As-175 and As-176 (fig. 15) was 88 and 69 μS/cm, respectively, whereas specific-conductance measurements of lagoon water ranged from 19 to 25 μS/cm. The International Joint Commission (1977) reported Lake Superior alkalinity averages 42 mg/L and the alkalinity of water from wells As-175 and As-176 was 29 and 40 mg/L, respectively. The lagoon's alkalinity was 4 mg/L.

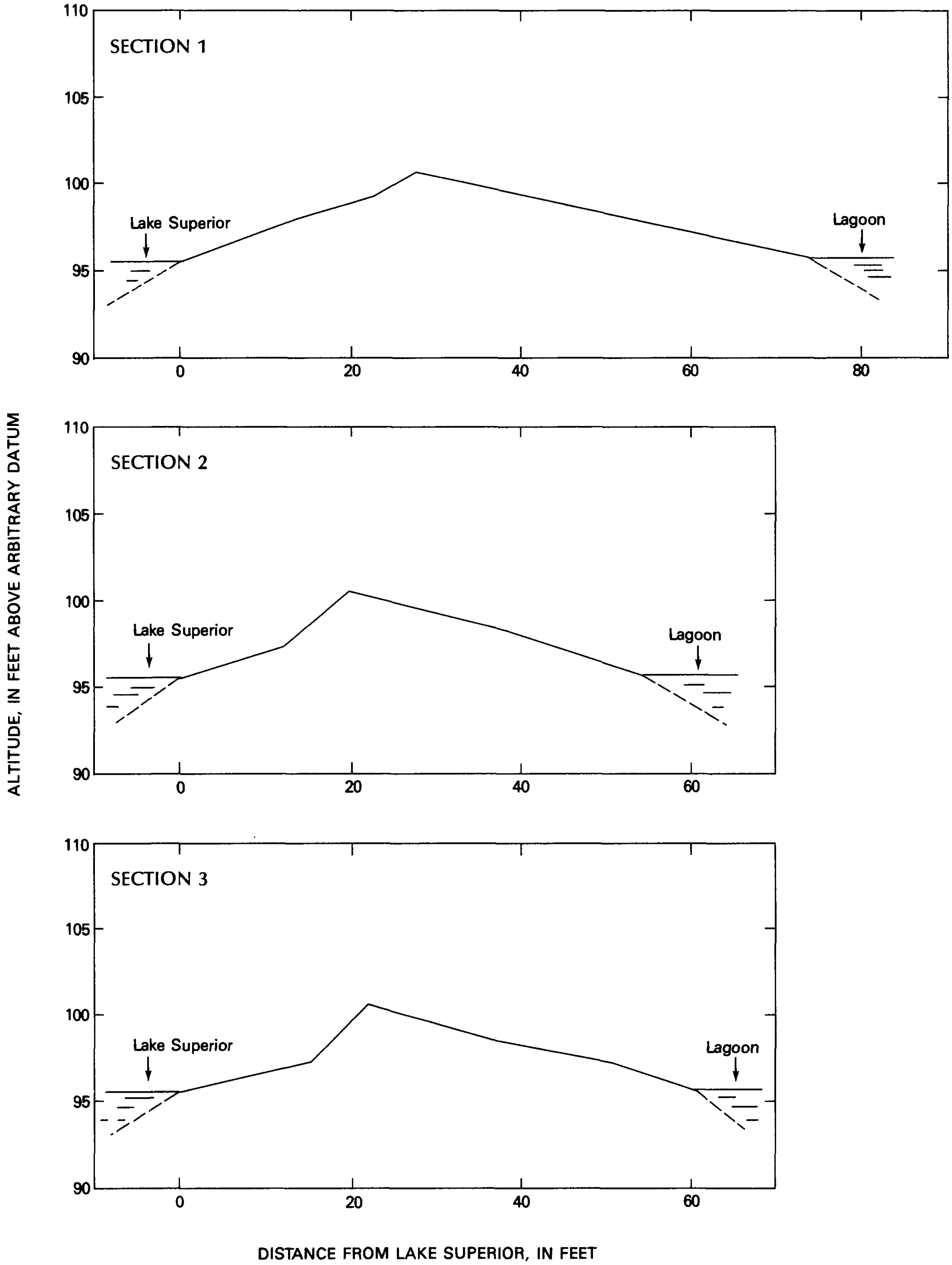

FIGURE 16. Transverse sections of bar separating Outer Island Lagoon from Lake Superior.

Michigan Island Lagoon

DESCRIPTION OF ARBITRARY DATUM

The arbitrary datum to which the altitudes of cross sections and water levels are referenced is at an altitude of approximately 495.5 ft above sea level. Reference points were not established to preserve this datum.

PHYSICAL CHARACTERISTICS AND SETTING

The lagoon is irregularly shaped and situated along the north bar of the cuspate foreland. Wetlands surround the lagoon. The maximum lagoon water depth is 6.5 ft, and the water surface area is about 4 acres. The area of the lagoon as delineated on the 7.5-minute Michigan Island topographic map, which was based on 1963 aerial photography, is 7.8 acres. The approximate boundaries of the 1963 and 1984 open-water area are shown in figure 19.

The bar along the northern side of the lagoon and wetland is about 3½ ft above the surface of the lake and about 50 ft wide at the base. Figure 20a shows a typical cross section of the bar.

The aquifer in which the lagoon and wetland are situated consists of sandy beach and dune deposits of unknown thickness. Till probably underlies the sand.

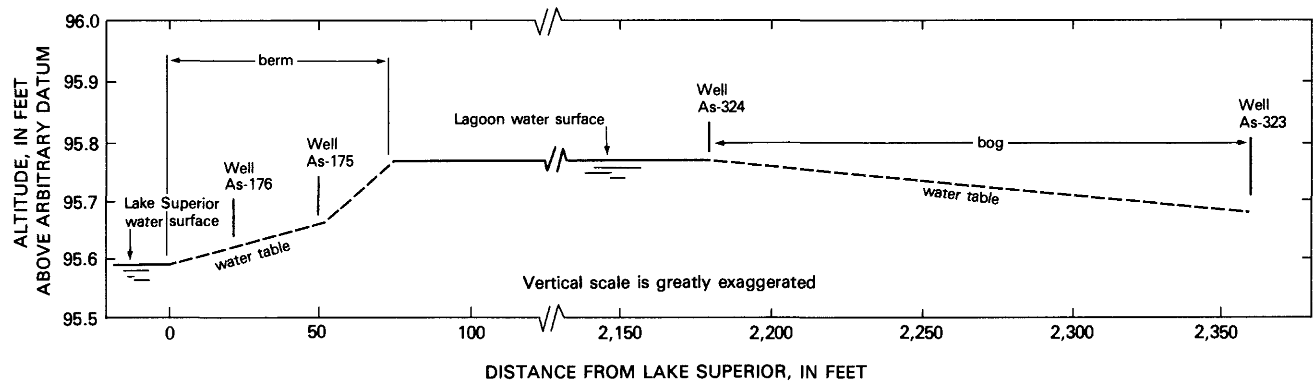

FIGURE 17. Section view showing relation of lagoon water surface to water table and Lake Superior on July 28, 1983.

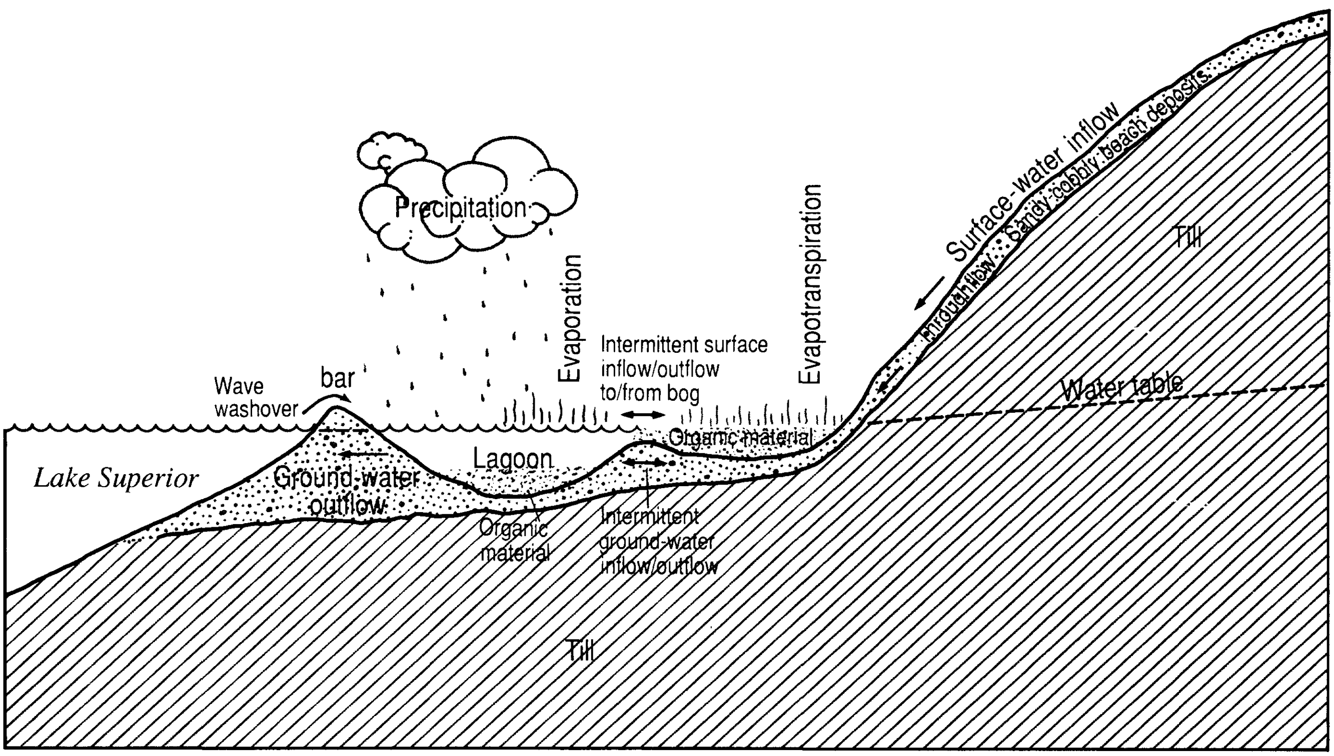

FIGURE 18. Diagrammatic sketch showing Outer Island Lagoon's water-budget components in relation to geology.

Table 9.—Chemical characteristics of the northern and southern basins of Outer Island Lagoon

[μS/cm = microsiemens per second at 25° Celsius; °C = degrees Celsius; mg/L = milligrams per liter; tons/ac-ft = tons per acre foot; dash indicates no data available]

Sample site	Date	Time	Specific conductance (μS/cm)	pH (standard units)	Temperature (°C)	Oxygen, dissolved (mg/L)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Percent sodium	Sodium adsorption ratio	Potassium, dissolved (mg/L as K)	Alkalinity field (mg/L as $CaCO_3$)
Southern basin	July 28, 1983	1030	20	5.8	26.0	7.6	8	3	2.1	0.66	0.60	13	0.0	0.80	4
Northern basin	July 28, 1983	1130	19	6.2	26.0	7.9	8	3	2.2	.69	.60	12	.0	.70	4
	Aug. 31 1983	1310	25	6.8	25.0	—	—	—	—	—	—	—	—	—	4

Sample site	Date	Time	Alkalinity lab (mg/L as $CaCO_3$)	Carbon dioxide, dissolved (mg/L as CO_2)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Silica, dissolved (mg/L as (SiO_2))	Solids, residue at 180° C dissolved (mg/L)	Solids, sum of constituents dissolved (mg/L)	Solids, dissolved (tons/ac-ft)	Nitrogen, NO2+NO3 dissolved (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)	Phosphorus, total (mg/L) as P)	Carbon, organic total (mg/L as C)
Southern basin	July 28, 1983	1030	5.0	15	9.0	0.80	0.2	36	17	0.05	—	—	—	—
Northern basin	July 28, 1983	1130	5.0	6.1	9.0	.80	.2	41	17	.06	—	—	—	—
	Aug. 31 1983	1310	—	1.1	—	—	—	—	—	—	<0.100	0.50	0.020	12

RELATION TO LAKE SUPERIOR AND GROUND WATER

The lagoon water surface varied from 0.06 to 0.30 ft and averaged 0.19 ft higher than Lake Superior for 12 sets of concurrent measurements made between August 23 and September 20, 1984. These measurements were made during the period of seasonal high Lake Superior water stages. It is likely, therefore, that the lagoon water surface is higher relative to the lake during periods of low lake stage than when the measurements were made.

The altitude of the lagoon water surface relative to the water table and Lake Superior on August 24, 1984, is shown in figure 20b. The ground-water gradient and movement are away from the lagoon and toward the lake because the lagoon water surface is generally higher than Lake Superior.

WATER-BUDGET COMPONENTS

The various components of the lagoon's water budget are shown in figure 21. Inflow components are

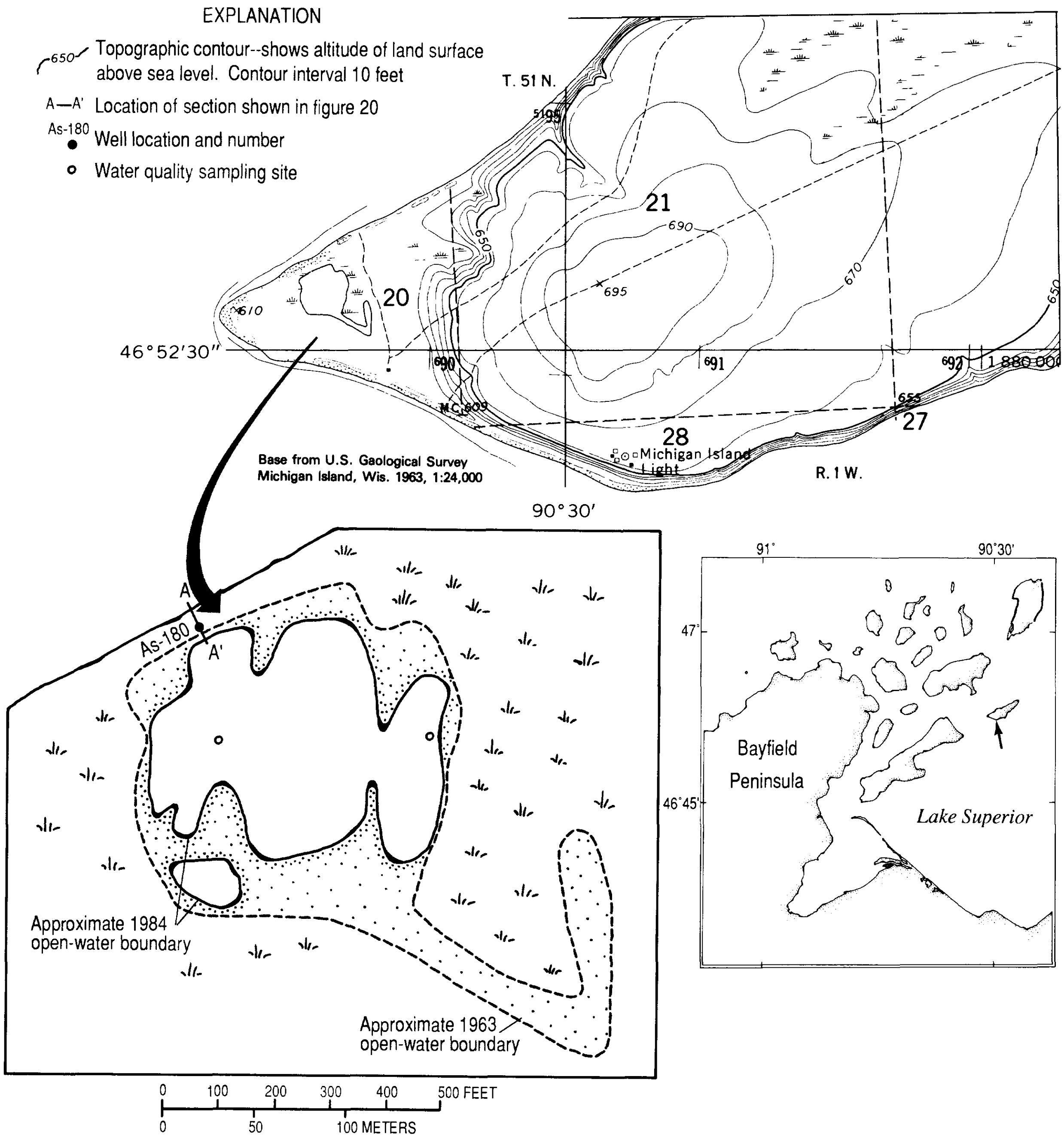

FIGURE 19. Map showing location of Michigan Island Lagoon in relation to Lake Superior and data-collection points.

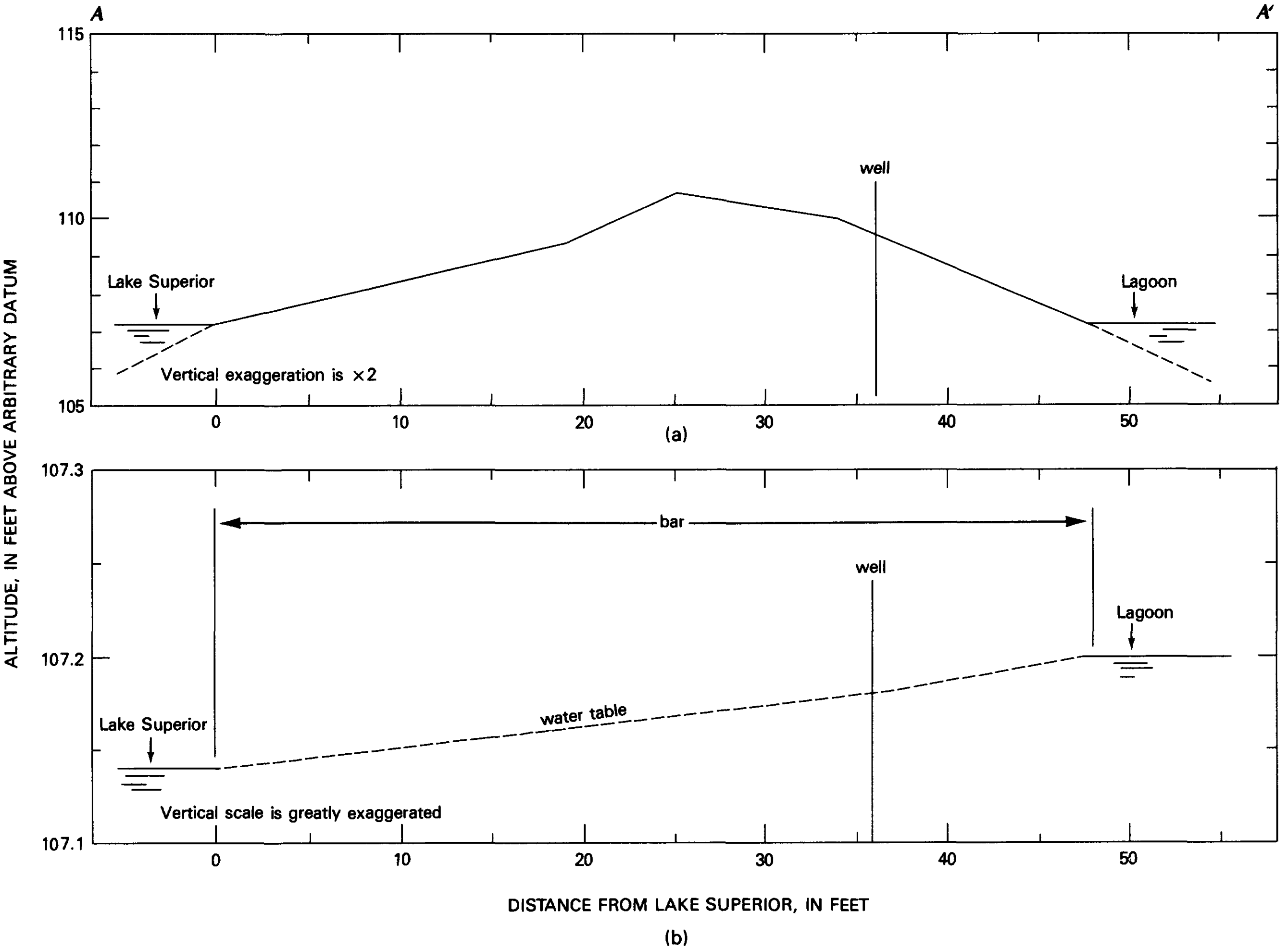

FIGURE 20. Typical transverse sections of: (a) bar separating Lake Superior from Michigan Island Lagoon and wetland, and (b) relation of lagoon to ground water and Lake Superior.

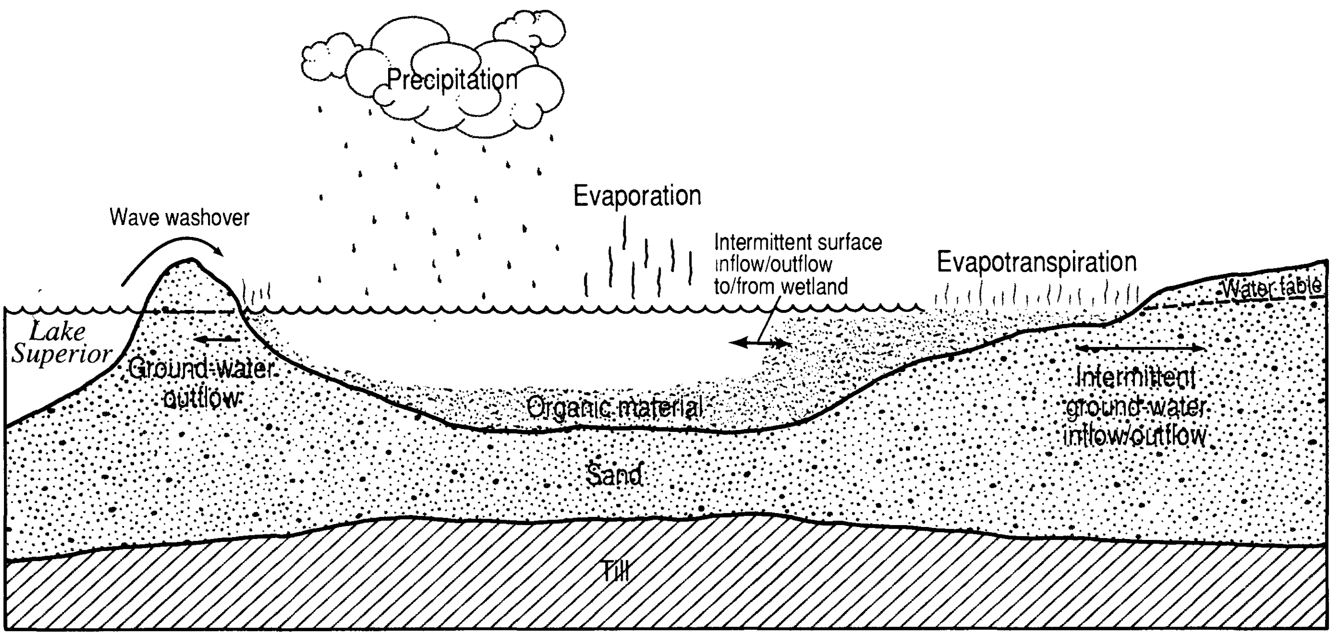

FIGURE 21. Michigan Island Lagoon's water-budget components in relation to geology.

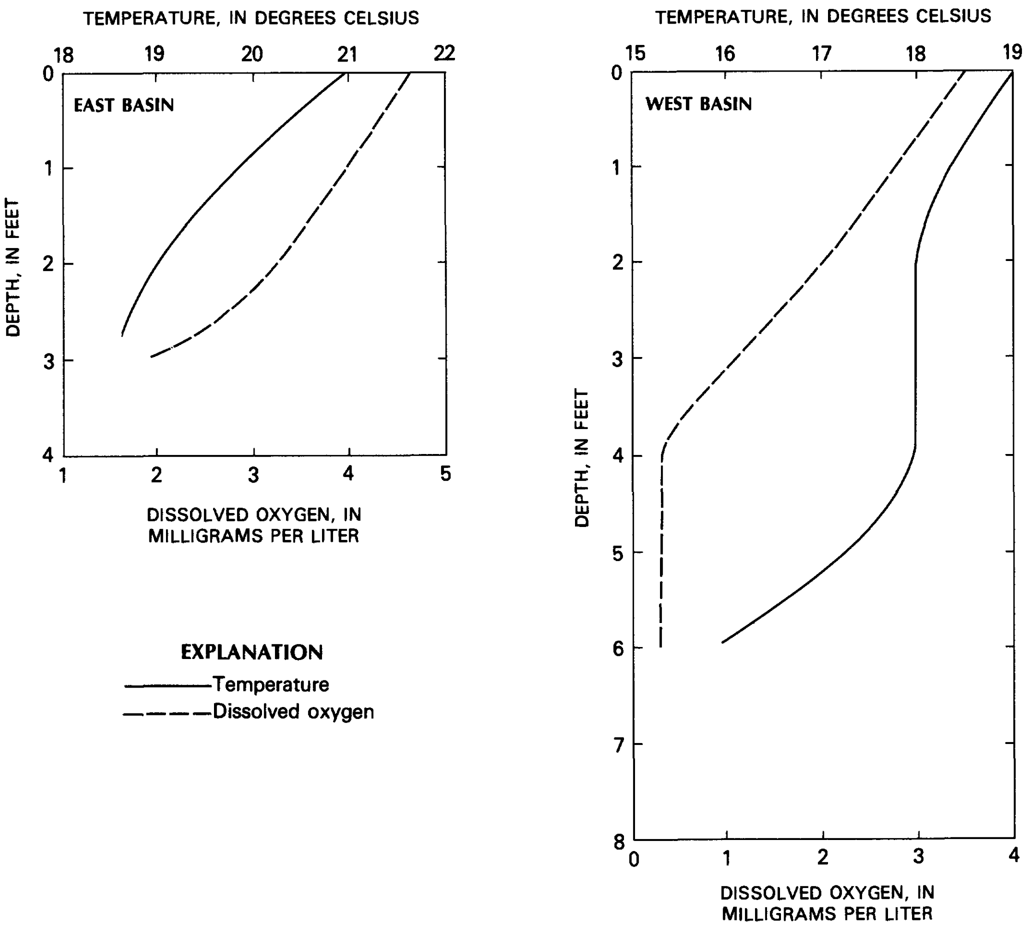

FIGURE 22. Temperature and dissolved-oxygen profiles at Michigan Island Lagoon sampling sites on August 24, 1984.

TABLE 10.—Chemical characteristics of the eastern and western basins of Michigan Island Lagoon

[°C = degrees Celsius; μS/cm = microsiemens per centimeter at 25° Celsius; mg/L = milligrams per liter]

Sample site	Date	Time	Specific conductance (μS/cm)	pH (standard units)	Temperature (°C)	Oxygen, dissolved (mg/L)	Calcium, dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity field (mg/L as $CaCO_3$)
Eastern basin	Aug. 24, 1984	1200	62	6.5	21	4.7	8.7	2.3	0.5	0.2	30
Western basin	Aug. 24, 1984	1130	90	6.4	19	3.5	12	2.8	.7	.2	41

Sample site	Date	Time	Alkalinity lab (mg/L as $CaCO_3$)	Sulfate dissolved (mg/L as SO_4)	Chloride, dissolved (mg/L as Cl)	Silica, dissolved (mg/L as SiO_2)	Solids, residue at 180° C dissolved (mg/L)	Nitrogen, NO2+NO3 dissolved (mg/L as N)	Nitrogen, ammonia + organic total (mg/L as N)	Phosphorus, total (mg/L) as P)	Carbon, organic total (mg/L as C)
Eastern basin	Aug. 24,	1200	31	1.4	0.8	9.3	59	0.7	0.7	0.010	7.5
Western basin	Aug. 24,	1130	43	1.5	1.1	8.2	67	.1	1.0	.096	7.6

precipitation, wave washover from Lake Superior, surface inflow from adjacent wetlands, and, perhaps, intermittent ground-water inflow. Precipitation and wave washover probably are the most significant inflow components. Wave washover appears to be more significant than it is at Outer Island Lagoon. The bar is only about 3½ ft high compared to about 5 ft high at Outer Island. There was visual evidence of recent wave washover, such as small gullies on the lagoon side of the bar and fresh sand deposits on small vegetation. The amount of wave washover in a given year would vary and depend on the number, direction, and severity of storms. Ground-water discharge to the lagoon probably is small and intermittent. It is likely that surges of ground-water recharge from snowmelt or heavy rain induce at least a temporary positive ground-water gradient and ground-water discharge to the lagoon.

Runoff from the eastern upland area of the island probably has little influence on the lagoon. Evapotranspiration and ground-water seepage to Lake Superior probably dissipate most overland flow or ground-water seepage from the upland area of the island.

The outflow components of the budget are evaporation, surface flow to adjoining wetlands, and ground-water outflow. Evapotranspiration from wetlands probably induces seepage from the lagoon. The most significant outflow component during periods of ice cover when evaporation is extremely small and evapotranspiration nonexistent, is ground-water outflow.

CHEMICAL QUALITY

The Michigan Island Lagoon water is a calcium magnesium bicarbonate type. Major constituents are summarized in table 10. Concentrations of most constituents were lower in the east basin than the west basin; this indicates poor mixing of the water. Poor mixing results from the relatively small size of the lagoon, sheltering from wind by surrounding trees, and the presence of large patches of rooted macrophytes. There was some vertical variation in temperature and dissolved oxygen as shown in figure 22.

The composition of water from Michigan Island Lagoon is compared with water from Outer Island

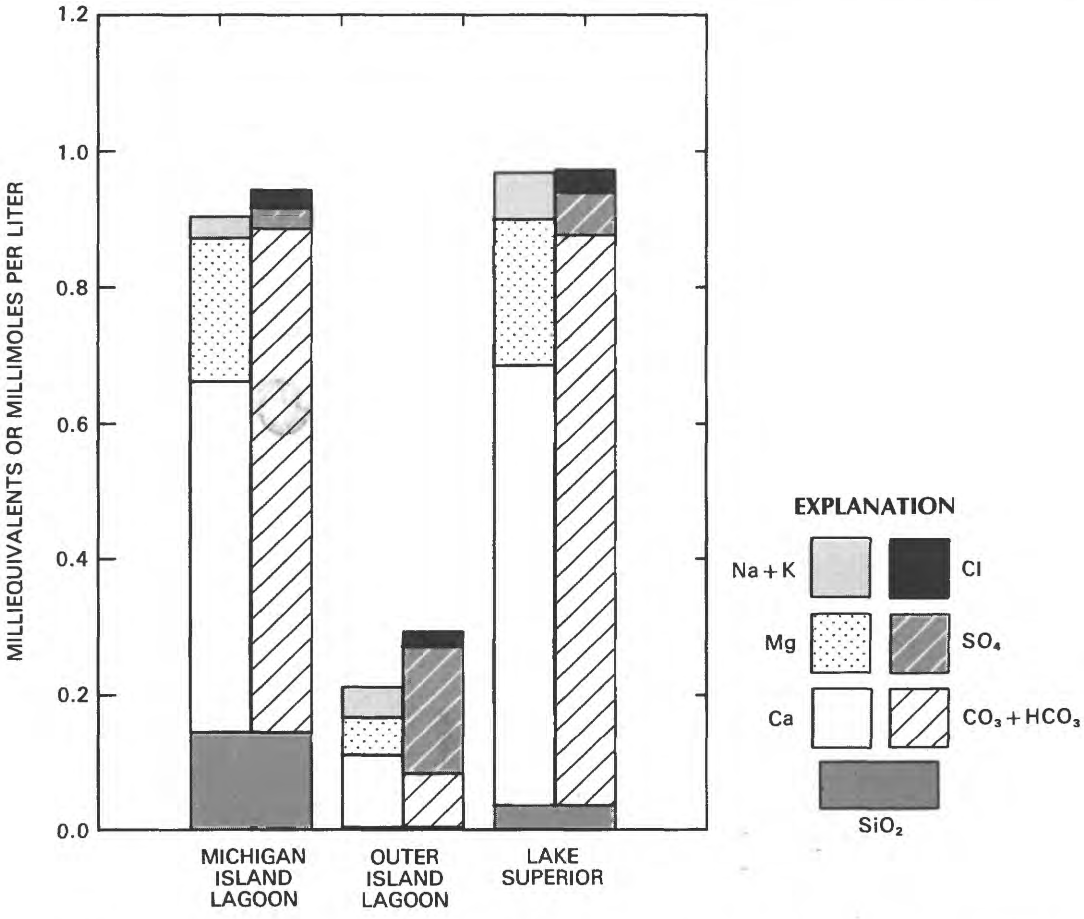

FIGURE 23. Comparison of major chemical constituents in Michigan and Outer Island Lagoons and Lake Superior.

Lagoon and Lake Superior in figure 23. The composition of Michigan Island Lagoon water regarding major cations and anions is more similar to Lake Superior than to Outer Island Lagoon; this supports the hydrologic interpretation that a major inflow component is wave washover from Lake Superior. The relatively high concentration of silica compared to Outer Island Lagoon or Lake Superior is not readily explainable. One possible explanation is that diatoms washed in from Lake Superior decompose in the warmer, more acidic lagoon environment and release silica to the water.

LAKE SUPERIOR

Two categories ("deep-water" and "heavy-use area") of monitoring were done. "Deep-water" monitoring sites are within or near the National Lakeshore boundaries and in deep (85 to 220 ft) water. The sites were selected to be representative of the deep-water areas of the Lakeshore. Presumably any changes in the character of the water, sediment or benthos at these sites would most likely be the result of activities occurring outside of the Lakeshore. "Heavy-use area" monitoring was intended to monitor the effects of activities occurring within the Lakeshore in local and generally shallow (0 to 80 ft) water areas.

Deep-Water Characteristics

Locations of the four deep-water monitoring sites are shown in figure 1. The general pattern of surface circulation in Lake Superior is counter clockwise or west-to-east in the Apostle Islands area (International Joint Commission, 1977). Hence, water and sediment quality at site 1, which is situated near the west side of the Lakeshore, is subject to influence by water moving from the western arm of Lake Superior. Sites 2 and 4 were chosen to monitor conditions that might be influenced by water moving northeastward from Chequamegon Bay. Site 4 is in a relatively deep (220 ft) depositional basin west of Stockton Island.

The latitude and longitude of the sampling sites are listed below.

Site Number	Latitude	Longitude
1	47°03′13″N	90°54′13″W
2	46°56′05″N	90°40′17″W
3	46°49′48″N	90°43′28″W
4	46°51′58″N	90°45′39″W

WATER QUALITY

Constituent concentrations varied little with depth or from site-to-site. The sites were sampled during July 1981 and July 1982. The water column was sampled at three depths: at each site near the surface, at or just above the thermocline, and 3 to 18 ft above the bottom. Dates and times of sampling and sampling depths are given in table 11.

Continuous temperature and dissolved oxygen profiles, which were measured at the time of sampling, are shown in figure 24. The water column was sharply stratified at Site 1 in 1982, and at Sites 2 and 4 in 1981. The maximum observed epilimnion temperatures ranged from 11 to 19.5° C at Sites 1 and 4 respectively. Minimum observed hypolimnion temperatures ranged from 4 to 6° C. The dissolved-oxygen profiles reflect the temperature profiles inversely. The entire water column is at or near oxygen saturation.

Measured values of total phosphorus, organic carbon, and recoverable mercury all were within the range reported by the International Joint Commission (1977) for "near-shore" waters of Lake Superior. Phosphorus concentrations varied from <0.01 to 0.02 mg/L. Only three samples contained concentrations greater than the 0.01 mg/L detection limit. Total organic carbon ranged from 1.1 to 5.3 mg/L and averaged 1.9 mg/L. The average total organic carbon concentration in the surface and medium-depth samples was 2.0 mg/L in each; the average concentration in the deep-water samples was 1.5 mg/L. Total recoverable mercury concentrations varied from <0.1 to 0.1 μg/L, and only six of 24 concentrations were greater than the 0.1 μg/L detection limit.

No pesticide residues were detected in water from any of the four sites or three depths sampled. Only the July 1981 samples were analyzed for pesticides. The pesticide for which analyses were done and laboratory detection limits are listed below.

Pesticide	Laboratory detection limit (μg/L)
PCB	0.1
polychlorinated naptholences	.1
aldrin	.01
chlordane	.1
DDD	.01
DDE	.01
DDT	.01
dieldrin	.01
endosulfan	.01
endrin	.01
heptachlor	.01
heptachlor epoxide	.01
lindane	.01
methoxychlor	.01
mirex	.01
perthane	.01
toxaphene	.1

TABLE 11.—Selected physical and chemical characteristics for the deep-water monitoring sites

[ft = feet; µS/cm = microsiemens per centimeter at 25° Celsius; °C = degrees Celsius; mg/L = milligram per liter; µg/L = microgram per liter; dash indicates no data available]

Site	Date	Time	Sampling depth (ft)	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)	Phosphorous total (mg/L)	Organic carbon, total (mg/L)	Mercury total recoverable (µg/L)
1	7/22/81	1055	0	83	7.5	11.0	<0.01	1.8	<0.1
		1100	23	88	7.6	8.0	—	5.3	< .1
		1107	164	83	7.3	4.0	< .01	1.4	< .1
	7/26/82	1135	0	83	6.8	16.9	< .01	2.9	< .1
		1140	10	82	7.2	16.5	< .01	1.8	.1
		1145	177	85	7.2	4.0	< .01	1.5	< .1
2	7/21/81	1000	0	83	7.5	16.5	< .01	1.9	.1
		1035	43	82	7.6	13.0	< .01	1.1	< .1
		1045	197	73	7.4	4.5	< .01	1.5	< .1
	7/26/82	1400	0	83	7.0	17.6	—	1.8	< .1
		1405	108	80	7.2	5.0	< .01	1.3	< .1
		1415	213	85	7.1	4.4	< .01	1.6	< .1
3	7/21/81	1300	0	83	7.5	18.5	< .01	2.1	.1
		1305	33	72	7.5	17.0	< .01	1.9	—
		1310	154	85	7.5	4.5	.02	1.6	< .1
	7/27/82	0905	0	—	7.2	19.2	< .01	1.7	< .1
		0858	85	80	7.3	5.8	< .01	1.3	< .1
		0855	171	80	7.2	4.4	< .01	1.1	< .1
4	7/21/81	1450	0	83	7.6	19.5	.01	2.2	.1
		1506	33	83	7.4	19.0	< .01	2.0	< .1
		1520	72	83	7.4	6.0	< .01	1.9	< .1
	7/26/82	0855	0	84	7.1	18.8	.01	2.0	< .1
		0900	20	80	7.1	12.7	< .01	1.7	.1
		0905	88	85	7.1	4.8	< .01	1.6	< .1

No fecal coliform bacteria were detected in any of the water samples taken from the surface. The middle and near-bottom water samples were not analyzed for bacteria.

BOTTOM SEDIMENT

Bottom sediment was sampled in July 1981 and 1982. Sediment was analyzed for total phosphorus, organic and inorganic carbon, and recoverable mercury in both 1981 and 1982; particle size was determined in 1982; and pesticide analyses were done only in 1981. The sampling depths and constituent analyses that were common to both samplings are given in table 12. Sampling depth at a given site differed from 1981 to 1982 by as little as 2 ft and as great as 13 ft because of inability to exactly duplicate the site location.

The bottom materials at Sites 1, 2, and 4 were similar in particle-size composition and coarser than the material at Site 3. This is illustrated by the particle-size distribution curves in figure 25. For example at Site 3, about 50 percent of the material is finer than 0.0625 mm; whereas at the other three sites only 10 to 20 percent of the material is finer than 0.0625 mm.

Phosphorus concentrations varied from 50 to 470 mg/kg (milligram per kilogram) and averaged 167 mg/kg. The International Joint Commission (1977) reported an average of 524 mg/kg for nondepositional zones of Lake Superior. There appears to be a relation between phosphorus concentration and the percentage of fine-grained particles (finer than 0.0625 mm), as shown in figure 26.

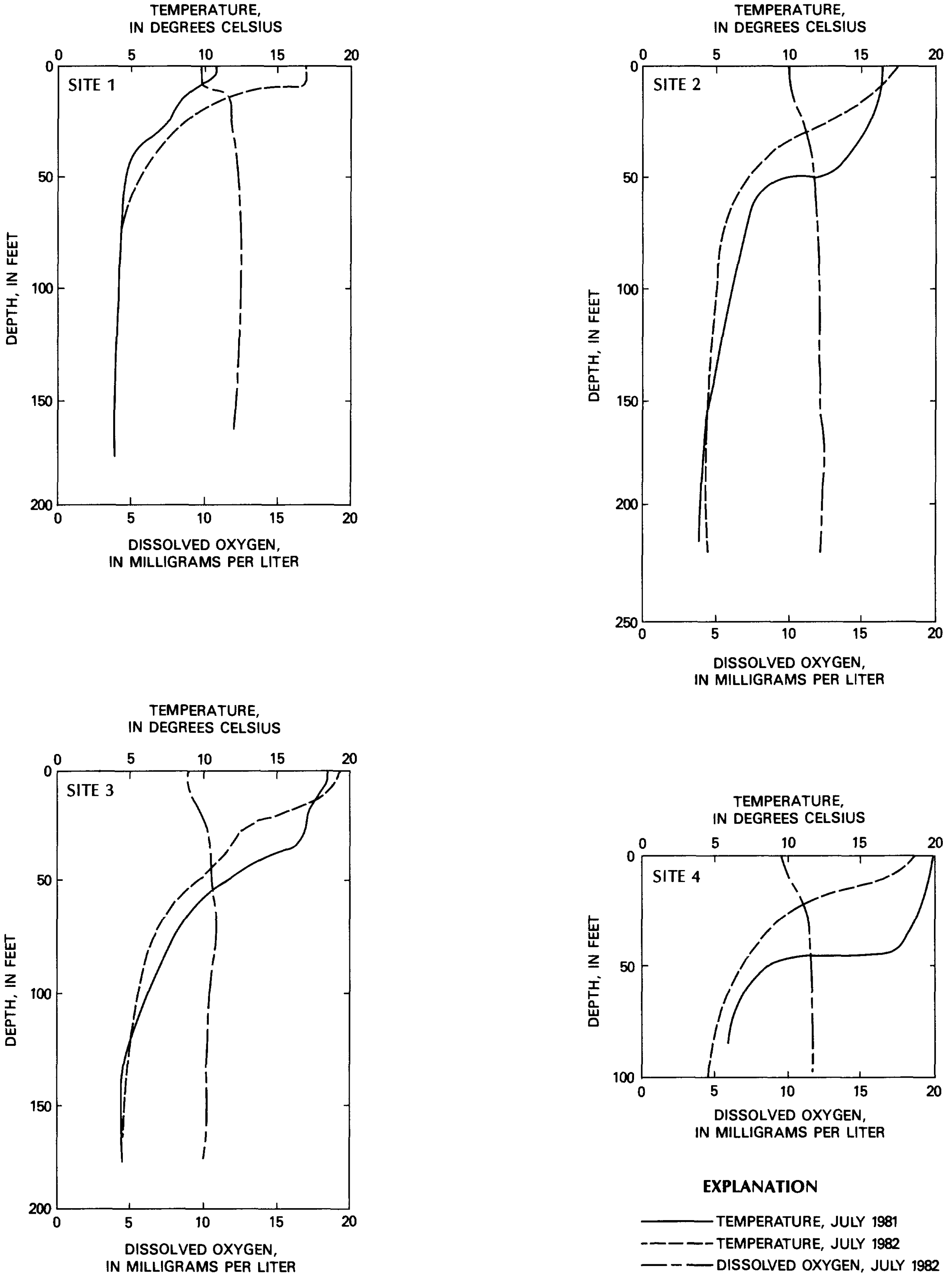

FIGURE 24. Temperature and dissolved-oxygen profiles for four Lake Superior deep-water monitoring sites.

TABLE 12.—Selected chemical constituents and median particle size in bottom sediment at the deep-water monitoring sites

[ft = foot; mg/kg = milligram per kilogram; g/kg = gram per kilogram; mm = millimeters; dash indicates no data available]

Site	Date	Sampling depth (ft)	Phosphorus, total (mg/kg)	Carbon, organic (g/kg)	Carbon, inorganic (g/kg)	Mercury, recoverable (mg/kg)	Median particle size, by weight (mm)
1	7/22/81	177	98	14	0.4	<0.01	—
	7/26/82	180	260	3.0	< .1	< .01	0.14
2	7/21/81	213	53	1.8	.2	< .01	—
	7/26/82	220	87	3.4	< .1	< .01	0.19
3	7/21/81	172	160	4.0	0.1	< .01	—
	7/27/82	174	470	14.0	< .1	< .01	0.063
4	7/21/81	85	50	4.0	.2	< .01	—
	7/26/82	98	160	5.3	< .1	< .01	0.17

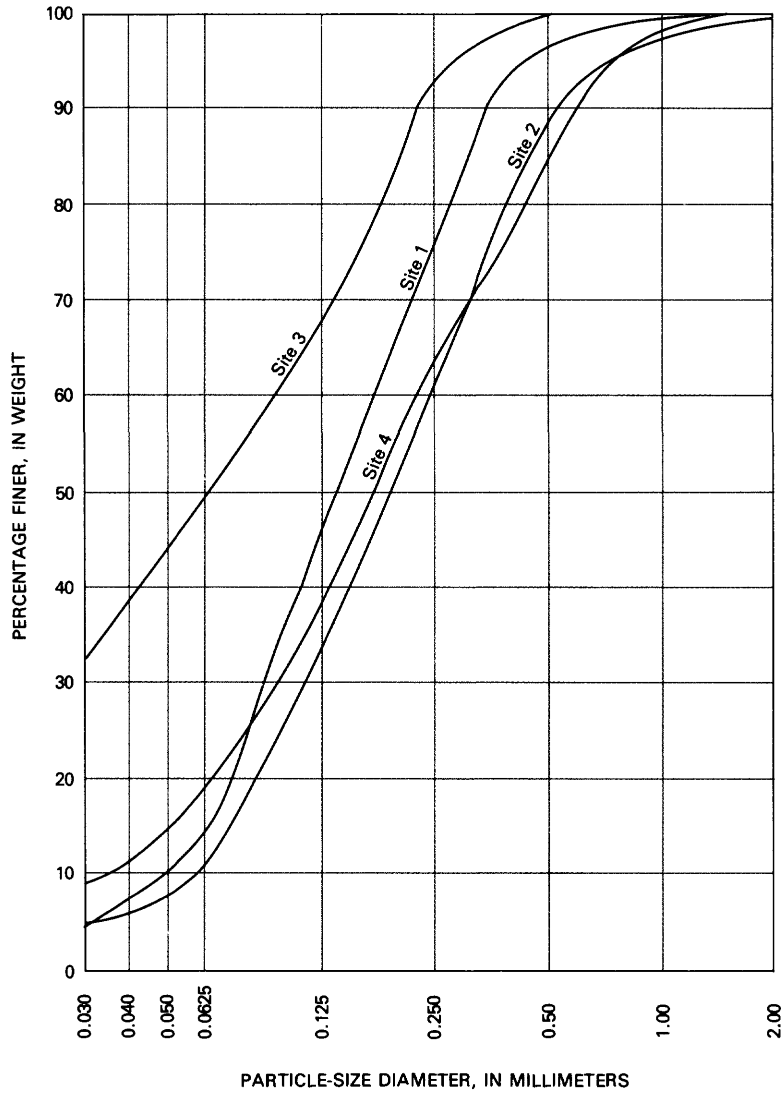

FIGURE 25. Particle-size distribution of bottom sediment at Lake Superior deep-water monitoring sites.

Concentrations of organic carbon, inorganic carbon, and mercury all were within the ranges reported by the International Joint Commission (1977) for sediment in "nondepositional" zones of Lake Superior. The term "nondepositional" is used to differentiate between the sedimentary environments of the generally shallower near-shore areas from the deeper "depositional" zones. Surface sediment in nondepositional zones generally contains some coarse (>0.0625 mm) sediment, whereas sediment in depositional zones is virtually all fine-grained (<0.0625 mm). The Apostle Islands area of Lake Superior lies within a zone designated "nondepositional."

Organic carbon and inorganic carbon concentrations varied from 1.8 to 14 g/kg (gram per kilogram) and <0.1 to 0.4 g/kg, respectively. Mercury concentrations above the 0.01 mg/kg (milligram per kilogram) detection limit were not found. These data are also summarized in table 12.

The only pesticide residues detected at any of the sites were DDE and DDT. DDE concentration was 2.0 μg/kg (microgram per kilogram) at Site 3 and 0.1 μg/kg at Site 4. The concentration of DDT at Site 4 was 0.2 μg/kg. No other pesticide residues were detected. The pesticides for which analyses were done and laboratory detection limits are listed below.

Pesticide	Laboratory detection limit (μg/kg)
PCB	1
PCN	1
aldrin	0.1
chlordane	1
DDD	0.1
DDE	0.1
DDT	0.1
dieldrin	0.1
endosulfan	0.1
endrin	0.1
heptachlor	0.1
heptachlor epoxide	0.1
lindane	0.1
methoxychlor	0.1
mirex	0.1
perthane	0.1
toxaphene	1.0

BENTHIC MACROINVERTEBRATES

Benthic macroinvertebrates were collected at the four deep-water sites. The composition of the benthos was similar to that found in earlier studies in Lake Superior (Freitag and others, 1976; Winter, 1971; Hiltunen, 1969; Henson, 1966) and to the benthos of Lake Michigan (Mozle and Howmiller, 1977). Table 13 is a list of organisms found and their numbers in organisms per square meter.

The amphipod, *Pontoporeia affinis*, dominated the benthos at all sites. The range in numbers of these organisms was 690 to 2,100 organisms/m² (organisms per square meter), with a mean of about 1,150 organisms/m². These values are lower than those found in Lake Michigan at similar depths but in the same range as found by Winter in western Lake Superior. Because of the relative trophic status of Lake Superior this is to be expected.

Clams of the family Sphaeriidae were the only organisms other than *Pontoporeia affinis* found at all sites. The distribution of this organism is extremely patchy, accounting for the wide range in densities found. When taken as a whole, all of the sites sampled have benthic communities representative of the Lake Superior profundal zone.

Shallow-Water Characteristics

No adverse impacts from visitor use were detected at monitoring sites on two of the most heavily used areas of the National Lakeshore's waters. The areas are Presque Isle Bay off the south side of Stockton Island and the area between Rocky and South Twin Islands. Both areas are subjected to relatively heavy use by sailboat traffic and adjacent shorelines are used by campers and other visitors. The most extensive (20 sites) and heavily used campground in the National Lakeshore is along the shoreline of Presque Isle Bay.

Nine monitoring sites were established and sampled in each area. The Presque Isle Bay sites were sampled on July 27, 1982, and the Rocky–South Twin sites on July 25, 1983. Locations of the sites are shown in figures 27 and 28. The latitude–longitude locations of the sites are given in tables 14 and 15.

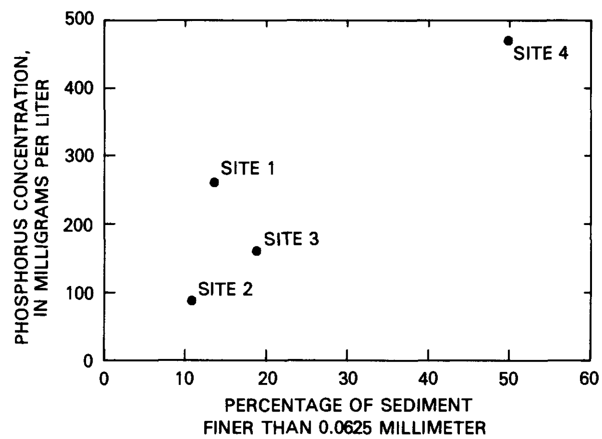

FIGURE 26. Relation of phosphorus concentration to percentage of fine-grained sediment at Lake Superior deep-water monitoring sites.

TABLE 13.—Benthic macroinvertebrates at deep-water sites
[A dash indicates organism not observed]

Site	Organism	Number per square meter	
		July 1983	July 1982
1	*Pontoporeia affinis* (amphipod)	806	960
	Chironomidae (midgefly)	—	76
	Hexagenia sp. (mayfly)	75	—
	Sphaeriidae (clam, probably *Pisidium*)	290	190
	Mysis relicta (mysid shrimp)	150	76
	oligochaete fragments	present	—
2	*Pontoporeia affinis*	840	1,190
	Chironomidae	60	38
	Sphaeriidae	345	380
	Mysis relicta	40	19
	oligochaete fragments	present	—
3	*Pontoporeia affinis*	690	2,100
	Chironomidae	115	270
	Sphaeriidae	20	19
	Mysis relicta	20	—
4	*Pontoporeia affinis*	805	1,890
	Chironomidae	—	38
	Sphaeriidae	380	780
	oligochaete fragments	present	—

TABLE 14.—Latitude and longitude of heavy-use area monitoring sites in Presque Isle Bay

Site	Latitude	Longitude
1	46°55′25″N	090°34′02″W
2	46°55′15″N	090°34′14″W
3	46°55′07″N	090°34′06″W
4	46°55′18″N	090°33′41″W
5	46°55′07″N	090°33′25″W
6	46°54′57″N	090°33′41″W
7	46°54′45″N	090°33′26″W
8	46°54′54″N	090°33′11″W
9	46°54′39″N	090°33′11″W

TABLE 15.—Latitude and longitude of heavy-use area monitoring sites between Rocky and South Twin Islands

Site	Latitude	Longitude
1	47°01′36″N	090°39′48″W
2	47°01′42″N	090°39′12″W
3	47°02′00″N	090°39′12″W
4	47°02′24″N	090°39′12″W
5	47°02′24″N	090°39′36″W
6	47°02′18″N	090°40′00″W
7	47°02′00″N	090°39′42″W
8	47°01′54″N	090°40′18″W
9	47°01′36″N	090°40′30″W

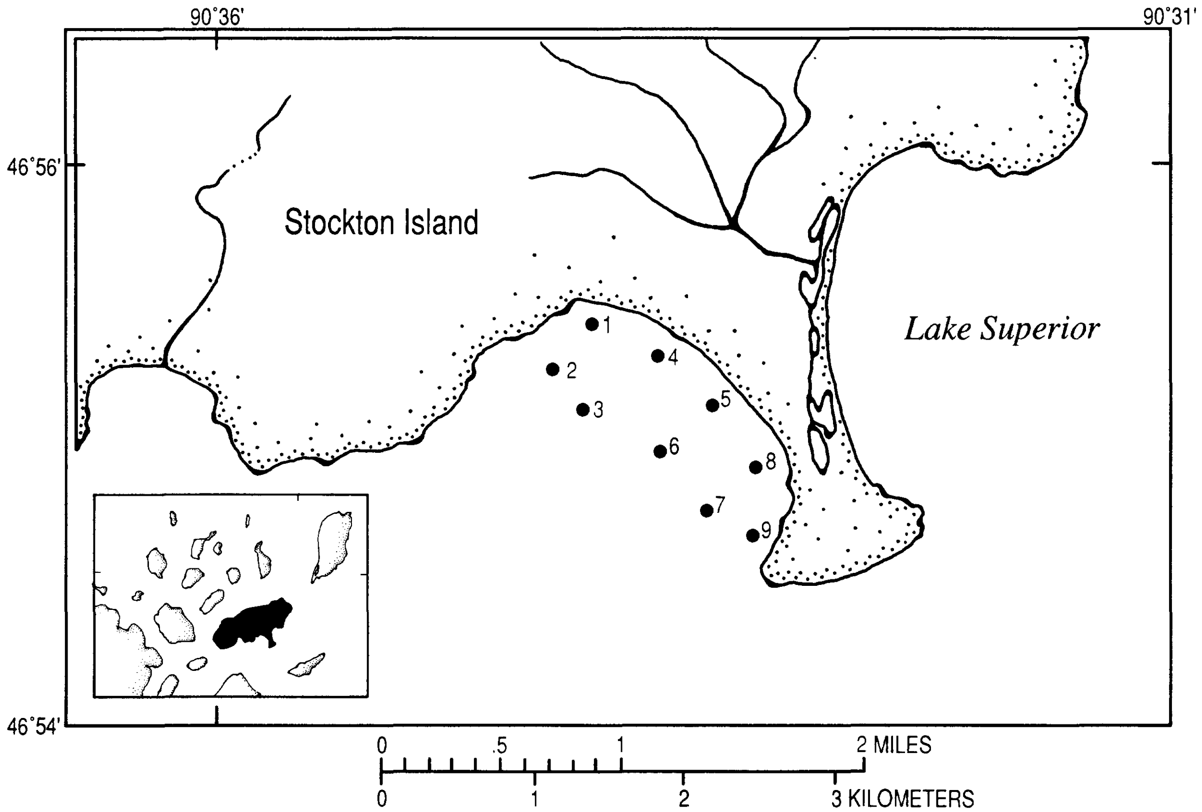

FIGURE 27. Location of Lake Superior shallow-water heavy-use area sampling sites in Presque Isle Bay off Stockton Island.

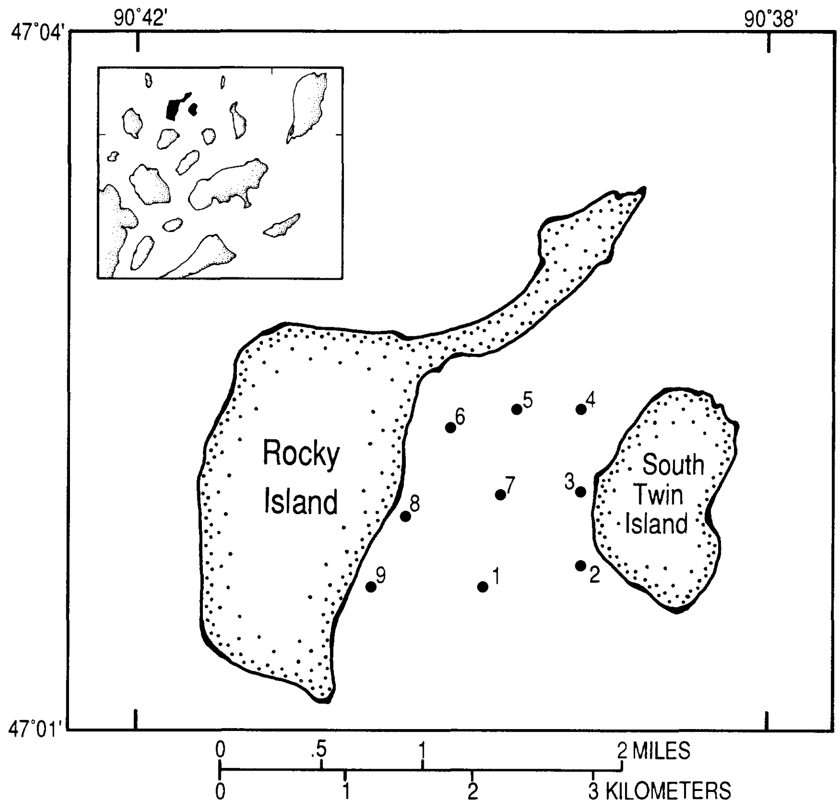

FIGURE 28. Location of Lake Superior shallow-water heavy-use area sampling sites between Rocky and South Twin Islands.

WATER QUALITY

The water was sampled at the surface, and temperature and dissolved oxygen were measured at various depths at each of the sites at the time of sampling.

The profiles shown in figures 29 and 30 indicate temperature stratification at both areas where depth was greater than about 10 ft. Temperatures at the Presque Isle Bay sites varied from 5.8 to 19.0° C at the bottom depending on depth and 17 to 19° C at the surface; at the Rocky–South Twin sites, the water temperature was 6.7 to 17.0° C depending on depth at the bottom and 17 to 18° C at the surface. Dissolved-oxygen profiles inversely reflected the temperature profiles. Oxygen was at or very near saturation at all sites and depths at both areas.

Selected constituent concentration values determined by analysis of the surface samples for the two heavy-use areas are in tables 16 and 17. Phosphorus concentration at the Presque Isle Bay area varied from <0.01 to 0.02 mg/L; at the Rocky–South Twin area, the concentration varied from <0.01 to 0.01 mg/L. The International Joint Commission (1977) reported that phosphorus concentrations in the Apostle Island area "nearshore" waters varied from 0.0047 to 0.0107 mg/L. Only one site at each heavy-use area was analyzed for mercury and the concentrations at both sites were less than the 0.01 μg/l detection limit. Organic carbon concentration varied from 1.3 to 2.4 mg/L at Presque Isle Bay; the concentration was between 2.3 to 3.2 mg/L at the Rocky–South Twin area.

Fecal coliform bacteria were not detected at any of the sampling sites in either the Presque Isle Bay or Rocky–South Twin areas.

BOTTOM SEDIMENT

Analyses of bottom sediment revealed that concentrations of nutrients and organic carbon were generally higher at the Rocky–South Twin area than at the Presque Isle Bay area. Concentrations of ammonia nitrogen, ammonia plus organic nitrogen, and phosphorus varied from <0.4 to 8.6 mg/kg, 190 to 5,200 mg/kg, and 27 to 850 mg/kg, respectively, at the Rocky–South Twin sites; concentrations were <0.4 to 11 mg/kg, 230 to 1,300 mg/kg, and 4 to 86 mg/kg, respectively, at the Presque Isle Bay sites. Organic carbon concentrations at the Rocky–South Twin sites were about twice as great at the Presque Isle Bay sites. These data are summarized in tables 18 and 19.

The percentage of fine-grained sediment was generally greater in the Rocky–South Twin area than in Presque Isle Bay. The sediment at only three of the nine monitoring sites in Presque Isle Bay contained fine-grained (<0.0625 mm) particles. Eight of the nine sites in the Rocky–South Twin area contained fine-grained particles. The greater water depth and percentage of fine-grained sediment in the Rocky–South Twin area indicates that it is in an environment more conducive to sedimentation than Presque Isle Bay.

Mercury was not detected at the 0.01 mg/kg detection limit at any of the three Presque Isle Bay sites (Sites 3, 7, and 8) that were sampled. A single sample (Site 7) from the Rocky–South Twin area was analyzed and its mercury concentration was 0.02 mg/kg.

BENTHIC MACROINVERTEBRATES

Nine sites in each of the two areas—Stockton Island and Rocky–South Twin Island—were sampled.

TABLE 16.—Selected physical and chemical characteristics of water from the Presque Isle Bay heavy-use area monitoring site on July 27, 1982

[ft = feet; μS/cm = microsiemens per centimenter at 25° Celsius; °C = degrees Celsius; mg/l = milligram per liter; μg/L = microgram per liter; dash indicates no data available]

Site	Time	Sampling depth (ft)	Specific conductance (μS/cm)	pH (standard units)	Temperature (°C)	Phosphorus, total (mg/L as P)	Carbon, organic total (mg/L as C)	Mercury total recoverable (μg/L as Hg)
1	1025	1.00	80	7.4	17.0	0.020	1.3	—
2	1055	1.00	80	—	18.0	.020	1.4	—
3	1115	1.00	70	7.4	18.0	—	1.5	<.1
4	1210	1.00	80	7.5	17.5	< .010	1.5	—
5	1225	1.00	80	7.5	17.5	.010	1.7	—
6	1240	1.00	80	7.5	18.0	< .010	1.6	—
7	1310	1.00	70	7.6	19.0	< .010	1.6	—
8	1320	1.00	75	7.5	18.0	.020	1.8	—
9	1330	1.00	75	7.5	18.0	.010	2.4	—

Tables 20 and 21 show the organisms present and their densities.

The samples reveal a benthic community similar to shallow communities found in earlier studies (Winter, 1971; Freitag and others, 1976). *Pontoporeia affinis* again was the dominant organism at most sites with a range in densities of 0 to about 1,150 organisms/m². The midgefly larvae family, Chironomidae, and the gastropod mollusc family, Planorbidae, were the only organisms present at all sites sampled.

When considering the major groups of organisms, the sites within each of the two areas seem to be similar in composition. The Stockton Island sites

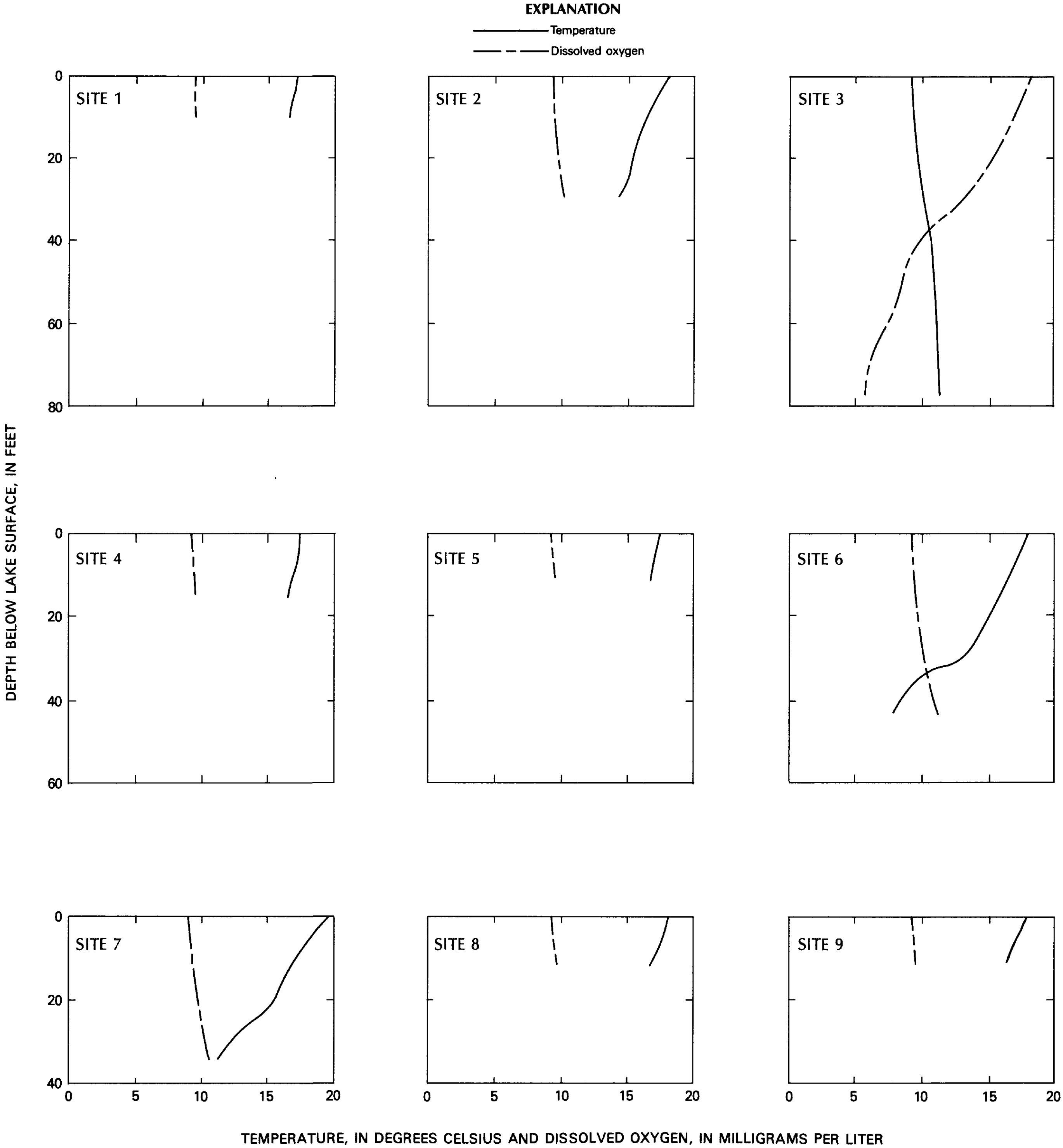

FIGURE 29. Temperature and dissolved-oxygen profiles for sampling sites in Presque Isle Bay heavy-use area of Lake Superior on July 27, 1982.

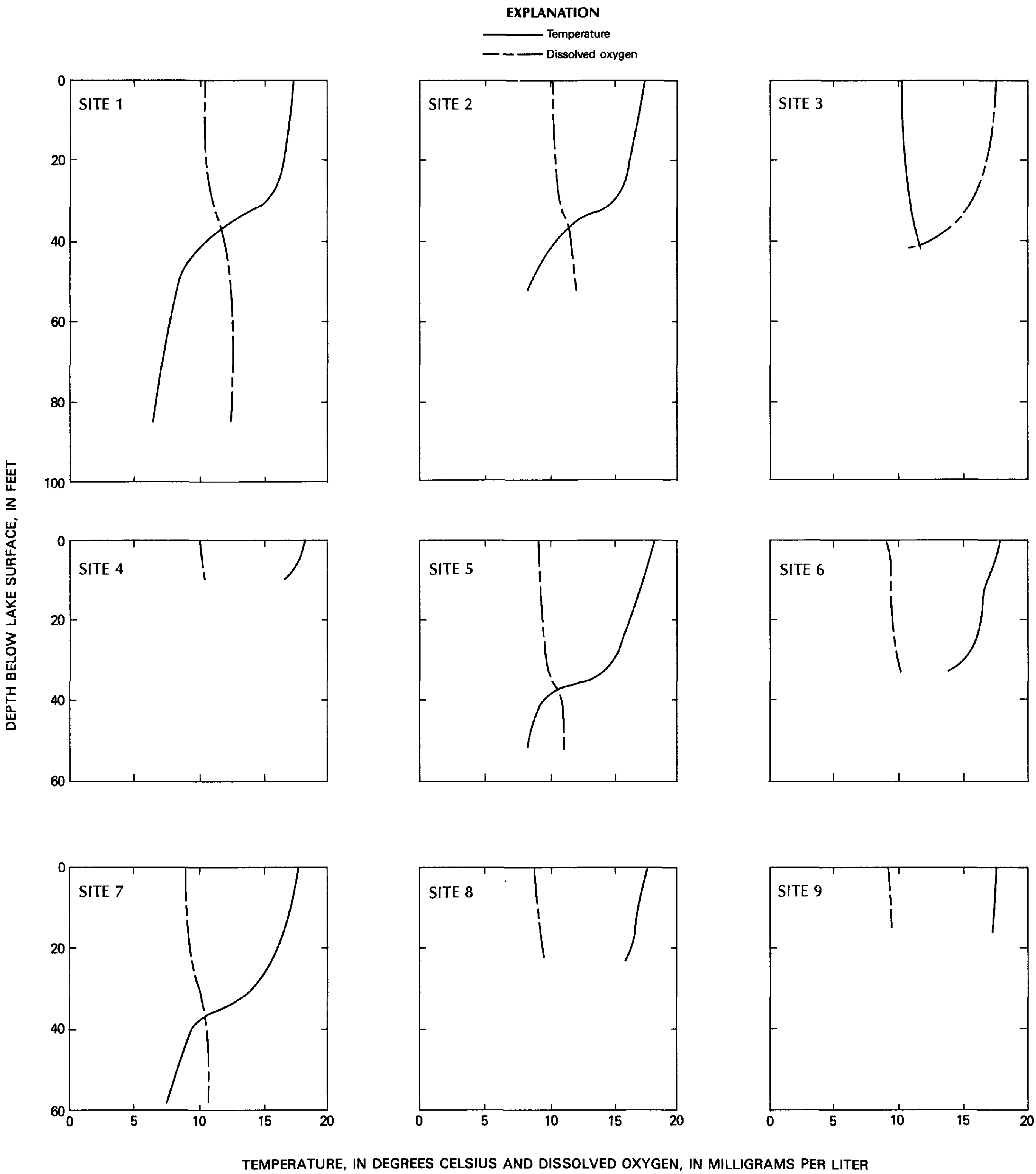

FIGURE 30. Temperature and dissolved-oxygen profiles for sampling sites in the Rocky–South Twin Island heavy-use area of Lake Superior on July 25, 1983.

TABLE 17.—Selected physical and chemical characteristics of water from the Rocky–South Twin heavy-use area monitoring sites on July 25, 1983

[ft = feet; μS/cm = microsiemens per centimenter at 25° Celsius; °C = degrees Celsius; mg/L = milligram per liter; μg/L = microgram per liter; dash indicates no data available]

Site	Time	Sampling depth (ft)	Specific conductance (μS/cm)	pH (standard units)	Temperature (°C)	Phosphorus, total (mg/L as P)	Carbon, organic total (mg/L as C)	Mercury total recoverable (μg/L as Hg)
1	0930	1.00	97	7.6	17.0	<0.010	3.1	—
2	1005	1.00	90	7.5	17.5	< .010	3.0	—
3	1035	1.00	87	7.5	17.5	< .010	3.2	—
4	1100	1.00	92	7.5	18.0	.010	3.0	—
5	1120	1.00	95	7.5	18.0	.010	2.3	—
6	1145	1.00	95	7.5	18.0	< .010	2.3	—
7	1250	1.00	96	7.5	18.0	.010	2.8	<.1
8	1315	1.00	96	7.6	17.5	< .010	2.6	—
9	1340	1.00	95	7.6	17.5	.010	2.6	—

TABLE 18.—Selected chemical constituents and percentage of fine-grained (<0.0625 mm) particles in bottom sediment at the Presque Isle Bay heavy-use area monitoring sites on July 26, 1981

[ft = feet; mg/kg = milligram per kilogram; g/kg = gram per kilogram; μg/L = microgram per liter; mm = millimeter; dash indicates no data available]

Site	Sampling depth (ft)	Nitrogen, NH4 total in bottom material (mg/kg as N)	Nitrogen, NH4+organic total in bottom meterial (mg/kg as N)	Phosphorus, total in bottom meterial (mg/kg as P)	Carbon organic, total in bottom material (g/kg as C)	Carbon inorganic total in bottom material (g/kg Aas C)	Mercury recoverable from bottom material (μg/L as Hg)	Percentage of sediment finer than 0.0625 mm (by weight)
1	10.0	<0.4	720	4	1.2	<0.1	—	0
2	30.0	2.6	880	10	3.3	< .1	—	1
3	79.0	11	1,300	86	7.2	< .1	<0.01	
4	15.0	2.3	510	6	1.8	< .1	—	0
5	11.0	3.5	450	12	.9	< .1	—	0
6	44.0	1.8	790	22	4.2	< .1	—	5
7	34.0	.7	600	19	4.8	< .1	< .01	0
8	11.0	1.8	230	27	.8	< .1	< .01	0
9	11.0	1.3	320	9	.7	< .1	—	0

TABLE 19.—Selected chemical constituents and percentage of fine-grained (<0.0625 mm) particles in bottom sediment at the Rocky–South Twin heavy-use area monitoring sites on July 25, 1983

[ft = feet; mg/kg = milligram per kilogram; g/kg = gram per kilogram; μg/L = microgram per liter; dash indicates no data available]

Site	Sampling depth (ft)	Nitrogen, NH4 total in bottom material (mg/kg as N)	Nitrogen, NH4+organic total in bottom meterial (mg/kg as N)	Phosphorus, total in bottom meterial (mg/kg as P)	Carbon organic, total in bottom material (g/kg as C)	Carbon inorganic, total in bottom material (g/kg A as C)	Mercury recoverable from bottom material (μg/L as Hg)	Percentage of sediment finer than 0.0625 mm (by weight)
1	85.0	8.6	4,100	44	1.7	0.1	—	7
2	52.0	3.6	540	44	5.3	< .1	—	10
3	43.0	7.3	1,700	90	9.4	< .1	—	7
4	10.0	< .4	190	59	.7	< .1	—	0
5	52.0	4.1	1,300	220	4.3	< .1	—	7
6	33.0	3.1	1,200	200	3.1	< .1	—	12
7	59.0	7.0	5,200	410	17	.1	.02	10
8	23.0	1.1	810	27	2.7	< .1	—	4
9	16.0	3.5	570	850	12	< .1	—	2

TABLE 20.—Benthic macroinvertebrates at Stockton Island shallow-water sites, July 1982

[A dash indicates organism not observed]

	Densities (organisms per square meter)							
	1	2	4	5	6	7	8	9
Pontoporeia affinis (amphipod)	287	1,030	287	134	1,145	554	306	497
Chironomidae (midgefly)	727	325	344	421	497	574	306	229
Sphaeriidae (clam)	153	421	287	268	344	688	172	497
Gastropds (snails)	38	669	325	191	229	841	38	134
Ceratopgonidae (no-see-um-fly)	57	76	38	115	19	19	153	96
Baetiscidae (mayfly)	115	—	—	19	—	—	19	19
Ephemerellidae (mayfly)	19	—	—	—	—	—	—	—
Ephemera (mayfly)	—	—	—	19	—	—	—	—
Hydropsychidae (caddisfly)	—	—	—	—	—	—	19	—
Empididae (dancefly)	—	—	19	—	—	—	—	—
Asellus (isopod)	—	19	—	—	38	—	—	—
Hirudinea (leech)	—	19	—	—	—	19	—	—

TABLE 21.—Benthic macroinvertebrates at Rocky and South Twin Islands shallow-water sites, July 1983

[A dash indicates organism not observed]

	Densities (organisms per square meter)								
	1	2	3	4	5	6	7	8	9
Pontoporeia affinis (amphipod)	986	479	670	—	191	105	814	19	115
Chironomidae (midgefly)	134	316	680	392	239	326	105	172	613
Sphaeriidae (clam)	—	10	—	—	19	—	—	38	86
Planorbidae (snail)	—	10	57	10	67	67	10	105	125
Lymnaeidae (snail)	—	—	—	10	—	—	—	—	—
Ostracoda	10	—	10	—	—	28	—	28	—
Ephemeridae *Ephemera sp.* (mayfly)	—	—	10	—	—	—	—	—	—
Hexagenia sp. (mayfly)	—	—	—	—	—	—	—	86	191
Leptophlebriidae (mayfly)	—	—	—	—	—	10	—	—	—
Limnephilidae (caddisfly)	—	—	—	—	—	—	—	—	19
Molanidae *molana sp.* (caddisfly)	—	—	—	—	—	—	—	—	10
Asellidae (isopod)	—	—	—	—	—	19	—	—	28
Tubificidae (oligochaete)	—	105	19	—	—	38	10	10	76

generally have higher densities of all of these groups (mollusca, amphipods, and chironomids). The sites differ mainly in the composition of the low-density groups—the mayflies and others. These are not major differences since the groups seem to be equally sensitive to disturbance and have similar functions ecologically.

GROUND-WATER RESOURCES

Ground-water use in the Lakeshore is primarily for consumption by Lakeshore visitors and employees. Wells, most equipped with hand pumps, have been constructed at many visitor and camping areas.

AVAILABILITY

Ground water in the National Lakeshore is obtained from glacial sand and gravel and sandstones. Ground water may also be available from sand deposits under cuspate bars and forelands, although this source has not been used. Glacial lake clays overlie the sandstone in most of the mainland unit of the Lakeshore. Thus, except for unmapped isolated deposits of sand and gravel underlying the clays, the sandstone is the only available aquifer in the mainland unit.

Of 14 wells constructed in the Lakeshore from 1979 through 1983, 4 were finished in glacial sand and gravel and 10 were finished in sandstone. All bedrock wells were 6 in. in diameter and cased to 10 ft below the bedrock surface. The specific capacities of wells finished in glacial drift ranged from 0.63 to 10 (gal/min)/ft (gallons per minute per foot). Specific capacities of wells finished in sandstone ranged from 0.88 to 50 (gal/min)/ft. Well-construction and specific-capacity test data are summarized in table 22 and locations of wells are shown in figure 1.

CHEMICAL QUALITY

Water in the sandstone, glacial sand and gravel, and cuspate-bar sand aquifers is of similar chemical composition, but of differing concentrations. The cations in the water are predominantly calcium and magnesium, and the predominant anion is bicarbonate. Constituent concentrations generally were highest in the sandstone aquifer and lowest in the cuspate-bar sand aquifer. The average concentrations of dissolved solids for the sandstone, glacial sand and gravel, and cuspate-bar aquifers were 215, 138, and 52 mg/L, respectively. A summary of constituent concentrations is in table 23.

Heavy metal analysis of water from selected wells revealed no occurrences of concentrations that exceeded Wisconsin's drinking water standards (Wisconsin Department of Natural Resources, 1978). Concentrations of iron and manganese in well As-110 exceeded Wisconsin's secondary (aesthetic) standard. Iron and manganese concentrations in water from the

TABLE 22.—Well-construction data and specific-capacity test data for wells constructed in the National Lakeshore from 1979–83

[ft = feet; (gal/min)/ft = gallons per minute per foot]

Well number	Aquifer	Total well depth (ft)	Casing depth (ft)	Screen length (ft)	Pumping rate (gal/min)	Time pumped (hours)	Drawdown (ft)	Specific capacity [(gal/min)/ft]
As-108	Sandstone	150	39.5	—	50	4.7	20.9	2.4
As-110	Sandstone	190	128.5	—	50	5.7	1.8	28
As-109	Sandstone	152	39.5	—	50	5.0	6.0	8.3
Ba-182	Sandstone	250	50.1	—	50	4.1	1.1	45
Ba-181	Sandstone	170	68.5	—	50	5.3	1.0	50
As-161	Sandstone	168	106	—	30	4.0	34.2	.88
As-162	Drift	114	105	9	50	3.0	63.0	.79
As-163	Drift	92	83	9	50	4.0	9.6	5.2
As-285	Drift	61	51	10	25	8.0	40.0	.63
As-286	Sandstone	150	69.5	—	50	8.0	17.0	2.8
Ba-257	Sandstone	140	49.5	—	40	2.0	37.0	1.1
As-287	Sandstone	150	79.5	—	50	8.0	37.0	1.4
As-283	Drift	61	51	10	50	8.0	5.0	10
As-282	Sandstone	150	52.5	—	50	8.0	10.0	5.0

TABLE 23.—Ground-water-quality data for water from selected wells in the National Lakeshore

[μS/cm = microsiemens per centimeter at 25° Celsius; mg/L = milligrams per liter; μg/L = micrograms per liter; dash indicates no data available]

Well number	Date of sample	Specific conductance (μS/cm)	pH (standard units)	Hardness (mg/L as $CaCO_3$)	Hardness, noncarbonate (mg/L as $CaCO_3$)	Calcium, dissolved (mg/L as Ca)	Magnesium dissolved (mg/L as Mg)	Sodium, dissolved (mg/L as Na)	Potassium, dissolved (mg/L as K)	Alkalinity (mg/L as ($CaCO_3$)	Carbon dioxide, dissolved (mg/L as CO_2)	Sulfate dissolved (mg/L as SO_4)
As-108	07-31-79	60	6.0	25	10	7.2	1.8	1.6	1.0	15	29	4.5
As-110	07-24-79	—	7.3	370	0	62	53	17	7.2	410	40	13
As-109	09-19-79	380	7.5	200	1	54	16	4.3	1.8	200	12	.0
Ba-182	08-09-79	180	—	180	0	39	19	6.2	2.9	180	—	3.9
Ba-181	08-02-79	175	6.5	94	0	24	8.2	3.6	1.2	95	59	6.7
As-161	07-07-81	470	7.3	240	0	60	23	5.2	4.5	260	—	1.5
As-162	07-10-81	350	7.7	170	—	38	18	5.2	2.3	180	—	2.6
As-163	07-01-81	115	6.5	56	4.0	15	4.6	11.9	1.0	52	—	7.4
As-175	07-28-83	88	6.0	33	1	8.4	3.0	.6	1.4	32	62	.6
As-176	07-28-83	69	5.8	31	2	7.9	2.7	.6	1.3	29	89	9.0
As-180	08-24-84	120	7.1	—	—	17	3.7	1.4	.6	—	—	2.0

Well number	Date of sample	Chloride dissolved (mg/L as Cl)	Fluoride dissolved (mg/L as F)	Silica, dissolved (mg/L as Si_2)	Solids, sum of constituents, dissolved (mg/L)	Nitrogen, nitrite dissolved (mg/L as N)	Nitrogen, NO2+NO3 dissolved (mg/L as N)	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)
As-108	07-31-79	0.4	0.1	22	49	—	0.22	1	10	0	1	3
As-110	07-24-79	2.0	.2	17	421	—	—	—	—	—	—	—
As-109	09-19-79	.9	.1	20	218	—	.16	1	60	2	<10	0
Ba-182	08-09-79	1.4	.1	16	198	—	.23	—	—	—	—	—
Ba-181	08-02-79	.7	.1	23	126	—	.17	0	30	1	2	1
As-161	07-07-81	1.1	≥ .1	25	277	≥.1	.05	—	—	—	—	—
As-162	07-10-81	.7	.3	22	177	≥.1	.25	—	—	—	—	—
As-163	07-01-81	.5	≥ .1	17	79	≥.1	.23	—	—	—	—	—
As-175	07-28-83	1.3	≥ .1	7.6	42	—	≥ .10	—	—	—	—	—
As-176	07-28-83	.8	≥ .1	5.8	45	—	—	—	—	—	—	—
As-180	08-24-84	0	.1	5.7	67	—	—	—	—	—	—	—

Well number	Date of sample	Iron, dissolved (μg/L as Fe)	Lead, dissolved (μg/L as Pb)	Manganese, dissolved (μg/L as Mn)	Mercury, dissolved (μg/L as Hg)	Nickel, dissolved (μg/L as Ni)	Selenium, dissolved (μg/L as Se)	Silver, dissolved (μg/L as Ag)	Zinc, dissolved (μg/L as Zn)
As-108	07-31-79	170	0	10	<0.5	—	—	—	20
As-110	07-24-79	3,300	—	100	—	—	—	—	—
As-109	09-19-79	10	1	—	≥ .5	0	0	—	10
Ba-182	08-09-79	10	—	2	—	—	—	—	—
Ba-181	08-02-79	80	0	5	≥ .5	—	0	0	20
As-161	07-07-81	10	—	2	—	—	—	—	—
As-162	07-10-81	60	—	4	—	—	—	—	—
As-163	07-01-81	50	—	10	—	—	—	—	—
As-175	07-28-83	—	—	—	—	—	—	—	—
As-176	07-28-83	—	—	—	—	—	—	—	—
As-180	08-24-84	—	—	—	—	—	—	—	—

well were 3,300 and 100 μg/L, respectively. The recommended maximum concentrations for aesthetic reasons for iron and manganese are 300 and 50 μg/L, respectively.

SUMMARY AND CONCLUSIONS

Water-resources data collected during water years 1979–84 in the Apostle Islands National Lakeshore and nearby areas were summarized and interpreted. The areal scope of the study included some hydrologic elements outside the Lakeshore boundaries, such as Bayfield Peninsula streams, that could influence the condition of resources within the Lakeshore. The study was limited to only those elements that were considered most important to Lakeshore management.

Flow characteristics of Bayfield Peninsula streams reflect their watershed characteristics that tend to produce high flood flows and low base flows. Flow in the Sand River at State Highway 13 ranged from 3.9 to 1,630 ft^3/s during the 1980–84 water years. Base-flow runoff as a percentage of annual runoff ranged from 17 to 55 percent in the 5-year period. The recurrence interval of the maximum observed discharge was about four years. The minimum 7-day low flow was 3.86 ft^3/s, which was less than the $Q_{7,2}$ but more than the $Q_{7,10}$.

The highest concentrations of most chemical constituents in Bayfield Peninsula streams occurred during base flow; this reflects the quality of ground-water runoff. Phosphorus concentrations generally increased with increasing stream discharge and reflect an association with direct runoff.

Estimated annual sediment loads at the Sand River at State Highway 13 ranged from 977 tons in 1980 water year 24,600 tons in 1984 water year. About 88 percent of the sediment was transported as suspended load and 12 percent was transported as bedload. The estimated average annual sediment load transported by Bayfield Peninsula streams to the National Lakeshore area of Lake Superior during water years 1980–84 was about 44,000 tons.

Estimated annual phosphorus loads at the Sand River at State Highway 13 range from 1,400 lb in 1980 water year to 11,100 lb in 1984 water year. The estimated average annual yield for the basin was about 235 lb/mi^2. The estimated average annual phosphorus load transported by Bayfield Peninsula streams to the National Lakeshore area of Lake Superior is about 21,500 lb.

Few island streams flow perennially, but Oak Island streams generally yield more base flow runoff than Stockton Island streams. The largest observed base flow was 0.29 ft^3/s at one Oak Island stream.

Specific conductance, pH, and alkalinity values indicate that Oak Island stream base flow is dominated by ground-water discharge, whereas Stockton Island stream base flow is sustained by seepage from wetlands and beaver ponds. Calcium and magnesium are the dominant cations and bicarbonate is the dominant anion composing Oak Island stream base flow.

The only "lakes" on the Apostle Islands other than beaver ponds, are lagoons that occur behind cuspate bars and forelands, the two largest lagoons are on Outer and Michigan Islands. The Outer Island Lagoon's area is 53 acres, maximum depth is 7 ft, and average depth is 2.6 ft. Inflow to the lagoon is dominated by precipitation and seepage from an adjacent bog. Outflow during open-water periods is dominated by evaporation. Ground-water seepage from the lagoon toward Lake Superior occurs year round. The lagoon's water is acidic, low in specific conductance, and has generally small concentrations of most chemical constituents.

The Michigan Island Lagoon is about four acres in area and its maximum depth is 6.5 ft. The most significant sources of inflow to the lagoon appear to be precipitation and wave washover from Lake Superior. The chemical composition of Michigan Island Lagoon's water is more similar to water in Lake Superior than to the water in Outer Island Lagoon. This fact supports the hydrologic interpretation that wave washover is a dominant inflow component to the lagoon.

The characteristics of water, sediment, and benthic macroinvertebrates at four "deep-water" monitoring sites in the National Lakeshore area of Lake Superior were similar to that reported by the International Joint Commission (1977). Total phosphorus, organic carbon, and recoverable mercury in the water column varied from <0.01 to 0.02 mg/L, 1.1 to 5.3 mg/L and <0.1 to 0.1 μg/l, respectively; and no pesticide residues or fecal coliform bacteria were detected. Total phosphorus concentration in bottom sediment ranged from 50 to 470 mg/kg and seemed to be related to the percentage of fine-grained (<0.0625 mm) sediment particles. The only pesticide residues detected in sediment at any of the sites were traces of DDE at two sites and DDT at one site. The most abundant benthic macroinvertebrate was *Pontoporeia affinis*, which was found in densities that ranged from 960 to 2,100 $organisms/mi^2$. The other main organisms were Chironomidae, Sphaeriidae, and *Mysis relicta*. The benthic fauna were similar to that found in earlier studies.

No adverse effects resulting from heavy visitor use were detected in shallow-water monitoring sites that were established in Presque Isle Bay off Stockton Island and in the waters between Rocky and South

Twin Islands. Phosphorus and organic carbon concentrations were similar to those observed in the deep water area. Mercury was not detected in water from either area. Concentrations of nutrients and organic carbon in bottom sediment generally were greater in the Rocky–South Twin area than the Presque Isle Bay area. Water depth and percentage of fine-grained (<0.0625 mm) sediment were greater in the Rocky–South Twin area than in Presque Isle Bay; this indicates that Rocky–South Twin area is more prone to sedimentation than Presque Isle Bay. *Pontoporeia affinis* was again the most abundant benthic macroinvertebrate. The two shallow-water areas were very similar in the composition of the major benthic groups. As might be expected, the deep-water sites differ in faunal composition from the shallow-water sites having generally higher densities of *Pontoporeia affinis* and lacking the diversity of the shallower sites.

Ground-water use in the National Lakeshore is primarily for consumption by Lakeshore visitors and employees. Of 14 wells constructed from 1979–84, 4 were finished in glacial sand and gravel, and 10 were finished in sandstone. Specific capacities of wells finished in glacial drift varied from 0.63 to 10 (gal/min)/ft; and wells finished in sandstone ranged from 0.88 to 50 (gal/min)/ft. Ground water probably is available from sand deposits in cuspate bars and forelands, but this has not been verified. In all three aquifers, the predominant cations are calcium and magnesium and the predominant anion is bicarbonate. Concentrations of heavy metals did not exceed Wisconsin's drinking water standard.

Most of the water-quality sampling done for this study was synoptic in nature, and provides only a general characterization of the quality of the water during the study period. The data base provided by this study is not adequate for detecting subtle future changes. Detailed monitoring focused on specific water resources that are most subject to degradation, such as the heavy-use area of Lake Superior, is needed to detect future trends.

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