WATER QUALITY OF LAKES AND STREAMS IN VOYAGEURS NATIONAL PARK, NORTHERN MINNESOTA, 1977-84

By Gregory A. Payne

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CONVERSION FACTORS

Multiply	By	To obtain
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
cubic foot per second (ft^3/s)	0.02832	cubic meter per second

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ABSTRACT

Water-quality investigations in six interconnected lakes that comprise most of the surface area of Voyageurs National Park in northern Minnesota revealed substantial differences in water-quality. Three large lakes; Sand Point, Namakan, and Rainy, near the eastern and northern boundaries of the Park; are oligotrophic to mesotrophic, having low dissolved solids and alkalinity, and dimictic circulation. In contrast, Kabetogama Lake, Black Bay, and Sullivan Bay, near the western and southern boundaries of the Park, were eutrophic, having higher dissolved solids and alkalinity, and polymictic circulation. Chemical characteristics of the three lakes along the eastern and northern boundary were similar to those of the Namakan River--a major source of inflow that drains an extensive area of exposed bedrock and thin noncalcareous drift east of the Park. The lake and embayments along the western and southern boundary receive inflow from two streams that drain an area west and south of the Park that is overlain by calcareous drift. Samples from one of these streams contained dissolved-solids concentrations about five times, and total alkalinity concentrations about eight times concentrations measured in the Namakan River. The nutrient-enriched lakes and embayments had high algal productivity that produced blooms of blue-green algae in some years. Annual patterns in the levels of trophic-state indicators revealed that the shallow, polymictic lakes experienced seasonal increases in total-phosphorus concentrations in their euphotic zones that did not occur in the deeper, dimictic lakes; this indicates a link between the frequent recirculation of these lakes and internal cycling of phosphorus. Secchi-disk transparency was limited by organic color in Sand Point, Namakan, and Rainy Lakes, and resuspended bottom material reduced transparency in Black Bay. Waters in the large lakes and embayments met nearly all U.S. Environmental Protection Agency criteria for protection of freshwater aquatic life, recreation, and drinking water. Some sites exceeded criteria because of oil and grease, phenols, sulfide, and ammonia. Reconnaissance sampling of 19 small lakes in remote areas of the Park indicated that most of them are sharply stratified and had very low dissolved solids and alkalinity concentrations (4.0-29 milligrams per liter total alkalinity). Thirteen of the lakes could be classified as moderately sensitive to acid precipitation, and two could be classified extremely sensitive. About half of the interior lakes had low nutrient concentrations (10-30 micrograms per liter total phosphorus) and low algal productivity (0.1-2.0 micrograms per liter chlorophyll *a*). Five of the lakes had a marked reduction in trophic state from spring to summer. The Namakan River is the largest source of inflow to the Park and was found to have better quality than its receiving waters based on dissolved solids and nutrient concentrations, algal productivity, and transparency. The Ash River was found to deliver water that generally was poorer in quality than its receiving waters.

INTRODUCTION

Voyageurs National Park was established in 1971 to preserve, and provide for the public's enjoyment, scenic and natural resources along a historic waterway. At the time of establishment, water quality in the Park was not well documented. Water-quality investigations were undertaken in Voyageurs National Park by the U.S. Geological Survey, in cooperation with the National Park Service, to provide data on water quality in the newly established Park and to provide a basis for understanding future changes in water quality that might occur as the Park is developed.

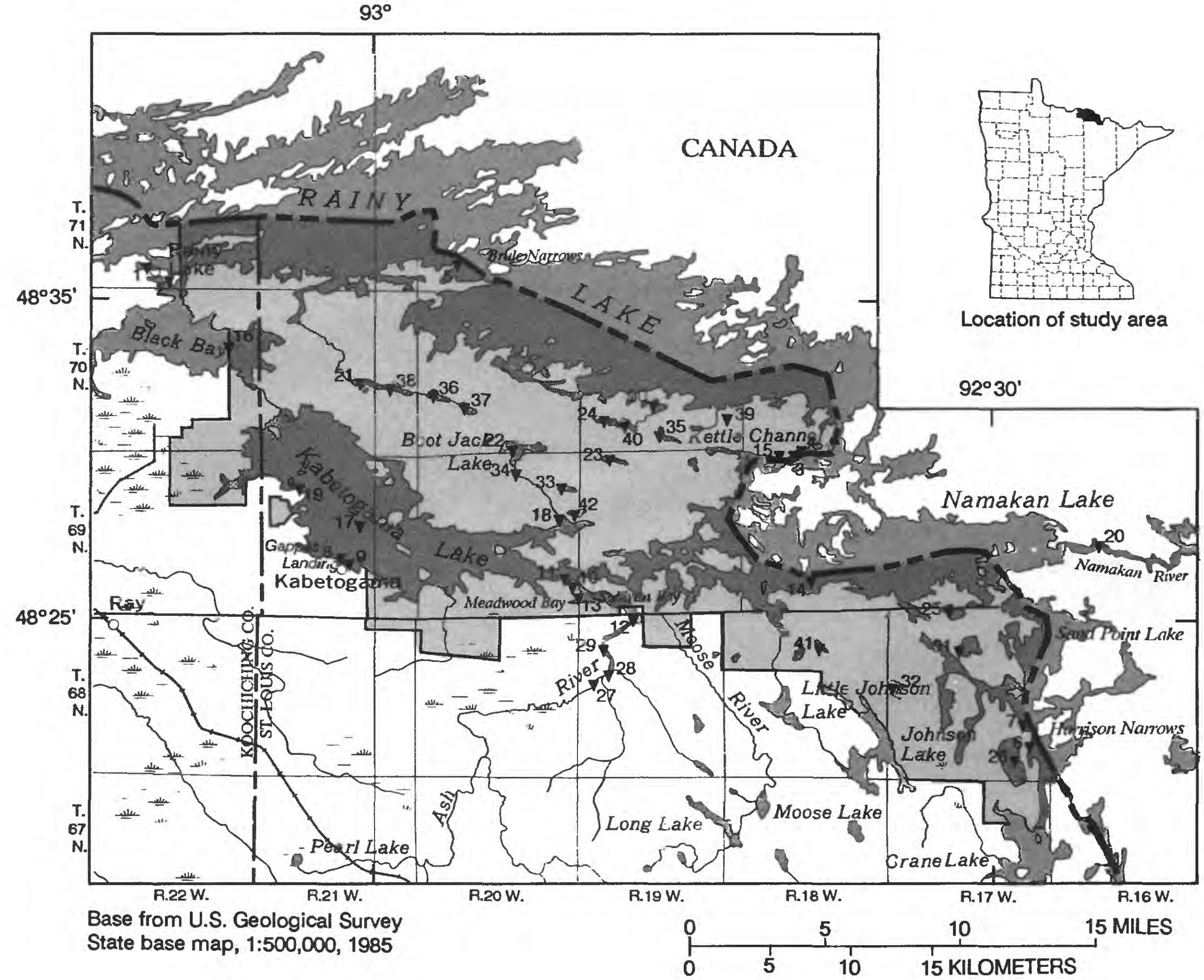
Purpose and Scope

This report contains the results of water-quality investigations conducted from March 1977 through August 1984. The report contains descriptions of the water quality of the four largest lakes in the Park, a discussion of the results of trophic-state monitoring, and the results of reconnaissance sampling of 19 small lakes in the Park's interior and two streams that flow into the Park.

Approach and Methods

The initial phase of the study involved sampling at 11 sites on the 4 large lakes that comprise the major waterways of the Park (Kabetogama, Rainy, Namakan, and Sand Point). All but one of the sites (site 5 on Rainy Lake) were paired sites that were designed to test the hypothesis that near-shore areas located close to recreational facilities would show evidence of water-quality degradation relative to sites located in mid-lake areas. These paired sites are shown in figure 1 (sites 1 and 2, 3 and 4, 6 and 7, 8 and 9, and 10 and 11). Site names and numbers are listed in table 1.

The first sampling was conducted under ice cover in March 1977, and was followed by a second sampling in August 1977. Results of these first two samplings were reported by Payne (1979). The sampling was repeated in 1978 with the following changes: (1) the under-ice sampling was replaced by sampling just after ice-out following spring turnover, which usually occurred in mid-May, and (2) an additional sampling was added (November 1978) to determine water-quality conditions at the time of fall turnover. Fall turnover sampling was not repeated in subsequent years. At the time of the fall 1978 sampling, three new sites (12, 13, and 14; fig. 1) were added to the study. Site 12 was sampled to determine the quality of water entering the Park via the Ash River. Site 13 was sampled to determine the effect of Ash River inflow on Sullivan Bay. Site 14 was added to provide more representative coverage of Namakan Lake--a large water body not adequately sampled by the original 11 sites. Samples were collected in May and August 1979. Sampling for chlorophyll *a* was added during the August 1979 sampling.



EXPLANATION

Voyageurs National Park

5 Sampling site and number

Figure 1.--Location of Voyageurs National Park and water-quality sampling sites

Table 1.--*List of sampling sites*

Site Name	Site number
Major Lakes and Bays	
Black Bay (Rainy Lake at Black Bay)	16
Black Bay (Rainy Lake at Black Bay Narrows)	1
Black Bay (Rainy Lake at Black Bay near Island View)	2
Kabetogama Lake at Gappas Landing	8
Kabetogama Lake near Gappas Landing	9
Kabetogama Lake at mouth of Meadwood Bay	11
Kabetogama Lake in Meadwood Bay	10
Kabetogama Lake in Lost Bay	18
Kabetogama Lake near Ray (mid-lake)	17
Kabetogama Lake near Wooden Frog Camp	19
Namakan Lake above Kettle Falls	15
Namakan Lake near Ray (mid-Lake)	14
Rainy Lake at Brule Narrows	5
Rainy Lake below Kettle Falls	3
Rainy Lake in Kettle Channel	4
Sullivan Bay (Ash River at entrance to Sullivan Bay)	12
Sullivan Bay (Kabetogama Lake at Sullivan Bay outlet)	13
Sand Point Lake above Harrison Narrows	6
Sand Point Lake below Harrison Narrows	7
Interior Lakes	
Beast Lake	35
Brown Lake	40
Cruiser Lake	23
Ek Lake	42
Jorgens Lake	33
Little Shoepack Lake	34
Little Trout Lake	31
Locator Lake	21
Loiten Lake	37
Lucille Lake	32
Mukooda Lake	26
O'Leary Lake	25
Oslo Lake	24
Peary Lake	30
Quill Lake	36
Ryan Lake	39
Shoepack Lake	22
Tooth Lake	41
War Club Lake	38
Inflow Sites	
Ash River above mouth of Gannon Creek	28
Ash River at Ash River Falls	27
Ash River below mouth of Gannon Creek	29
Namakan River	20

Analysis of data collected from 1977-79 indicated little or no difference in water quality between near-shore developed areas and mid-lake areas. Consequently, the paired sites were dropped. Sites 1 and 2 were replaced by site 16. Sites 3 and 4 were replaced by site 15. Site 6 was dropped but site 7 was retained. Sites 8 and 9 were replaced by sites 17 and 18. Site 10 was dropped. A 5-year trophic-state monitoring plan was adopted in 1980, whereby sites 5, 7, 11, 12, 13, 14, 15, 16, 17, and 18 would serve the following functions:

Site 5 - Monitor water quality of Rainy Lake.

Site 7 - Monitor water quality of Sand Point Lake.

Site 11 - Monitor water quality at east end of Kabetogama Lake.

Site 12 - Monitor quality of water entering the Park.

Site 13 - Monitor water-quality changes in Ash River inflow within Sullivan Bay.

Site 14 - Monitor water quality of Namakan Lake.

Site 15 - Monitor combined water from Kabetogama and Namakan Lakes before entering Rainy Lake at Kettle Falls Dam.

Site 16 - Monitor water quality in Black Bay.

Site 17 - Monitor water quality in mid-lake, Kabetogama Lake.

Site 18 - Monitor water quality in a large, sheltered bay of Kabetogama Lake.

In addition to the above, a one-time sampling for all water-quality constituents for which there were established criteria or standards was conducted during 1980. The sampling was conducted at five sites (5, 7, 14, 16, and 17) considered to be light-use areas and at five sites (2, 6, 8, 12, and 19) considered to be intensive-use areas.

During 1981-83, trophic-state monitoring was conducted at 10 sites (5, 7, 11, 12, 13, 14, 15, 16, 17, and 18). In addition new sites were sampled beginning in 1982. Six sites (21, 22, 23, 24, 25, and 26) in interior waters were sampled on a reconnaissance basis. Three sites (27, 28, and 29), located on the Ash River upstream from site 12, were sampled one time (August 1982) to determine water-quality changes as the Ash River flowed through an intensive-use area between Ash River Falls and Sullivan Bay. The Namakan River inflow (site 20) was sampled in May and August 1982. The Namakan River inflow sampling was not repeated in subsequent years. Trophic-state monitoring at 10 sites along with reconnaissance sampling of 6 interior lakes was conducted during 1983. During 1984, reconnaissance sampling was conducted at seven interior lakes.

Sampling activity was limited to May and August of each year except for the March 1977 and November 1978 samplings described earlier. The May period was chosen to sample the lakes as soon after ice-out as possible and before onset of summer stratification and periods of high algal productivity. This also allowed sampling prior to the heavy-use season. The August sampling periods, in contrast, were selected to obtain samples at a time of maximum thermal stratification, high algal productivity, and just after maximum recreational use. The August sampling period was selected because it was considered to be representative of worst-case water-quality conditions.

The constituents analyzed (sampling schedule) were changed throughout the study in response to changing data needs and in response to the results of prior sampling--that is, if review and analysis of the data showed that a particular constituent did not appear to be indicating a water-quality problem, or was not functioning as a reliable indicator, it was deleted from the schedule. Some constituents were dropped because of the high cost of collection and analysis. Selected constituents, however, were maintained as part of the sampling schedule throughout the study. These include vertical profiles of temperature, specific conductance, and dissolved oxygen, field alkalinity, total and dissolved phosphorus, dissolved nitrite plus nitrate nitrogen, total ammonia plus organic nitrogen, chlorophyll *a*, phytoplankton identification and cell count, and Secchi-disk transparency. Much of the discussion of this report focuses on these constituents. A listing of the constituents sampled in each year is shown in table 2. The results of analyses have been published annually (U.S. Geological Survey, 1978-85).

Vertical profiles of temperature, dissolved oxygen, and, when possible, specific conductance, were made with multi-parametric instruments calibrated at the beginning and end of each day of sampling. Transparency was measured with a black-and-white 20-centimeter Secchi disk.

Water samples were collected with a Van Dorn-type sampler. Samples for laboratory analysis were composited from the top, center, and bottom of that part of the water column equal to twice the Secchi-disk reading. Samples for determination of field alkalinity and pH were collected only from the center sample to avoid agitation of the sample. Additional samples were collected from below the thermocline at sites 6 and 14 during August 1979. Bottom-material samples were collected using U.S. Geological Survey BM 60 samplers and ponar-type grab samplers.

Samples for determination of chemical constituents were collected, filtered, preserved, and analyzed using the methods described in Brown and others (1970), Goerlitz and Brown (1972), and Skougstad and others (1979). Samples collected for determination of biological constituents were collected and analyzed according to methods described in Greeson and others (1977). Analyses were performed by the U.S. Geological Survey laboratories in Denver, Colorado, and Atlanta, Georgia.

WATER-QUALITY CHARACTERISTICS OF MAJOR LAKES AND BAYS

Water Chemistry

Results of analyses for major cations and anions, alkalinity, and total dissolved solids were evaluated to determine major water types and characteristics of the large lakes and bays. Samples collected from Voyageurs Park Lakes during the first year of study showed that waters had much lower concentrations of major ions, conductivity, and alkalinity when compared to surface waters in most other parts of Minnesota. It also was apparent that waters in the Park, although dilute, could be divided into three groups on the basis of specific conductance, a gross measure of dissolved- solids content. The groups are (1) Rainy, Namakan, and Sand Point Lakes, which had mean conductances ranging from 44 to 52 μS/cm (microseimens per centimeter at 25 degrees Celsius); (2) Kabetogama Lake and Black Bay which had mean conductances ranging from 79 to 91 μS/cm, and (3) Sullivan Bay, which had mean specific conductances ranging from 157 to 182 μS/cm. The water bodies can be grouped in a similar manner on their nutrient concentrations, alkalinity, algal productivity, and transparency. In each of these important aspects, the water bodies in groups 1 and 3 are at opposite extremes, whereas characteristics of Kabetogama Lake and Black Bay fall approximately midway between the extremes. This grouping formed the basis for much of the additional study and data analysis.

Dissolved Solids

The mean dissolved-solids concentrations and range of values are shown in figure 2. These values are the results of six samples collected at each site during 1980-83. Figure 2 also shows data for the mouth of the Ash River (site 12) and Sullivan Bay (site 13), which receives the inflow from Ash River to the Park. Namakan and Rainy Lakes had the lowest dissolved solids with identical mean concentrations (49 mg/L (milligrams per liter)). The three sites in Kabetogama Lake had nearly identical means (68 to 70 mg/L). Sand Point Lake had dissolved-solids concentrations midway between those in Rainy and Kabetogama Lakes but, based on alkalinity, nutrient concentrations, algal productivity, and transparency, more closely resembles Rainy and Namakan Lakes.

Black Bay (site 16) is an embayment of Rainy Lake, but is very different from Rainy Lake in water-quality characteristics. Figure 2 shows that it had dissolved-solids concentrations similar to those measured in Kabetogama Lake.

Sullivan Bay (site 13) had the highest dissolved-solids concentrations of the lake sites measured, reflecting input from the Ash River (site 12). Lower dissolved-solids concentrations at site 13 relative to site 12 suggest mixing with waters from Namakan and Kabetogama Lakes and indicates that, at times, reverse flow occurs through the narrow channel at the outlet of Sullivan Bay.

Table 2.--*Sampling schedule for water-quality and bottom-material constituents*

[X = Sample collected for indicated constituent, Xa = Sample collected at selected sites only (repeat sampling at sites where constituent exceeded recommended level in previous sample), Xb = Sample collected at Ash River sites only, Xc = Sample collected in interior lakes only, MBAS = Methylene blue active substances, . = not sampled.]

Constituent or property	1977		1978			1979		1980		1981		1982		1983		1984	
	March	August	May	August	November	May	August	May	August	May	August	May	August	May	August	May	August
WATER QUALITY																	
Physical Properties																	
Dissolved oxygen	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Xc	Xc
pH	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Xc	Xc
Specific conductance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Xc	Xc
Temperature	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Xc	Xc
Trophic State Indicators																	
Phosphorus, total	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Xc	Xc
Phosphorus, dissolved	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Xc	Xc
Nitrite plus nitrate nitrogen, dissolved	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Xc	Xc
Ammonia plus organic nitrogen, total	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Xc	Xc
Chlorophyll <u>a</u> and <u>b</u>	.	.	.	.	.	.	X	X	X	X	X	X	X	X	X	Xc	Xc
Phytoplankton, genera and cell counts	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Xc	Xc
Secchi-disk transparency	.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Xc	Xc
Other Constituents and Properties																	
Alkalinity	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Xc	Xc
Ammonia nitrogen, total	X	X	.	.	.	.	.	.	X	.	Xa	.	Xb	.	.	.	.
Ammonia plus organic nitrogen, suspended	X	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Arsenic	.	.	.	.	.	.	.	X	.	X	.	.	.	.	.	.	.
Barium	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.
Cadmium	.	.	.	.	.	.	X	.	X	.	.	.	.	.	.	.	.
Calcium	X	X	.	.	.	.	.	.	.	.	.	Xc	Xc	Xc	Xc	Xc	Xc
Carbon, organic dissolved	X	X	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.
Chloride	.	.	.	.	.	.	.	.	.	.	.	Xc	Xc	Xc	Xc	Xc	Xc
Chromium	.	.	.	.	.	.	X	.	X	.	.	.	.	.	.	.	.
Color	.	.	.	.	.	.	.	.	X	.	.	Xc	Xc	Xc	Xc	Xc	Xc
Copper	.	.	.	.	.	.	X	.	X	.	.	.	.	.	.	.	.
Cyanide	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.
Detergents (MBAS)	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.
Dissolved solids	.	.	.	.	.	.	.	.	X	.	.	X	X	X	X	Xc	Xc
Fecal coliform	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.
Fecal <u>Streptococci</u>	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.
Fluoride	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.
Hardness	X	X	.	.	.	.	.	.	.	.	.	Xc	Xc	Xc	Xc	Xc	Xc

Table 2.--*Sampling schedule for water-quality and bottom-material constituents*--Continued

Constituent or property	1977 March	1977 August	1978 May	1978 August	1978 November	1979 May	1979 August	1980 May	1980 August	1981 May	1981 August	1982 May	1982 August	1983 May	1983 August	1984 May	1984 August
WATER QUALITY--Continued																	
Other Constituents and Properties--Continued																	
Iron	X	X	.	.	.	.	X	.	X	.	.	Xc	Xc	Xc	Xc	Xc	Xc
Lead	.	.	.	.	.	.	X	.	X	.	.	.	.	.	.	.	.
Magnesium	X	X	.	.	.	.	.	.	.	.	.	Xc	Xc	Xc	Xc	Xc	Xc
Manganese	X	X	X	X	X	X	X	.	.	.	.	Xc	Xc	Xc	Xc	Xc	Xc
Mercury	.	.	.	.	.	.	X	.	X	.	.	.	.	.	.	.	.
Nickel	.	.	.	.	.	.	X	.	X	.	.	.	.	.	.	.	.
Nitrate	X	X	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.
Nitrite	X	X	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.
Nitrite plus nitrate nitrogen, total	X	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Nitrogen, organic, total	X	X	.	.	.	.	.	.	X	.	.	.	Xb	.	.	.	.
Oil and grease	.	.	.	.	.	.	.	.	X	.	Xa	.	.	.	.	.	.
Pesticides	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.
Phenols	.	.	.	.	.	.	.	.	X	.	Xa	.	.	.	.	.	.
Potassium	X	X	.	.	.	.	.	.	.	.	.	Xc	Xc	Xc	Xc	Xc	Xc
Radiochemical	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.
Selenium	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.
Sodium	X	X	.	.	.	.	X	.	.	.	.	Xc	Xc	Xc	Xc	Xc	Xc
Sulfate	.	.	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.
Sulfide	.	.	.	.	.	.	X	.	X	.	.	.	.	.	.	.	.
Suspended solids	.	.	.	.	.	.	X	.	X	.	.	Xc	Xc	Xc	Xc	Xc	Xc
Turbidity	X	X	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Zinc	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.
BOTTOM MATERIAL																	
Carbon, organic	X	X	.	.	.	X	X	.	.	.	.	.	.	.	.	.	.
Carbon, inorganic	.	.	.	.	.	X	X	.	.	.	.	.	.	.	.	.	.
Ammonia plus organic nitrogen	X	X	X	X	X	X	X	.	.	.	.	.	.	.	.	.	.
Nitrite plus nitrate nitrogen	X	X	X	X	X	X	X	.	.	.	.	.	.	.	.	.	.
Ammonia nitrogen	X	X	X	X	X	X	X	.	.	.	.	.	.	.	.	.	.
Phosphorus	X	X	X	X	X	X	X	.	.	.	.	.	.	.	.	.	.
Arsenic	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.
Cadmium	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.
Chromium	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.
Cobalt	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.
Copper	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.
Iron	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.
Lead	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.
Mercury	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.
Nickel	.	.	.	.	.	.	X	.	.	.	.	.	.	.	.	.	.

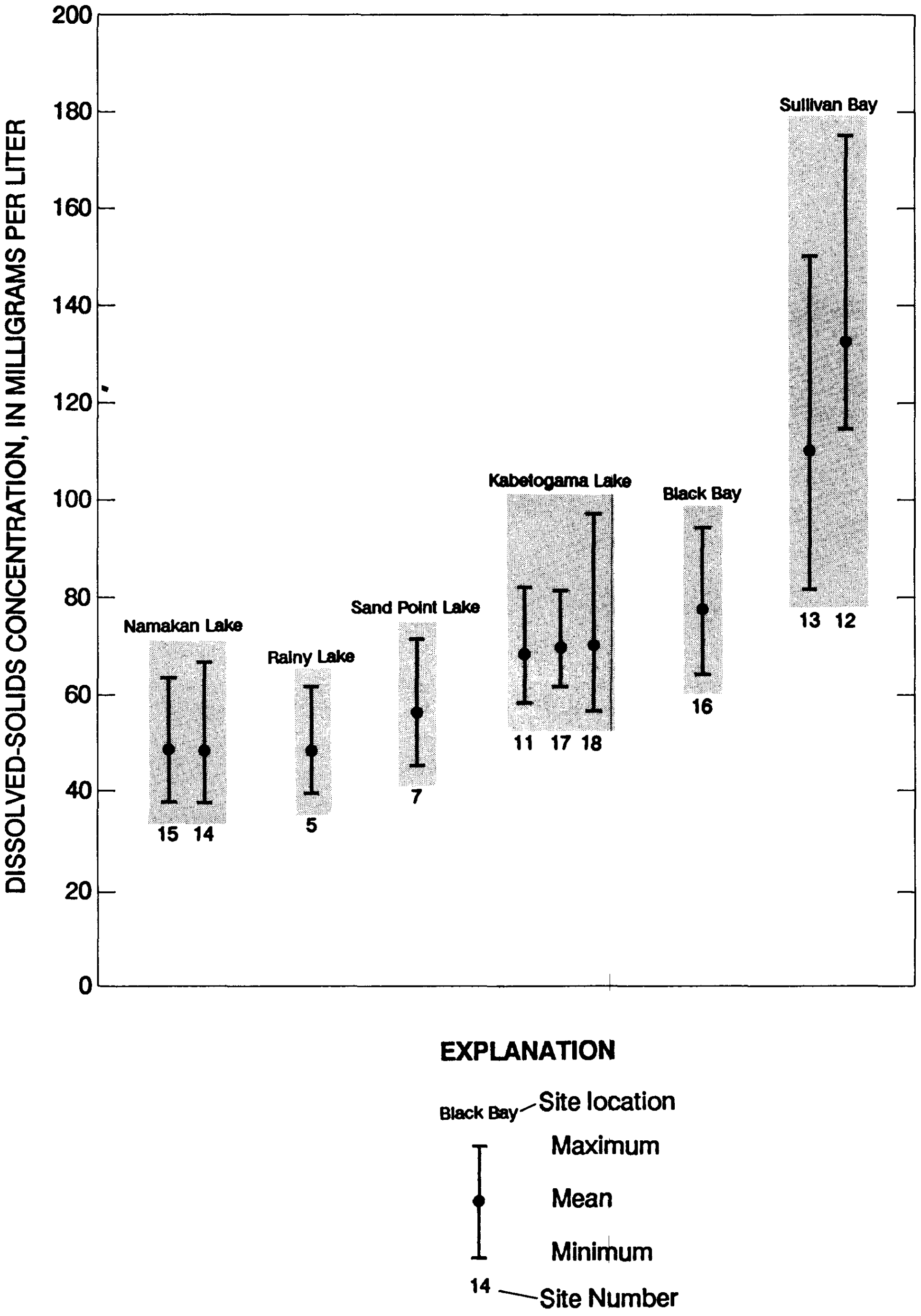


Figure 2.--Range and mean values of total dissolved-solids concentrations, 1980-83

Major Cations and Anions

Samples collected during 1977 were analyzed for major cations and anions. Results from analyses of the August samples were examined for consistent patterns in the proportions of major cations (table 3). Results from sites 10 and 11 (Kabetogama Lake) were not used in this analysis because data on bicarbonate concentrations, specific conductance, and total dissolved solids for these sites suggested that Namakan Lake water was mixing with Kabetogama Lake water at the time of sampling. This also is indicated by the percent-sodium value for sites 10 and 11, which is between that of Namakan Lake (site 14) and Kabetogama Lake at sites 8 and 9. Water chemistry at site 3 was considered to be representative of Namakan Lake because site 3 was located immediately downstream from Kettle Falls Dam in the outflow from Namakan Lake. Site 4 was not used in this analysis because it was receiving wastewater effluents from the developed area at Kettle Falls at the time of sampling.

Table 3 shows that calcium and magnesium are the dominant cations, comprising 84 to 93 percent of the total. Although total dissolved-solids content varies considerably between the large water bodies, calcium remains virtually constant at 57 to 59 percent of total cations. The principal difference in cations that serves to differentiate the major water bodies is the calcium to magnesium ratio. The major water bodies in table 3 can be divided into two groups: (1) Black Bay, Kabetogama, and Sand Point, which have a calcium-magnesium ratio of about 1.7-1.8:1 and (2) Namakan and Rainy, which have a ratio of about 2.2-2.3:1. The difference is brought about by proportionally less magnesium in Namakan and Rainy, compensated by a proportional increase in sodium and potassium. As will be discussed in the section of this report dealing with inflows, the Namakan River provides a large amount of water to Namakan Lake and Rainy Lake, thereby exerting significant influence on the major-ion chemistry. Sand Point, Kabetogama, and Black Bay are influenced, respectively, to a greater extent by the Vermilion, Ash, and Rat Root Rivers. The differences in cation ratios shown in table 3 may be a result of differences in the chemical composition of bedrock and drift in the drainage basins of the respective inflowing rivers. A detailed discussion of the bed-rock and overlying glacial drift of the drainage basins is beyond the scope of this report, but, in general, the drainage basin of the Namakan River is characterized by thin deposits of Rainy lobe drift, whereas the Rat Root and Ash Rivers drain areas covered by Des Moines lobe drift. The Vermilion River drains areas covered by both types of drift, but the Des Moines lobe drift is more prevalent in the lower reaches of the Vermilion River near its mouth.

Nutrients

Total phosphorus concentrations are shown in figure 3. The graphs show that Namakan, Rainy, and Sand Point Lakes (sites 14, 5, and 7) had lower concentrations, a narrower range of concentrations, and little difference between mean spring and mean summer concentrations. In contrast, phosphorus concentrations in Kabetogama Lake (sites 9, 17, 18, 11), Sullivan Bay (sites 12, 13), and Black Bay (site 16) had a wide range of concentrations, particularly during summer, and had mean concentrations that were greater during summer than during spring. Sites 9 and 17 on Kabetogama Lake are close to one another so their data were combined to increase the amount of data available.

Table 3.--*Comparative cation data for the major lakes and bays in Voyageurs National Park*

[Data from sites 1-19 except as noted. Dissolved-solids concentrations in milligrams per liter; calcium to magnesium ratio and percentages calculated using millequivalents per liter]

Lake	[1] Mean dissolved solids concentration	Ratio, calcium: magnesium	Percent calcium	Percent magnesium	Percent sodium	Percent potassium
Black Bay	78	1.79	58	33	7	2
Kabetogama	68	1.66	58	[2] 35	6	2
Sand Point	56	1.81	57	30	10	4
Namakan	49	2.27	58	26	13	4
Rainy	49	2.21	59	27	12	3

[1] Dissolved solids data from 1980-83, only for sites 5, 7, 14, 15, 16, 17, 18.
[2] Magnesium value for site 9 not used because of suspect analytical results.

The higher mean total phosphorus concentrations in summer suggest that there is an input of phosphorus during the summer season from either external (inflow or precipitation) or internal (lake sediments) sources. The input processes may be operating in all the lakes, but do not result in a buildup of phosphorus in the epilimnions of Namakan, Rainy, and Sand Point Lakes owing to their stratification. A constant state of stratification throughout the summer may provide a mechanism whereby particulate phosphorus can settle through the thermocline and become isolated from the epilimnion. The non-stratified conditions frequently observed in Kabetogama, Sullivan Bay, and Black Bay prevent long-term isolation of settled phosphorus and may provide a mechanism for recycling of phosphorus from the sediment to the euphotic zone. Phosphorus recycling from the sediment may be occurring in Kabetogama Lake and Sullivan and Black Bays if periods of weak temporary stratification cause anaerobic conditions to develop at the sediment-water interface. The development of anaerobic conditions at the interface can promote release of soluble phosphorus which then can be circulated to the euphotic zone during periods of mixing.

In most years the elevated phosphorus concentrations measured in summer were not present the following spring. The reduction may result from a series of events that begin with final destratification and mixing during fall. At that time, the water column becomes uniformly oxygenated, and lowered light intensity, along with colder temperature, causes die-off of summer algal blooms. Phosphorus in algal cells is lost to the aerobic sediment interface as the algal cells settle to the bottom. Surface outflow during winter also may remove some of the phosphorus.

The data for Kabetogama Lake show that when phosphorus concentrations remained high the following spring (1980 and 1982), the total phosphorus concentrations that next summer reached very high levels. Because no samples were collected during fall or winter in those years, it is not known whether the high concentrations in spring resulted from a failure of the loss mechanism or an unusually high external input of phosphorus during spring just before sampling.

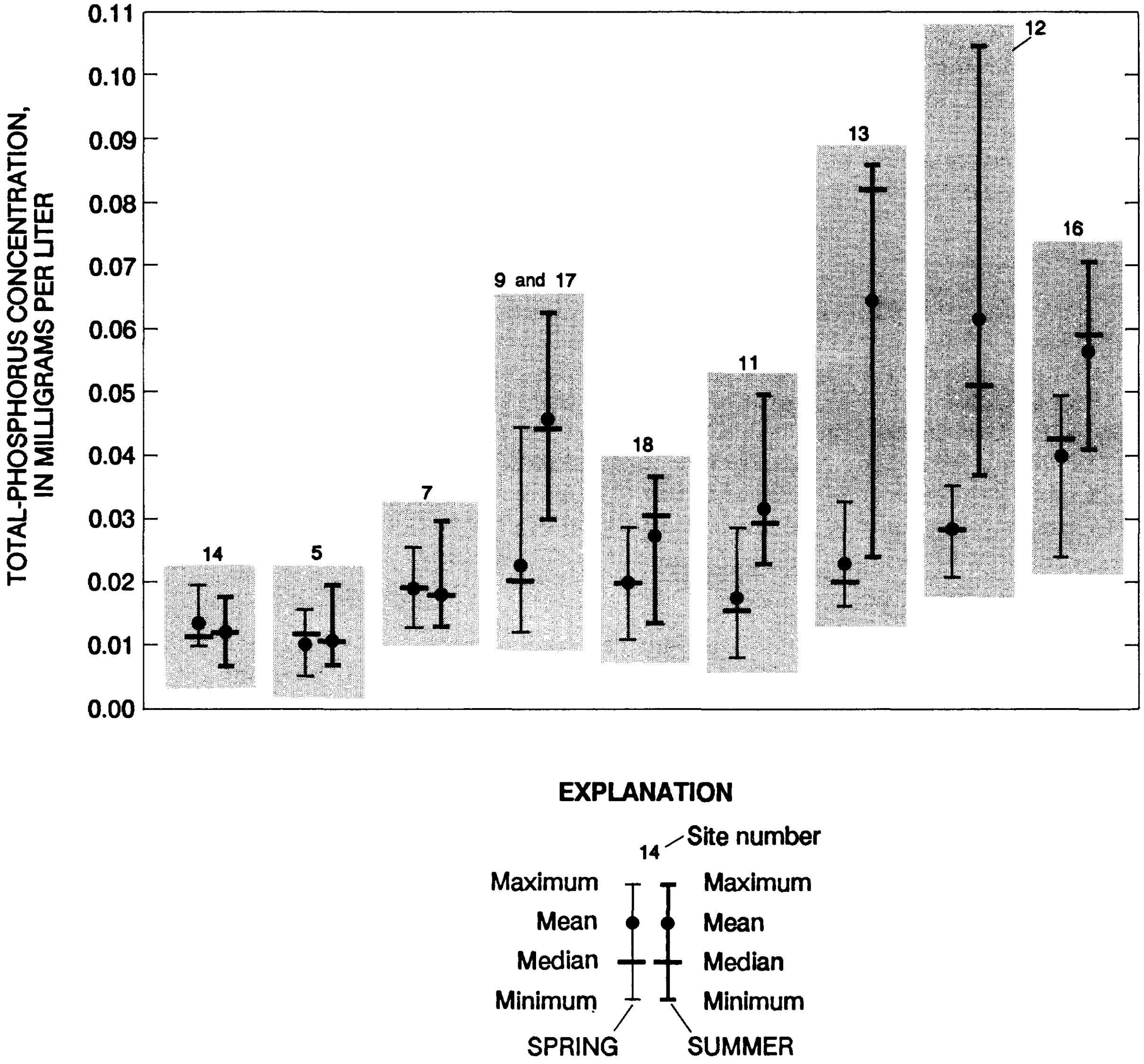


Figure 3.--Mean, median, and range of total phosphorus concentrations

Nitrite plus nitrate nitrogen concentrations showed little correlation with total phosphorus concentrations. Nitrite plus nitrate concentrations fluctuated over a wide range in all the lakes and were as high in the lakes having low total phosphorus concentrations, such as Rainy and Namakan, as they were in lakes having high total phosphorus concentrations, such as Kabetogama and Sullivan Bay. The range of values, means, and medians are shown in figure 4. The mean values for some of the lakes are skewed by one or two extremely high values or by some values that were less than detection limits; therefore, median values are more useful for comparisons between lakes. The least productive lakes, Rainy and Namakan, had median values that were about double the median values for the highly productive lakes, although the overall range in values was similar. This may be a result of higher utilization of nitrate in the highly productive lakes. Nitrite plus nitrate concentrations were below detection limits several times in the highly productive lakes, suggesting that utilization was very high.

Total ammonia plus organic nitrogen data are summarized in figure 5. Ammonia plus organic nitrogen will be discussed in terms of its organic component because ammonia comprised a negligible portion of the total. The range, mean, and median values are more closely matched to total phosphorus concentrations in the lakes than were nitrite plus nitrate nitrogen, but not proportionally. For example, values for Kabetogama Lake (sites 9, 11, and 17) were only slightly higher than values for Rainy and Namakan Lakes (sites 5 and 14), in contrast to the large differences in their total phosphorus concentrations.

Chlorophyll *a* concentrations correlated weakly with organic nitrogen concentrations. Total organic nitrogen frequently was high when chlorophyll *a* was low, which suggests that the organic nitrogen in the water column was not totally accounted for by nitrogen contained in algal cells. The high concentrations of total organic nitrogen do not necessarily result from instantaneous algal productivity at the time of sampling, but can reflect the metabolic processes of living organisms, plant and animal, as well as decomposition of dead organisms. Blue-green algae, for example, secrete nitrogenous materials that they are not able to utilize as nitrogen sources (Ried and Wood, 1976). The total (dissolved plus suspended) organic nitrogen values, particularly the mean and median values from the entire period of study, may be fairly good integrators of total biological activity over the long term.

Sites 12 and 13 in Sullivan Bay had the most discernable patterns in organic nitrogen values. The range of values for spring and summer did not overlap, whereas they did at all other sites, and the summer mean and median values were well above those from spring. This may indicate high summer loading of organic nitrogen from the Ash River. A substantial increase in organic nitrogen was observed in the Ash River between Ash River Falls and site 12 in Sullivan Bay during the reconnaissance sampling conducted in August 1982.

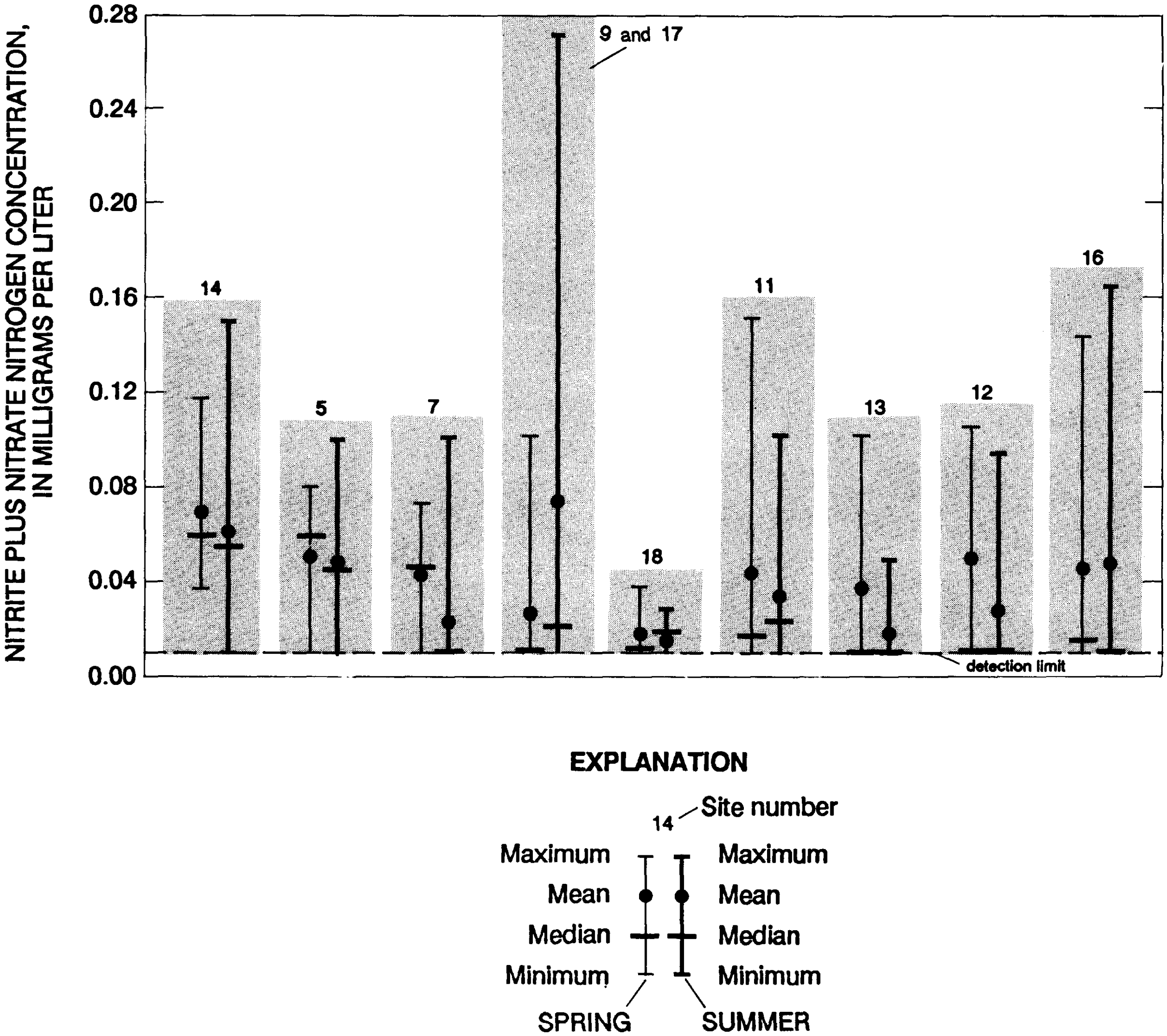


Figure 4.--Mean, median, and range of nitrite plus nitrate nitrogen concentrations

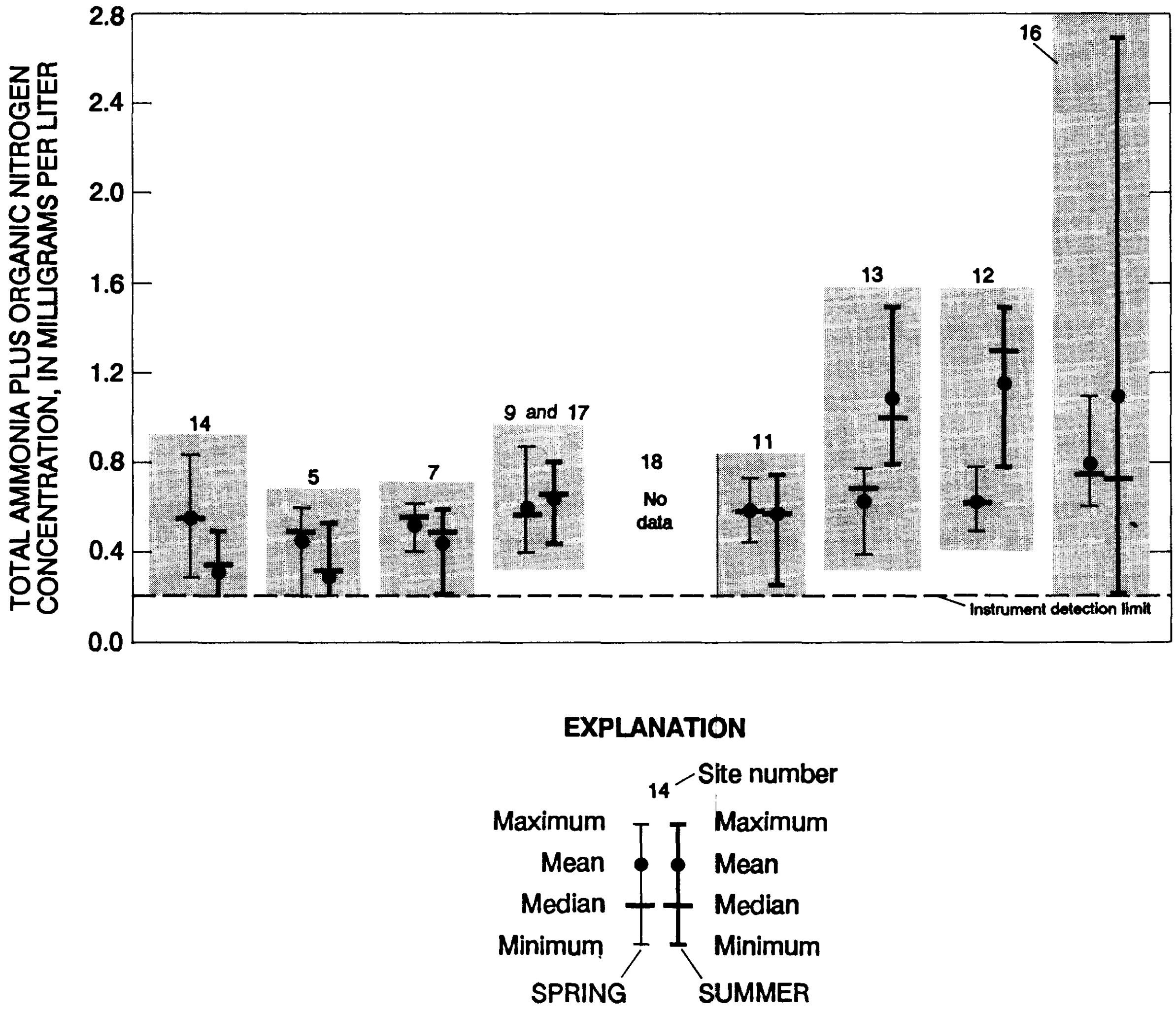


Figure 5.--Mean, median, and range of total ammonia plus organic nitrogen concentrations

Vertical Profiles of Temperature, Specific Conductance, and Dissolved Oxygen

Physical characteristics were determined from vertical profiles of temperature, dissolved oxygen, and, usually, specific conductance obtained at each site beginning in May 1978. Data from the profiles were evaluated to determine the occurrence of thermal stratification, hypolimnetic oxygen depletion, and changes in specific conductance with depth. The results are listed in detail in table 20. Total depth between samplings varied because vertical profiles were not measured at exactly the same location. Much of the depth fluctuation, however, was caused by changing lake levels, especially at sites above Kettle Falls where lake levels are regulated. Figures 6-9 illustrate temperature profiles at selected locations, sites 18, 14, 15, and 6, where thermal stratification produced well-defined thermoclines. The results for all sites in each lake are summarized below.

Kabetogama Lake

Site 8 - This site is near shore in a small bay at Gappas Landing. Depths measured ranged from 6 to 14 ft (feet). Temperatures were uniform throughout the water column in most of the profiles. Maximum temperature change from top to bottom was 0.5 °C (degrees Celsius). Dissolved oxygen and conductivity also were uniform, varying at most 0.5 mg/L and 1 μS/cm, respectively.

Site 9 - Depths at site 9 ranged from 24 to 28 ft. Uniform profiles were obtained in August 1978 and November 1978. Maximum change with depth was observed in May 1979 when temperature declined 2.7 °C and dissolved oxygen declined 1.3 mg/L from top to bottom.

Site 10 - Depths at site 10 ranged from 7 to 12 ft. Site 10 is located in a sheltered area near shore. Uniform profiles were obtained in May 1978, August 1978, November 1978, and August 1979. The maximum change with depth was observed in May 1979, when temperature declined 1.0 °C and dissolved oxygen declined 0.5 mg/L from top to bottom.

Site 11 - Depths ranged from 21 to 42 ft at site 11. Profiles obtained in August 1978, November 1978, August 1979, and May 1980 showed uniform temperatures from top to bottom. The other profiles indicated thermal stratification. In August 1980, August 1981, August 1982, May 1983, and August 1983, the thermal stratification was accompanied by a decline in dissolved-oxygen concentrations to values less than 5.0 mg/L. The depressed oxygen conditions occurred at depths ranging from 23 to 30 ft.

Specific conductance varied as much as 20 μS/cm in the water column. In most cases, conductivity rose in the part of the water column underlying the thermocline. Notable exceptions were May 1981, May 1982, and August 1982, when lower-conductivity water was layered between higher-conductivity water at the surface and bottom. This suggests movement of low-conductivity water from Namakan Lake into Kabetogama Lake.

Site 17 - Depths ranged from 30 to 35 ft at site 17. Uniform temperature profiles were obtained in May 1980, August 1980, and May 1983. The other profiles showed either a gradual decline of 1.0 to 2.0 °C from the surface to bottom or the presence of a thermocline.

One of the profiles (August 1981) showed depression of dissolved-oxygen concentrations to values less than 5.0 mg/L. The profile indicated uniform temperature down to 27 ft. The bottom layer of water was 6.0 ft thick and was 1.0 °C colder than the overlying water column. Stratification was further indicated by a 4.5-mg/L drop in dissolved oxygen and a 7-μS/cm rise in conductivity between 27 and 30 ft. Less severe oxygen declines were observed in August 1982, May 1983, and August 1983. In these profiles, dissolved-oxygen concentrations declined from about 11 mg/L in the upper layers to about 6.5 mg/L near the bottom. In August 1983, the profile showed an abrupt drop of 2.5 mg/L in dissolved oxygen between 10 and 13 ft depth that was associated with a 1.0 °C drop in temperature. A similar, but more gradual, drop in dissolved oxygen was noted in the May 1983 profile when temperatures were uniform throughout the water column.

Specific conductance in the profiles at site 17 varied only 1 to 4 μS/cm, declining gradually from surface to bottom except as noted during August 1981. This contrasted with the profiles measured at site 11.

Site 18 - Depths ranged from 29 to 38 ft at site 18. As shown in figure 6, all August profiles indicated thermal stratification. The position of the thermocline varied from 6.0 ft below the surface in August 1982 to as much as 24 ft below the surface in August 1980. The water column above the thermocline was characterized by uniform temperature and conductance profiles and a gradual decline in dissolved-oxygen concentration with depth. Dissolved-oxygen concentrations in the epilimnion were, however, at least 6.5 mg/L.

A steep thermal gradient began at 26 to 29 ft and continued to the bottom. Within this zone, dissolved-oxygen concentrations ranged from 0.3 mg/L in August 1982 to 2.1 mg/L in August 1980. The steep thermal gradient was accompanied by an increase in specific conductance of about 50 μS/cm.

The May profiles indicated the onset of thermal stratification. In May 1980 and May 1983, the stratification was accompanied by declines in dissolved-oxygen concentrations to values less than 5.0 mg/L. None of the May profiles showed the rises in specific conductance that were observed in the August profiles

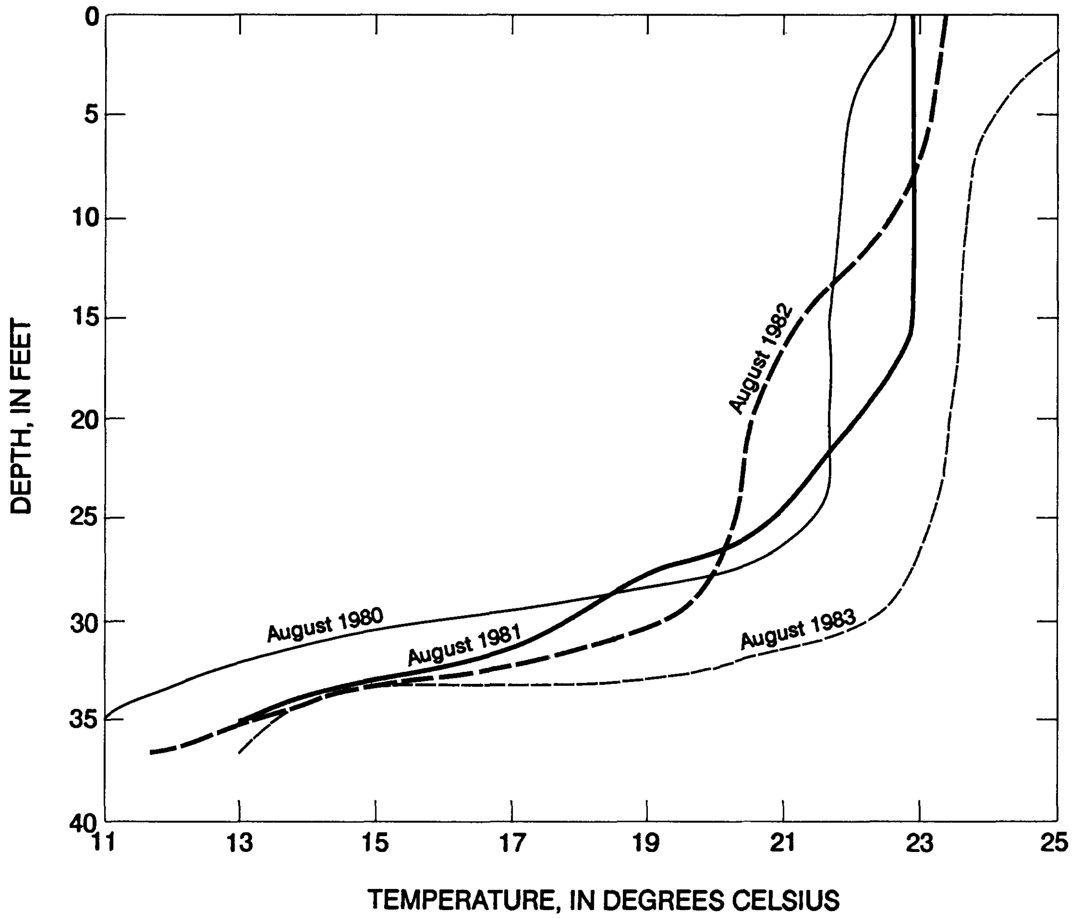


Figure 6.--Vertical temperature profiles for Kabetogama Lake, site 18

The profile data collected for Kabetogama Lake indicate that, in mid-lake areas (represented by site 17), stratification is not always present during summer. Only one profile was measured during each summer season, so no data are available to verify the development and subsequent breakdown of stratification within a summer season. The presence of strong stratification at site 11 in August 1980 concurrent with nonstratified conditions at site 17 suggests that destratification takes place during the summer season. While conditions observed at sites 11 and 17 probably are representative of most of Kabetogama Lake, a different stratification pattern appears to occur in the narrow, sheltered area of Lost Bay.

The data collected at site 18 suggest that stratification in Lost Bay persists throughout the summer. Dissolved-oxygen concentrations within the thermocline dropped below 5.0 mg/L as early as May as thermal stratification sets in. Increases in specific conductance below the thermocline were greater in Lost Bay than in the rest of the lake, suggesting a longer and more permanent period of stratification.

Rainy Lake

Site 5 - Site 5 is located in the Brule Narrows, a rocky, shallow area where depths in the profiles ranged from 12 to 24 ft. The temperature, dissolved-oxygen, and specific-conductance profiles obtained at site 5 are not representative of conditions in the large, open-water areas of Rainy Lake where depths commonly exceed 60 ft.

In the Brule Narrows, temperature profiles ranged from being completely uniform to having a weak thermal gradient. One exception was in May 1978 when temperatures declined from 10.0 °C at a depth of 3 ft to 5.0 °C at a depth of 23 ft, indicating the onset of sharp thermal stratification. The next sampling in August 1978 showed nearly uniform temperatures, however, suggesting that thermal stratification in the Brule Narrows is temporary.

Dissolved-oxygen concentrations were nearly uniform from top to bottom even when thermal gradients were present. Concentrations did not drop below 7.2 mg/L within the water column. Specific-conductance profiles were uniform, varying only 2 μS/cm from top to bottom.

Namakan Lake

Site 14 - The depth at site 14 exceeded 100 ft. Most profiles were obtained to a depth near 65 ft (90 ft during August 1979) because of the limitations of the profiling equipment. May profiles showed a very gradual temperature decline with depth of about 2.0 °C over the entire profile. During August, however, all profiles indicated strong thermal stratification (fig. 7). Depth to the top of the thermocline ranged from 20 to 28 ft. The thermocline extended to a depth of about 70 ft (as indicated by the August 1979 profile). Temperatures above the thermocline were about 20 to 23 °C while temperatures below the thermocline were about 9.0 °C.

Dissolved-oxygen concentrations were nearly uniform above the thermocline, but dropped slowly with depth within the thermocline. Minimum dissolved-oxygen concentrations within the thermocline ranged from 5.3 mg/L in August 1981 to 7.4 mg/L in August 1980. Specific conductance was virtually uniform within the profiles, showing a maximum change of only 6 µS/cm throughout the water column (May 1983).

Site 15 - This site is about 1 mile upstream from the dam at Kettle Falls. The profiles were measured in a 100-ft-deep hole a short distance downstream from Squirrel Narrows.

August profiles varied from strongly stratified (August 1980) to nonstratified (August 1982) (fig. 8). When stratified, the epilimnion extended to about 20 ft below the surface. Thermal gradients within the thermocline were not as steep as those observed at site 14 and temperatures below the thermocline were as high as 18 °C.

The onset and stability of thermal stratification at site 15 is likely influenced by currents associated with flow in Squirrel Narrows and at Kettle Falls dam. This is suggested by the lack of stratification during August 1982 when site 14 was strongly stratified and by higher temperatures in the hypolimnion that suggest later onset of stratification than at site 14.

The minimum dissolved-oxygen concentration observed in the thermocline was 5.9 mg/L (August 1981). Specific conductance changed only slightly with depth. The maximum change was a drop of 7 µS/cm observed in May 1982.

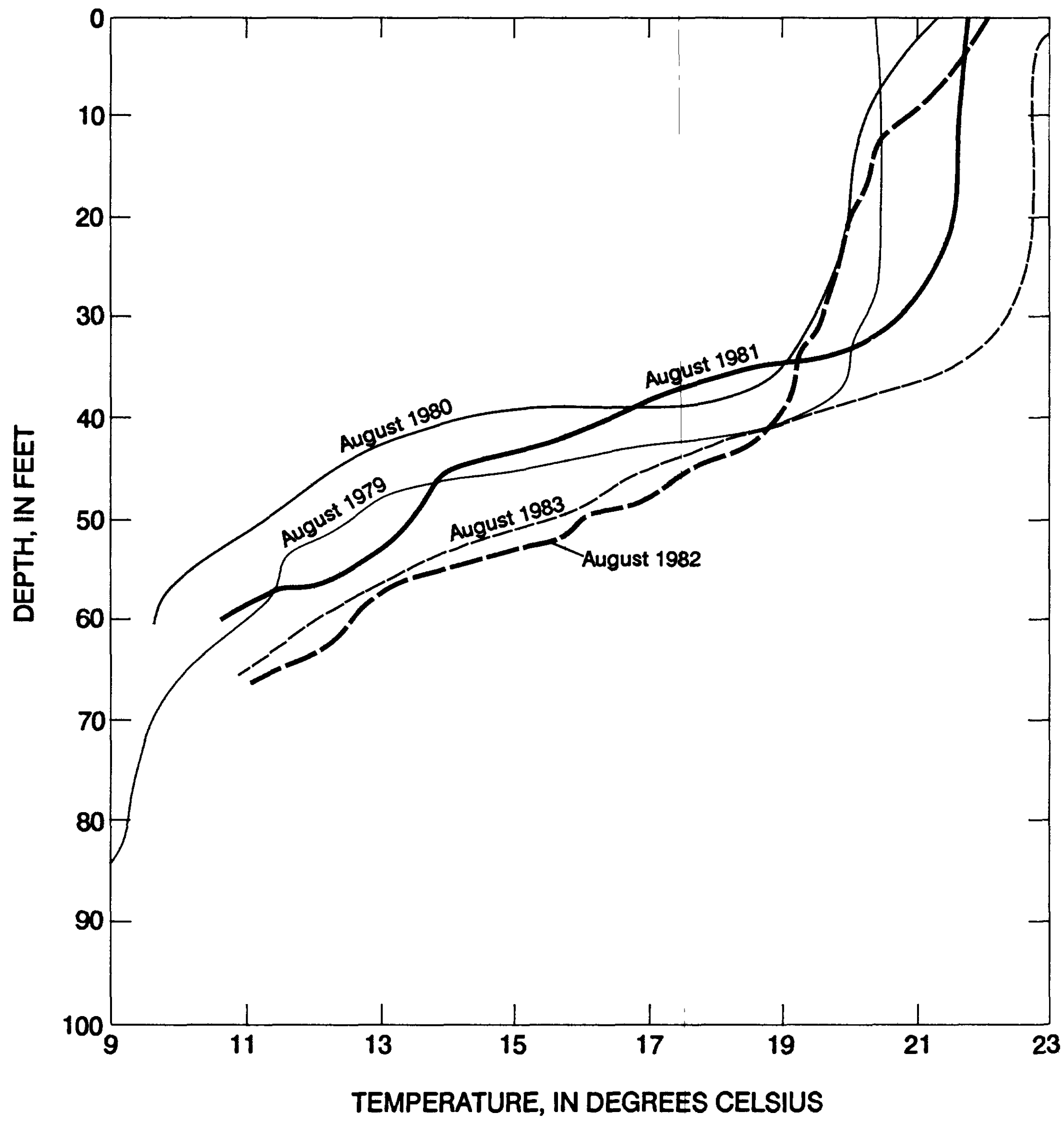


Figure 7.--Vertical temperature profiles for Namakan Lake, site 14

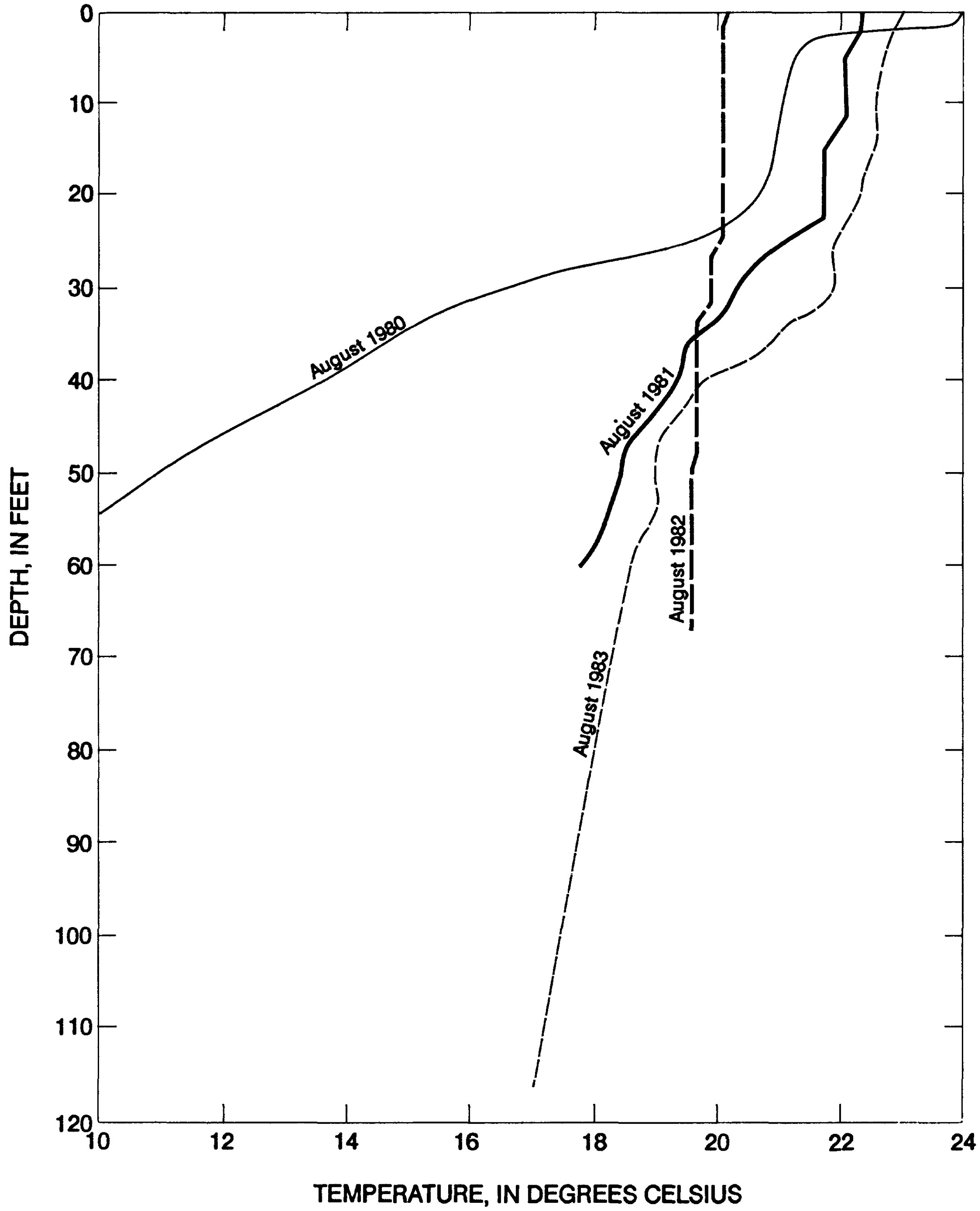


Figure 8.--Vertical temperature profiles for Namakan Lake, site 15

Sand Point Lake

Site 6 - Depth at site 6 was 60 ft. This site showed strong thermal stratification in both May and August (fig. 9). In May 1978, the top of the thermocline was 10 ft below the surface. By August 1978, the top of the thermocline was about 25 ft below the surface. Two other summer profiles (August 1979 and August 1980) showed similar characteristics. During August, thermoclines extended to about 45 ft below the surface. Temperatures above the thermocline ranged from 19 to 21 °C while temperatures below the thermocline were 8 to 9 °C.

Dissolved-oxygen concentrations within the thermocline dropped below 5.0 mg/L at 30 ft below the surface in August 1978 and August 1979. In August 1980, the concentration dropped to 5.1 mg/L within the thermocline. During the May 1978 stratification, dissolved-oxygen concentrations showed only a gradual decline from 10.0 mg/L in the epilimnion to 9.3 mg/L in the hypolimnion.

In contrast to Kabetogama Lake, there was no rise in specific conductance in the hypolimnion.

Site 7 - Site 7 is in the Harrison Narrows. Depths are variable in the narrows and profiles were obtained at depths ranging from 11 to 37 ft. The profiles show thermal stratification in August 1978, August 1980, and August 1983 when there were strong thermal gradients at depths of 27 to 30 ft below the surface. Lack of stratification in August 1979, August 1981, and August 1982 probably was a result of measuring the profile in portions of the Harrison Narrows that had total depths of less than 21 ft.

Dissolved-oxygen concentrations generally were uniform in the water column. Notable exceptions were in August 1983 when concentrations dropped sharply to less than 5.0 mg/L at 25 ft below the surface and continued dropping to 3.4 mg/L at 30 ft. In May 1983, temperatures were uniform throughout the water column, but dissolved oxygen declined steadily from 10.4 mg/L at a depth of 3 ft to 6.0 mg/L at 23 ft.

Specific conductance was nearly uniform in the water column, varying at most 4 μS/cm from top to bottom.

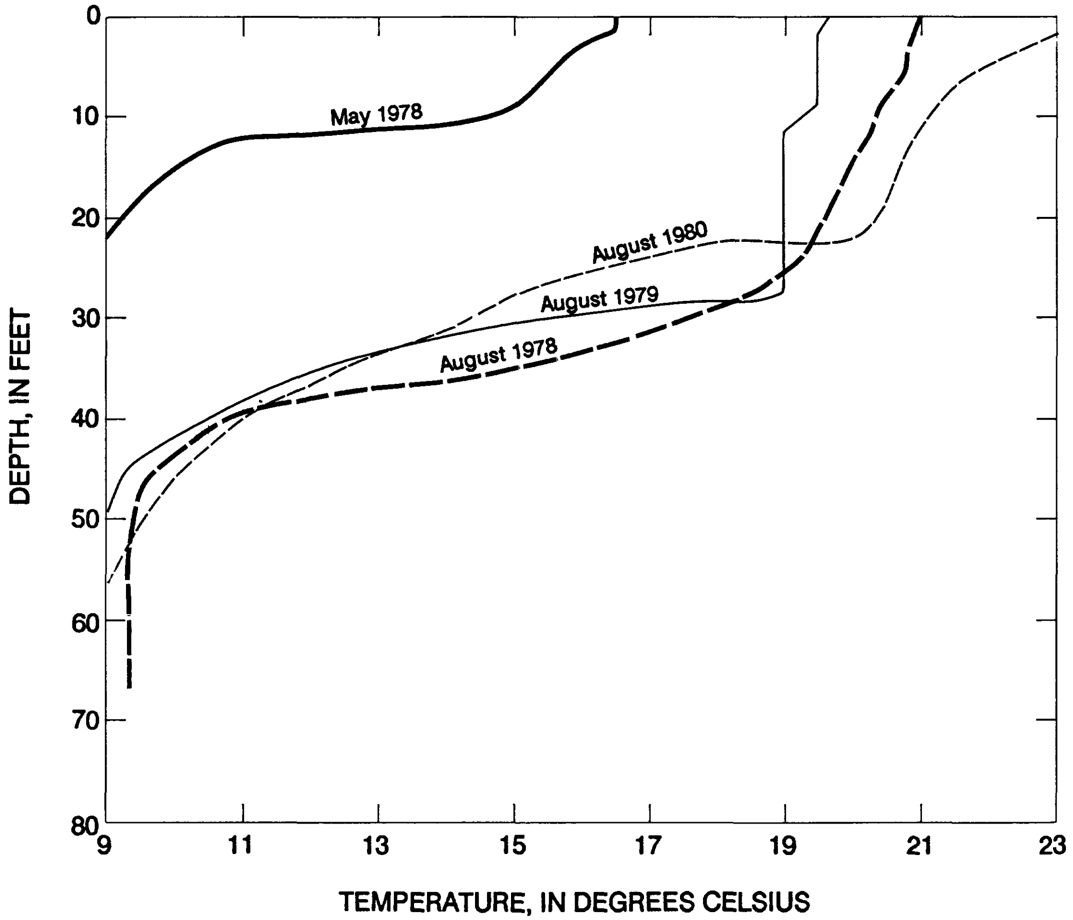


Figure 9.--Vertical temperature profiles for Sand Point Lake, site 6

Sullivan Bay

Site 12 - This site is at the mouth of the Ash River. Depths were shallow, ranging from 6 to 16 ft. The profiles showed nearly uniform temperatures, dissolved-oxygen concentrations, and specific conductance in the water column. An exception was in August 1983 when dissolved-oxygen concentrations declined from 19.6 mg/L at 3 ft below the surface to 3.7 mg/L at 11.5 ft below the surface.

One of the most notable physical characteristics observed at site 12 was the fluctuation in specific conductance between sampling periods. Specific conductance varied from a high of 235 μS/cm in November 1978 to a low of 149 μS/cm during May 1982. The fluctuations may be a result of changing water quality in the Ash River or from varying mixing processes caused by changes in the Ash River discharge.

Site 13 - Site 13 is immediately upstream from the outlet channel of Sullivan Bay. Profiles were measured in water columns that ranged from about 10 to 26 ft in depth.

Temperature profiles ranged from uniform to sharply stratified in both May and August. Thermal stratification was evident in May 1979 when temperatures in the water column were 17.5 ^{o}C at a depth of 9 ft, but were only 9.6 ^{o}C at a depth of 12 ft. Destratification had taken place by the time the August profile was measured, as shown by a uniform 20.5 ^{o}C temperature throughout the water column.

Dissolved-oxygen concentrations were less than 5.0 mg/L in the lower part of the water column when thermal stratification was present during August. Oxygen depletion was severe during August 1982 as indicated by dissolved-oxygen concentrations that were less than 0.5 mg/L in the lower 3 ft of the water column.

Specific conductance changed as much as 50 μS/cm within the water column during stratification. In August, higher-conductivity water was found below the thermocline, but during the single instance of May stratification (1979), the higher-conductivity water (147 μS/cm) was found above the thermocline and water below the thermocline had a conductance of only 84 to 86 μS/cm. The conductance of the water in the bottom layer was well below that measured near the surface at site 12 and site 13 and suggests movement of low-conductivity water from either Kabetogama Lake or Namakan Lake into Sullivan Bay (reverse flow in the outlet channel).

Black Bay

Sites 1, 2, and 16 - These sites are very shallow, ranging from as little as 3.8 ft at site 16 (May 1981) to 8.5 ft at site 1 (May 1979). Temperature, dissolved-oxygen concentrations, and specific conductance were nearly uniform within each profile. The maximum observed change in dissolved-oxygen concentrations with depth was less than 1.0 mg/L, while specific conductance varied only 4 μS/cm. In November 1978, there was a substantial difference in specific conductance between sites 1 and 2. Site 2 had a specific conductance of 85 μS/cm while specific conductance at site 1 was 57 μS/cm. This indicates that water from Black Bay was mixing with water from the main part of Rainy Lake in the Black Bay Narrows at site 1.

Transparency

Mean transparency values are shown in table 4. Transparency varied seasonally as well as annually at some sites. Because of this variation, mean values were calculated separately for May and August data. Data for site 9 (1977-79) and site 17 (1980-83) were combined to provide a long-term record for mid-lake conditions in Kabetogama Lake.

The August transparency data are shown graphically in figure 10. The graph shows that, during August, the lakes fall into three groups: (1) Namakan, Rainy, and Sand Point Lakes are the most transparent, having transparencies that usually are greater than 6 ft; (2) Kabetogama Lake has transparencies that nearly always are between 3 and 6 ft; and (3) Sullivan Bay and Black Bay are the least transparent, having transparencies that usually are less than 3 ft.

Figure 11 shows May transparency data. In May, there was less difference in transparency between the lakes. This is partly because Kabetogama Lake is more transparent during May, whereas Sand Point Lake usually is more transparent during August.

The May transparency data should be evaluated with caution. The measurements were made during a period when the lakes are changing rapidly with respect to algal growth. Because only one measurement was made at each site during May, the value obtained may not be representative of conditions a few days prior to, or just after, the day of measurement.

Table 4.--*Mean Secchi-disk transparency*

[---, not computed]

Lake and Site	Period of record	Mean Secchi-disk transparency (feet)	
		May	August
Namakan			
Site 14	1979-83	10.5	10.5
Site 15	1980-83	10.5	10.5
Rainy			
Site 5	1977-83	---	7.9
	1978-83	8.5	---
Sand Point			
Site 7	1977-83	---	8.2
	1978-83	7.2	---
Kabetogama			
Site 11	1977-83	---	5.2
	1978-83	7.9	---
Sites 9 and 17	1977-83	---	4.9
	1978-83	8.9	---
Site 18	1980-83	8.9	5.6
Sullivan Bay			
Site 12	1979-83	3.3	2.5
Site 13	1979-83	5.2	2.5
Black Bay			
Site 16	1980-83	2.7	2.7

Phytoplankton Populations

Phytoplankton analyses from one or more sites on each major lake and embayment have been compiled in a condensed format in table 5. Table 5 shows cell count along with algal type and name of the dominant algal genera for each sampling. The dominant genera in a sample is any group that comprises 15 percent or more of the total cell count.

The data in table 5 show that the lakes are dominated by populations of either blue-green algae or diatoms most of the time. Green algae were dominant in only three of the samples listed and cryptomonads were dominant in only one sample. Yellow-brown algae, fire algae (dino flagellates) and euglenoids were present in some samples but were never dominant.

During August, the more eutrophic lakes and bays (Kabetogama Lake, Sullivan Bay, and Black Bay) always were dominated by blue-green algae, including, at times, the filamentous genera, Anabaena and Aphanizomenon. This situation also occurred in less eutrophic Sand Point Lake, differentiating it from Rainy Lake and Namakan where diatoms dominated the populations in some of the August samples. In Sand Point Lake, however, the August blue-green populations never exceeded 10,000 cells/mL (cells per milliliter), whereas, in Kabetogama Lake, Sullivan Bay, and Black Bay, blue-green populations always exceeded 10,000 cells/mL in August and frequently exceeded 100,000 cells/mL.

During May, cell counts at all sites shown in table 5 usually were less than 10,000 cells/mL and frequently were less than 1,000 cells/mL. A notable exception occurred in May 1983 when Black Bay and Sullivan Bay had algal populations comprised of the blue-green algae Anacystis that reached and exceeded 10,000 cells/mL.

In Black Bay, Sullivan Bay, and Kabetogama Lake, seasonal fluctuations in phytoplankton cell counts were synchronous, having population densities either rising or falling simultaneously. The relative magnitude of change also was similar, although absolute cell counts during any single sampling ranged over about one order of magnitude between sites. Population fluctuations in Rainy Lake, Sand Point Lake, and Namakan Lake, in contrast, were not synchronous, showing substantial declines in one while the others increased.

The synchronous patterns observed in Black Bay, Sullivan Bay, and Kabetogama Lake occurred from March 1977 through August 1983 with only one exception. Based on the study period, one can conclude that onset of a visible population pulse in any one of these areas likely would be accompanied by a substantial, but not necessarily visible, population pulse in each of the others. The single exception to the observed pattern, and a very interesting one, occurred at site 2 in Black Bay during March 1977. This sample, collected through an ice cover, contained 500,000 cells/mL at a time when the other lakes and bays had counts of less than 3,000 cells/mL. The algal population in the sample was dominated by the blue-green algae Anacystis (48 percent), but also had a codominant group comprised of diatoms, mostly Melosira (28 percent). The results from this sample demonstrated that algal production can be very high, rivaling summer peaks, during late winter conditions under an ice cover.

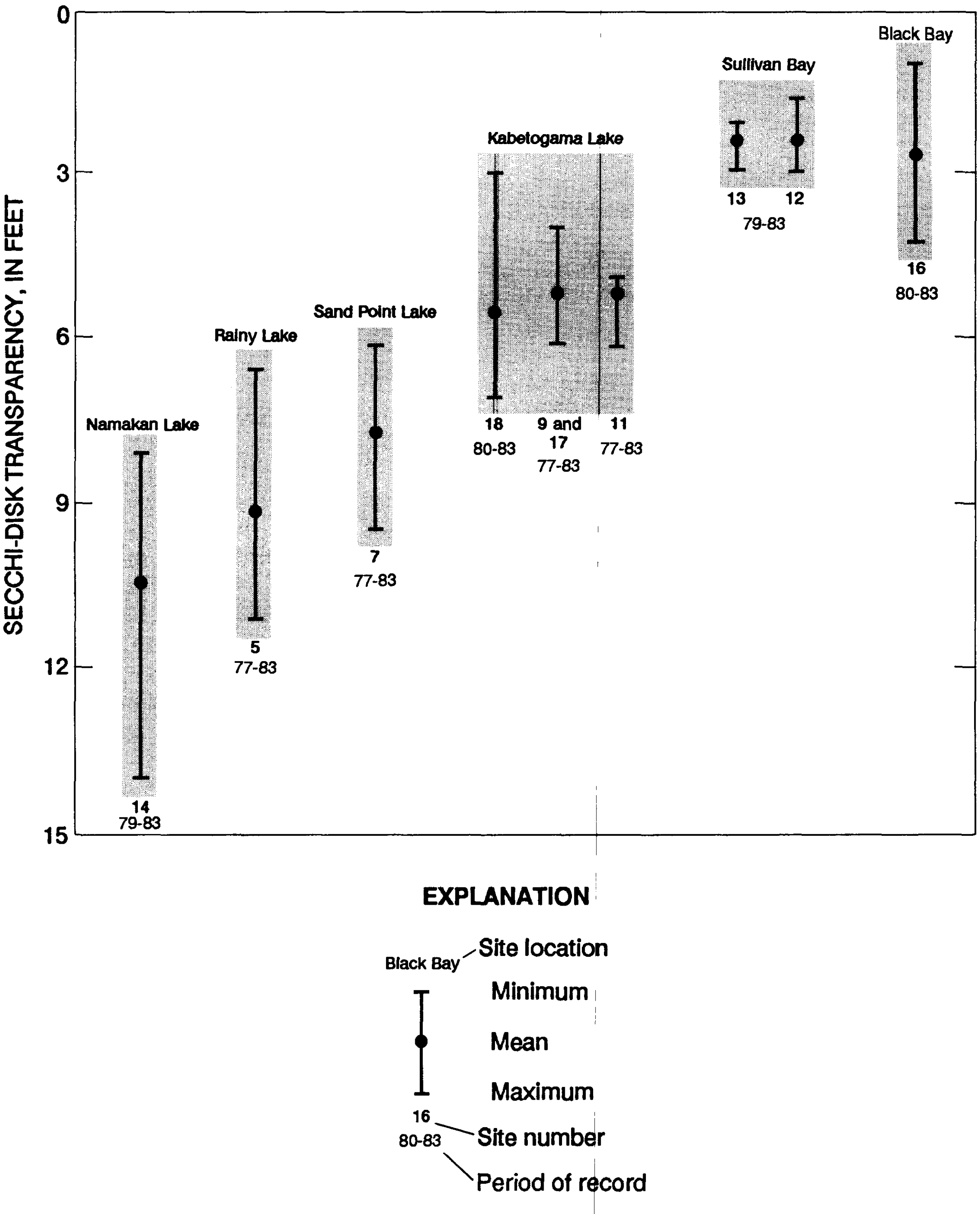


Figure 10.--Range of August transparency values, 1977-83

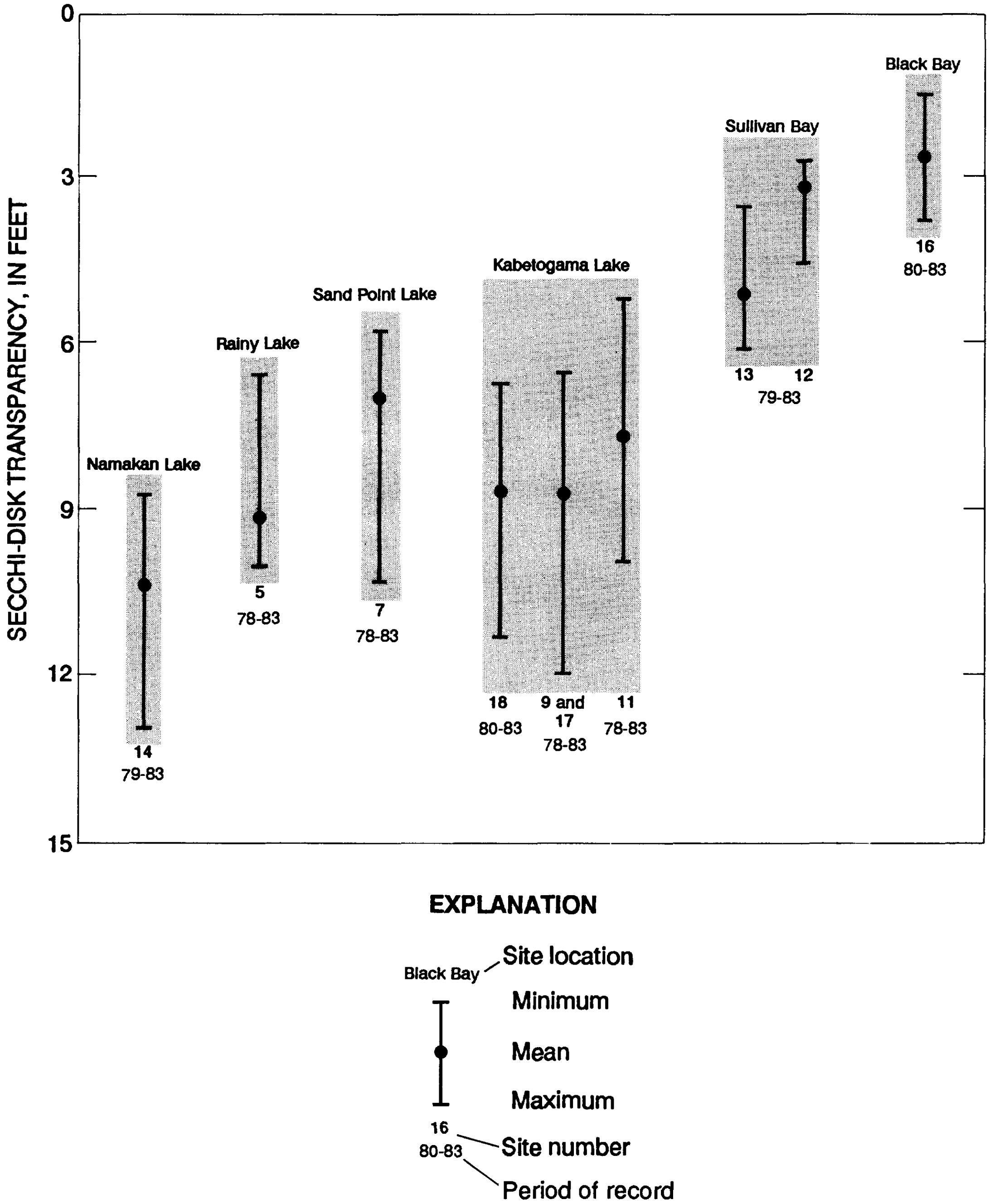


Figure 11.--Range of May transparency values, 1978-83

Table 5.--*Total cell count and dominant organisms in phytoplankton samples*

[---, samples not collected; mL, milliliters]

Date	Total cells per 100 mL	Dominant type	Dominant organism	Date	Total cells per 100 mL	Dominant type	Dominant organism
	Kabetogama Lake site 11				Kabetogama Lake sites 9 and 17		
March 1977	2,300	blue-green	Gomphosphaeria	March 1977	1,800	blue-green	Gomphosphaerium
August 1977	43,000	blue-green	Anacystis	August 1977	14,000	blue-green	Gomphosphaerium
May 1978	1,700	blue-green	Anabaena	May 1978	960	diatoms	Cyclotella
August 1978	48,000	blue-green	Aphanizomenon	August 1978	41,000	blue-green	Aphanizomenon
November 1978	1,300	diatoms	Melosira	November 1978	490	diatoms	Stephanodiscus
May 1979	370	blue-green	Anacystis	May 1979	90	diatoms	Cyclotella
August 1979	59,000	blue-green	Oscillatoria	August 1979	51,000	blue-green	Aphanizomenon
May 1980	5,800	diatoms	Cyclotella	May 1980	13,000	blue-green	Anacystis
August 1980	25,000	blue-green	Anacystis	August 1980	72,000	blue-green	Anabaena
May 1981	450	diatoms, blue-green	Asterionella, Anacystis	May 1981	1,100	diatoms	Stephanodiscus
August 1981	63,000	blue-green	Gomphosphaeria	August 1981	98,000	blue-green	Gomphosphaeria
May 1982	3,900	diatoms	Cyclotella	May 1982	7,800	diatoms	Cyclotella
August 1982	230,000	blue-green	Anabaena	August 1982	270,000	blue-green	Aphanizomenon
May 1983	3,100	blue-green	Anacystis	May 1983	7,200	diatoms	Asterionella
August 1983	32,000	blue-green	Anacystis	August 1983	90,000	blue-green	Anabaena
	Kabetogama Lake site 18				Sullivan Bay site 12		
March 1977	---	---	---	March 1977	---	---	---
August 1977	---	---	---	August 1977	---	---	---
May 1978	---	---	---	May 1978	---	---	---
August 1978	---	---	---	August 1978	---	---	---
November 1978	---	---	---	November 1978	7,400	diatoms	Melosira
May 1979	---	---	---	May 1979	800	blue-green	Anacystis
August 1979	---	---	---	August 1979	72,000	blue-green	Aphanizomenon
May 1980	5,600	diatoms	Cyclotella	May 1980	4,100	chryptomonads	Chroomonas
August 1980	22,000	blue-green	Anabaena	August 1980	200,000	blue-green	Anabaena
May 1981	920	diatoms	Stephanodiscus	May 1981	1,200	blue-green	Oscillatoria
August 1981	73,000	blue-green	Gomphosphaeria	August 1981	190,000	blue-green	Oscillatoria
May 1982	5,200	diatoms	Cyclotella	May 1982	1,500	diatoms	Nitzschia
August 1982	130,000	blue-green	Anabaena	August 1982	430,000	blue-green	---
May 1983	5,800	blue-green	Anacystis	May 1983	10,000	blue-green	Anacystis
August 1983	46,000	blue-green	Oscillatoria	August 1983	140,000	blue-green	Anabaena
	Sullivan Bay site 13				Black Bay sites 2 and 16		
March 1977	---	---	---	March 1977	500,000	blue-green	Anacystis
August 1977	---	---	---	August 1977	210,000	blue-green	Anacystis
May 1978	---	---	---	May 1978	10,000	diatoms	Melosira
August 1978	---	---	---	August 1978	61,000	blue-green	Lyngbya
November 1978	8,900	diatoms	Melosira	November 1978	5,000	diatoms	Melosira
May 1979	3,100	blue-green	Oscillatoria	May 1979	2,000	diatoms	Melosira
August 1979	59,000	blue-green	Oscillatoria	August 1979	430,000	blue-green	Oscillatoria
May 1980	4,000	green	Ankistrodesmus	May 1980	14,000	diatoms	Melosira
August 1980	120,000	blue-green	Anabaena	August 1980	140,000	blue-green	Anacystis
May 1981	3,100	blue-green	Anacystis	May 1981	3,500	diatoms	Melosira

Table 5.--*Total cell count and dominant organisms in phytoplankton samples* --Continued

Date	Total cells per 100 mL	Dominant type	Dominant organism	Date	Total cells per 100 mL	Dominant type	Dominant organism
	Sullivan Bay site 13 --Continued				Black Bay sites 2 and 16 --Continued		
August 1981	320,000	blue-green	Oscillatoria	August 1981	46,000	blue-green	Gomphosphaeria
May 1982	2,200	diatoms	Melosira	May 1982	6,900	diatoms	Melosira
August 1982	160,000	blue-green	Oscillatoria	August 1982	150,000	blue-green	Aphanizomenon
May 1983	26,000	blue-green	Anacystis	May 1983	19,000	blue-green	Anacystis
August 1983	310,000	blue-green	Oscillatoria	August 1983	100,000	blue-green	Anacystis
	Rainy Lake site 5				Namakan Lake site 14		
March 1977	720	green	Dictyosphaerium	March 1977	---	---	---
August 1977	4,400	blue-green	Anacystis	August 1977	---	---	---
May 1978	1,900	diatoms	Melosira	May 1978	---	---	---
August 1978	2,100	diatoms	Fragilaria	August 1978	---	---	---
November 1978	130	diatoms	Melosira	November 1978	2,100	green	Dictyosphaerium
May 1979	320	diatoms	Asterionella	May 1979	680	blue-green	Anacystis
August 1979	970	blue-green	Anacystis	August 1979	94,000	blue-green	Oscillatoria
May 1980	860	diatoms	Melosira	May 1980	1,100	diatoms	Cyclotella
August 1980	1,000	diatoms	Asterionella	August 1980	6,800	blue-green	Anacystis
May 1981	1,900	diatoms	Melosira	May 1981	750	diatoms	Melosira
August 1981	6,800	blue-green	Anacystis	August 1981	14	diatoms	Synedra
May 1982	3,500	diatoms	Melosira	May 1982	1,500	diatoms	Diatoma
August 1982	750	blue-green	Anacystis	August 1982	1,500	diatoms	Diatoma
May 1983	1,700	blue-green	Anacystis	May 1983	7,900	blue-green	Anacystis
August 1983	2,900	blue-green	Anacystis	August 1983	1,500	blue-green	Anacystis
	Sand Point Lake site 7						
March 1977	1,000	blue-green	Gomphosphaeria				
August 1977	9,100	blue-green	Anacystis				
May 1978	1,600	green, bluegreen, diatoms, yellow-brown	No dominant organism				
August 1978	3,800	blue-green	Anabaena				
November 1978	730	blue-green	Anacystis				
May 1979	360	blue-green	Anacystis				
August 1979	2,600	blue-green	Anacystis				
May 1980	1,100	blue-green	Anacystis				
August 1980	4,900	blue-green	Anacystis				
May 1981	570	diatoms	Melosira				
August 1981	4,800	blue-green	Gomphosphaeria				
May 1982	990	blue-green	Anacystis				
August 1982	3,500	blue-green	Anabaena				
May 1983	5,700	blue-green	Anacystis				
August 1983	9,500	blue-green	Gomphosphaeria				

Water Quality of Lakes Relative to Water-Quality Criteria

During August 1980, sampling was undertaken to determine water quality in the Park with respect to established water-quality criteria. Samples were collected and the results were compared to criteria established or recommended by the U.S. Environmental Protection Agency (USEPA) (1972) for drinking water, recreation, and protection of aquatic life.

Sampling was conducted at 10 sites evenly divided between light-use areas and intensive-use areas.

INTENSIVE-USE AREAS	LIGHT-USE AREAS
Kabetogama Lake, site 8	Kabetogama Lake, site 17
Kabetogama Lake, site 19	Namakan Lake, site 14
Ash River at entrance to Sullivan Bay, site 12	Sand Point Lake, site 7
Sand Point Lake, site 6	Rainy Lake at Brule Narrows site 5
Black Bay near Island View, site 2	Black Bay, site 16

Each site was sampled for the following constituents or properties:

Suspended solids
Ammonia, total
Arsenic, total
Fecal <u>Streptococci</u>
Fecal coliform
Barium, total
PCB's, total
Cadmium, total
Chloride, dissolved
Chromium, total
Color
Copper, total
Cyanide, total
Dissolved oxygen
Fluoride, total
Detergents (Methylene-Blue Active Substances)
Iron, dissolved
Mercury, total
Nitrite, dissolved
Nitrate, dissolved
Nickel, total
Sulfide, total
Oil and grease, total
Selenium, total
Sulfate, dissolved
Zinc, total
Carbamate insecticides, total
Chlorinated phenoxy-acid herbicides, total
Organochlorine insecticides, total
Organophosphorus insecticides, total
Triazine herbicides, total
Gross alpha radioactivity, total
Gross beta radioactivity, total
Phenols, total
pH

Nearly all the constituents and properties listed above were found to be within recommended limits. Sites where concentrations of any constituent exceeded the recommended level in August 1980 were resampled during August 1981. Those that exceeded recommended limits in 1980 and the results of resampling were as follows:

Oil and grease--The recommended limit is that water used for public water supply be essentially free of oil and grease. The oil and grease recommendation was exceeded at the following sites (< means less than).

	August 1980	August 1981
Sand Point Lake, site 7	4.0 mg/L	<1.0 mg/L
Kabetogama Lake, site 8	3.0	1.0
Ash River, site 12	1.0	1.0
Kabetogama Lake, site 19	4.0	1.0

Phenols--No more than 1.0 μg/L (micrograms per liter) of phenols is recommended in order to prevent odors in public water supplies. The limit was exceeded at the following sites.

	August 1980	August 1981
Rainy Lake, site 5	6.0 μg/L	1.0 μg/L
Sand Point Lake, site 7	3.0	<1.0
Kabetogama Lake, site 8	6.0	<1.0
Ash River, site 12	5.0	<1.0
Black Bay, site 16	4.0	<1.0
Kabetogama Lake, site 19	4.0	<1.0

Sulfide--In order to protect aquatic life, the recommendation is that total sulfides not exceed 0.002 mg/L. The limit was exceeded at the following sites.

	August 1980	August 1981
Black Bay, site 16	0.2 mg/L	<0.1 mg/L
Black Bay, site 2	0.3 mg/L	<0.1 mg/L
Ash River, site 12	0.2 mg/L	---

Ammonia--Unionized ammonia (NH_3) is recommended not to exceed 0.02 mg/L for protection of freshwater aquatic life. Ammonium (NH_4) was measured in the samples and NH_3 was estimated by use of the ammonium concentrations, field pH, and a conversion chart. The ammonia recommendation was exceeded in the Ash River as follows (> means greater than).

	August 1980	August 1981
Ash River, site 12	>0.12 mg/L	<0.01 mg/L

PCB--Total PCB concentrations should not exceed 0.002 μg/L for protection of aquatic life. This level is lower than the detection limit (0.1 μg/L) of the analytical method used. PCB concentrations exceeded the detection limit in Kabetogama Lake as follows.

	August 1980	August 1981
Kabetogama Lake, site 19	0.1 μg/L	<0.1 μg/L

The results from resampling show that oil and grease and phenols were substantially reduced from levels measured during 1980, but were still detectable at some sites. The ammonia detected at site 12, similarly, had declined to concentrations within recommended limits. Sulfide and PCB concentrations were also found in lower concentrations, but, owing to the detection limits of the analytical methods, it was not possible to determine if concentrations had declined below the recommended levels.

Bottom Material

Bottom material can serve as either a source or sink for numerous constituents found in the overlying waters; including nutrients, natural and manmade organic compounds, and trace metals. Therefore, bottom-material samples were collected during the first 3 years of the study to provide baseline data and to monitor the bottom material for conditions that might indicate impacts of recreational use and waste disposal in the Park.

Review of the data after the third year of study showed that there was a large amount of between- and within-site variability in concentrations of common constituents such as organic carbon, phosphorus, and nitrogen. Considerable between-site variability also was observed in August 1979 when samples were collected for analysis of iron, manganese, and several trace metals.

The variability in results, which ranged over an order of magnitude, may be attributable to difficulty encountered in collecting consistent, representative samples of bottom material. Bottom material at some sites, for example, varied from fine organic material to coarse sand. It was determined that the multiple sampling effort required to obtain sets of a sufficient number of representative samples in order to resolve the within-site variability was beyond the scope and resources of this study. Therefore, bottom-material sampling was discontinued after 1979 and the available resources were reallocated to more adequately define conditions in the overlying waters.

The variability in the data is well illustrated by the results from samples collected during August 1979, which are shown in table 6. Between-site, order-of-magnitude variations are seen for several constituents including total carbon, total nitrogen, iron, and manganese. Some between-site variability would be expected owing to the differing trophic-state, morphometry, and water chemistry between sites, but the large differences between sites and differences within sites observed from 1977 to 1979 suggest that the data are affected by inconsistencies in sample collection and the limitations of analytical methods.

The data in table 6 show that those sites having higher concentrations of total carbon and nitrogen generally also have higher concentrations of trace metals, especially lead, copper, chromium, and arsenic. Bottom-material results are reported on a dry-weight basis, requiring application of a moisture-correction factor. The high concentrations reported for nearly all organic and inorganic constituents within a single sample suggests that difficulty may have occurred in determination of the moisture-correction factor, thereby, affecting the results.

Table 6.--*Results of analyses of bottom-material samples collected from lakes in Voyageurs National Park during August 1979*

[g/kg, grams per kilogram; mg/kg, milligrams per kilogram; µg/g, micrograms per gram; <, less than]

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11	Site 12	Site 13	Site 14
Total carbon (g/kg)..........	98	---	6.9	18	20	82	5.1	20	6.9	9.4	74	28	60	74
Total phosphorus (mg/kg).....	450	590	340	370	290	570	190	440	130	400	950	450	580	2,100
Total nitrogen (mg/kg).......	31,000	33,000	2,200	5,200	6,500	27,000	2,800	2,100	2,110	2,710	40,000	8,000	21,000	24,000
Iron (µg/g)..................	17,000	15,000	63,000	49,000	6,000	27,000	5,500	45,000	25,000	6,000	24,000	11,000	19,000	51,000
Lead (µg/g)..................	<10	<10	<10	<10	20	50	10	30	<10	<10	<10	20	40	50
Copper (µg/g)................	30	30	<10	40	10	30	<10	<10	<10	<10	40	10	70	50
Chromium (µg/g)..............	50	40	10	20	10	40	<10	10	<10	10	50	20	30	40
Arsenic (µg/g)...............	4	3	1	1	1	7	1	1	0	1	5	1	5	15
Cobalt (µg/g)................	<10	<10	<10	<10	<10	50	<10	<10	<10	<10	<10	20	<10	50
Cadmium (µg/g)...............	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Mercury (µg/g)...............	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Nickel (µg/g)................	<10	---	<10	<10	<10	<10	<10	<10	<10	10	<10	20	40	50
Manganese (µg/g).............	350	520	240	160	180	900	380	270	240	320	11,000	350	520	7,000
Zinc (µg/g)..................	100	90	20	30	30	170	20	20	<10	10	90	40	90	120

Refer to table 1 for lake names corresponding to site numbers.

Examination of the data in table 6 shows that sites 6, 14, 11, 13, 1, and 2 have elevated trace-metal concentrations in comparison to the remaining sites where trace-metal concentrations were, in most instances, reported as lower than the detection limits of the analytical method.

Selected Constituents for Continued Monitoring

The data collected for this study during 1977 through 1983 will serve as a baseline for comparison with results from future water-quality monitoring. It will be desirable to compare future results with minimum, maximum, median, and mean results from the baseline period.

In order to facilitate making comparisons, tables 7-9 show the results for selected constituents. Constituents were selected on the basis of length of record and their value as key indicators of water quality. Emphasis was placed on selecting indicators that can be measured by use of field instruments.

The values in the tables have applications other than time and trend monitoring. For example, the wide differences in total alkalinity between Namakan Lake, Kabetogama Lake, and Sullivan Bay can be used to gain more information about the mixing patterns of these waters in the vicinity of Meadwood Bay and the outlet of Sullivan Bay. During periods of high flow in the Ash River, the areal impact of the Ash River inflow could be traced by a series of alkalinity measurements along the various flow paths into Kabetogama Lake and Namakan Lake. Furthermore, comparison with the baseline data will show the impact of the high-flow period relative to conditions during the 7-year baseline period.

May and August minimums, maximums, medians, means, and standard deviation were computed separately for total phosphorus and Secchi-disk transparency because of their seasonal variability.

The number of observations in the data sets is small because sites were sampled only twice each year and some sites were not sampled throughout the study period. Extensive statistical testing of mean and median values to determine significance of the apparent differences between and within sites was not undertaken except for sites 9 and 17 in Kabetogama Lake.

As shown in tables 8 and 9, data for site 9 were combined with data for site 17 to provide a data set for Kabetogama Lake that spanned the entire period of study. It was expected that sites 9 and 17 would have similar characteristics owing to their close proximity. A series of parametric and nonparametric tests of the mean and median values for each site were conducted before combining the data from each site into one data set. The tests showed that there was no significant difference between the sites with respect to mean values for specific conductance, total phosphorus, and total alkalinity. On this basis, it was deemed appropriate to combine the data into one data set so that Kabetogama Lake could be compared with Sand Point and Rainy Lakes over a corresponding time period encompassing the entire study period.

Table 7.--*Minimum, maximum, median, mean, and standard deviation for measurements of specific conductance and total alkalinity*

[Values for specific conductance are in microsiemens per centimeter at 25 degrees Celsius. Values for total alkalinity are in milligrams per liter]

Lake	Number of observations	Minimum	Maximum	Median	Mean	Standard deviation
	Specific Conductance					
Sullivan Bay, site 12	11	150	235	181	182	27
Sullivan Bay, site 13	11	132	207	153	157	23
Black Bay, site 16	8	77	100	92	91	8.1
Kabetogama Lake, site 17	8	83	105	88	89	6.9
Kabetogama Lake, site 9	7	78	100	90	89	7.1
Kabetogama Lake, site 18	8	76	107	84	86	9.6
Kabetogama Lake, site 11	15	60	108	77	79	15
Sand Point Lake, site 7	15	43	70	52	52	6.7
Namakan Lake, site 15	8	41	62	45	47	6.5
Namakan Lake, site 14	12	40	68	42	44	7.6
Rainy Lake, site 5	15	32	58	43	44	5.8
	Total Alkalinity					
Sullivan Bay, site 12	11	71	112	91	90	14
Sullivan Bay, site 13	11	60	102	73	77	13
Black Bay, site 16	8	31	49	42	41	6.2
Kabetogama Lake, site 17	8	34	49	39	40	4.8
Kabetogama Lake, site 9	7	35	48	40	40	4.4
Kabetogama Lake, site 18	8	34	47	36	38	4.5
Kabetogama Lake, site 11	15	25	72	34	37	12
Sand Point Lake, site 7	15	13	21	18	17	2.2
Namakan Lake, site 15	8	15	18	16	17	1.1
Namakan Lake, site 14	12	13	21	15	15	2.3
Rainy Lake, site 5	15	5	18	15	15	3.0

Table 8.--*Minimum, maximum, median, mean, and standard deviation for measurements of Secchi-disk transparency*

[All values are in feet]

Lake	Number of observations	Minimum	Maximum	Median	Mean	Standard deviation
Sullivan Bay, site 12						
May....................	5	2.8	4.6	3	3.3	0.7
August.................	5	1.6	3	2.6	2.5	.6
Sullivan Bay, site 13						
May....................	5	3.6	6.2	5.6	5.2	1
August.................	5	2.1	3	2.3	2.5	.3
Kabetogama Lake, sites 9 and 17						
May....................	6	6.6	12.1	8.5	8.9	1.9
August.................	7	3	6.2	5.2	4.9	1.1
Kabetogama Lake, site 11						
May....................	6	5.2	10.2	7.9	7.9	1.6
August.................	7	3.6	6.2	5.6	5.2	.8
Sand Point Lake, site 7						
May....................	6	5.9	10.5	6.6	7.2	1.7
August.................	7	6.2	9.5	8.2	8.2	1.1
Rainy Lake, site 5						
May....................	6	6.6	11.2	8.2	8.5	1.7
August.................	7	4.3	11.2	8.5	7.9	2.2
Namakan Lake, site 14						
May....................	5	8.9	13.1	9.5	10.5	1.9
August.................	5	8.2	14.1	9.5	10.5	2.1

Table 9.--*Minimum, maximum, median, mean, and standard deviation for analyses of total-phosphorus concentrations*

[All values are in micrograms per liter]

Lake	Number of observations	Minimum	Maximum	Median	Mean	Standard deviation
Sullivan Bay, site 12						
May....................	5	21	35	28	28	5.7
August.................	5	37	105	51	61	26
Sullivan Bay, site 13						
May....................	5	16	33	20	23	8.5
August.................	5	24	86	82	64	27.3
Kabetogama Lake, sites 9 and 17						
May....................	6	12	45	20	23	12
August.................	7	30	63	44	45	13
Kabetogama Lake, site 11						
May....................	6	8	29	16	17	8.4
August.................	7	23	50	30	32	10
Sand Point Lake, site 7						
May....................	6	13	26	19	19	4.6
August.................	7	13	30	18	18	5.8
Namakan Lake, site 14						
May....................	5	10	20	12	14	4.7
August.................	5	7	18	12	12	3.9
Rainy Lake, site 5						
May....................	6	5	16	12	11	3.8
August.................	7	7	20	9	11	4.5

Testing of data within the Kabetogama data set showed that seasonal differences (May versus August) were significant for the primary trophic-state indicators (total phosphorus, Secchi-disk transparency, and chlorophyll *a*).

TROPHIC STATE

Trophic-State Indices

Trophic-state indices (TSI) were computed using the equations developed by Carlson (1977). Carlson's index is a numeric trophic scale intended to represent the amount of algal biomass in surface waters. Each 10-unit increase in the scale represents a doubling of algal biomass. The numeric values are calculated using the following equations:

$$TSI\ TP = 14.42\ (\ln TP) + 4.15$$
$$TSI\ SD = 60 - 14.41\ (\ln SD)$$
$$TSI\ CHL = 9.81\ (\ln CHL) + 30.6$$

where:

TSI TP = Trophic-state index based on total phosphorus concentration,
TSI SD = Trophic-state index based on Secchi-disk transparency,
TSI CHL = Trophic-state index based on chlorophyll *a* concentration,
TP = Total phosphorus concentration, in μg/L,
SD = Secci-disk transparency, in meters;
CHL = Chlorophyll *a* concentration, in μg/L.

The mean spring and summer TSI values for each site are shown in table 10. The mean values shown were computed from 1980-83 data. This period was chosen because chlorophyll *a* data, along with corresponding total-phosphorus and Secchi-disk data, were available throughout the period.

Table 10.--*Mean spring and summer trophic-state index values, 1980-83*

Site	TSI CHL		TSI TP		TSI SD	
	May	August	May	August	May	August
Sullivan Bay, site 12	46	65	52	63	61	65
Sullivan Bay, site 13	45	64	50	62	54	64
Kabetogama Lake, site 17	43	63	50	60	46	56
Black Bay, site 16	49	60	57	62	63	65
Kabetogama Lake, site 18	44	57	46	51	46	53
Kabetogama Lake, site 11	42	55	46	52	48	53
Rainy Lake, site 5	40	39	38	34	45	45
Namakan Lake, site 14	41	37	42	39	43	43
Sand Point Lake, site 7	42	36	47	44	49	46
Namakan Lake, site 15	40	32	42	34	44	43

The TSI CHL values were selected as the primary indicators of trophic state because they are based on direct measurements of chlorophyll *a*, which results from primary productivity in the water column. A good case can be made for using TSI TP as a base indicator because it is a measurement of the level of nutrient enrichment, but this discussion will focus on the end result of that enrichment, algal productivity, which, depending on its level, may be an asset or detriment to lakes in the Park. TSI SD will be considered as a secondary trophic-state indicator because, as will be shown later in this discussion, Secchi-disk transparency in the Park is, at times, affected by factors not directly related to either nutrient enrichment or algal productivity.

Relation of Nutrients to Productivity

The sites in table 10 are listed from top to bottom in decreasing order of trophic state as determined by August TSI CHL. Note that the sites would be ranked in a slightly different order if TSI TP or TSI SD had been used. For example, if TSI SD had been used, Black Bay would have ranked first or second and numerically close to the Sullivan Bay sites, whereas Kabetogama Lake site 17 would be a distant fourth, having a numeric TSI closer to that of the other Kabetogama Lake sites. Some of the differences between TSI CHL, TSI TP, and TSI SD can be attributed to the usual errors introduced during sampling and laboratory analysis, but consistent patterns and trends in the observed differences between and within the three trophic-state indicators can serve to alert the investigator to conditions or processes that are affecting the lakes.

Some of these processes are indicated by examining the change in TSI between May and August. The TSI CHL values for Sullivan Bay, Black Bay, and Kabetogama Lake indicate a strong increase in trophic state from May to August. The change also is seen in TSI TP values, but the magnitude of change is about half of that observed in TSI CHL. In addition, comparison of corresponding seasonal values of TSI CHL with TSI TP indicate that May values of TSI CHL are appreciably less than TSI TP, whereas August values of TSI CHL are more nearly the same as TSI TP. These observations support the hypothesis that, in these lakes, spring chlorophyll production does not reach the potential provided by the nutrient supply. By August, however, chlorophyll production is more nearly in agreement with production expected from the total phosphorus values except at sites 11 and 18 in Kabetogama Lake. At sites 11 and 18 algal productivity appears to exceed the potential indicated by the phosphorus values. The observed pattern of productivity agrees with expected low response of algal populations during May owing to limitation of growth caused by suboptimal temperatures and, perhaps, suboptimal solar energy input. The data indicate that, during August, algal populations make full use of the phosphorus supply and that phosphorus is under-utilized during May.

The TSI values for Sand Point, Namakan, and Rainy Lakes, however, provide sharp contrast to the responses observed in Sullivan Bay, Black Bay, and Kabetogama Lake. In Sand Point, Namakan, and Rainy Lakes, the large increase in chlorophyll production from May to August was not observed. August TSI CHL values indicate a drop in productivity, ranging from a slight change in Rainy Lake to a change of 8 TSI units in Namakan Lake. The decrease also is seen in the TSI TP values.

In further contrast to Sullivan Bay, Black Bay, and Kabetogama Lake, May TSI CHL values do not fall greatly short of TSI TP values, and in Rainy and Namakan Lakes, TSI CHL closely approximates TSI TP. During August, TSI CHL fell short of the potential indicated by TSI TP in Sand Point Lake, approximately equaled potential in Namakan Lake, and exceeded potential in Rainy Lake.

The data seem to indicate that, on the average, total phosphorus concentrations in Sand Point, Namakan, and Rainy can be expected to decline between May and August and that chlorophyll *a* production will drop accordingly. The effect, however, will be much less in Rainy Lake than in Sand Point or Namakan. Much of what was observed in Rainy, Sand Point, and Namakan Lakes can be explained by the onset of continuous thermal stratification during summer. When stratification persists, particulate phosphorus can be lost from the epilimnion as algal cells die and settle through the thermocline. The profile data show that stratification is not continuous in Sullivan Bay, Black Bay, and Kabetogama Lake and the trophic-state data show that, in these lakes, total phosphorus concentrations and productivity do not decline.

TSI SD, as mentioned previously, appears to be affected by factors not directly related to chlorophyll production. In Black Bay, Rainy, Sand Point, and Namakan, TSI SD is consistently higher than TSI CHL during both May and August, suggesting that something other than algal density is limiting light penetration.

Black Bay is a large, shallow, wind-swept water body. Observations made during sampling indicated that wave action is sufficient to resuspend fine particles in the bottom material. This material clogged the filters used in processing samples and its presence likely reduced Secchi-disk readings.

Sand Point, Namakan, and Rainy Lakes are noticably colored owing to the presence of natural organic substances contributed from bogs, fens, and peatlands. These substances likely reduced Secchi-disk readings in Sand Point, Namakan, and Rainy Lakes.

In Sullivan Bay, TSI SD is similar to TSI CHL during August, but during May, TSI SD is higher than TSI CHL, suggesting that light penetration during May is limited by some factor other than algae. The higher TSI SD values at site 12 (mouth of Ash River) relative to site 13 (outlet of Sullivan Bay) suggests that fine sediments carried by the spring freshets in the Ash River may contribute to the low Secchi-disk readings during May.

In Kabetogama Lake, TSI SD appears to be a fairly good estimator of TSI CHL during both May and August, especially at sites 17 and 18. At Kabetogama Lake site 11, May TSI SD was higher than TSI CHL. As discussed in a previous section, the profile data suggest that Namakan Lake water mixes with Kabetogama Lake water at site 11. The colored water from Namakan Lake may be affecting Secchi-disk readings at site 11.

Seasonal Changes and Trends

The preceding discussion was based on data collected during 1980-83, when chlorophyll data were available for comparison with phosphorus and Secchi-disk data. Phosphorus and Secchi-disk data, however, were collected before 1980, and examination of these data provides an opportunity to examine conditions in the lakes since 1977.

Three sites have total-phosphorus and Secchi-disk data from 1977-83; Rainy Lake site 5, Sand Point Lake site 7, and Kabetogama Lake site 11. In addition, the period of record for Kabetogama Lake site 17 can be extended back to 1977 by use of data for Kabetogama Lake site 9 (1977-79), which is very near site 17. The period of record for TSI TP at Namakan Lake site 15, similarly, can be extended by using data for Rainy Lake below Kettle Falls, site 3, located a short distance below site 15 in flowing water coming out of Namakan Lake.

TSI TP results for the 1977-83 period are shown in figure 12. The differences in trophic state between the lakes are obvious when the data are shown graphically, especially during the summer peaks in Kabetogama Lake when TSI TP greatly exceeds values in the other lakes. It is interesting to note, however, that in some years spring TSI TP values in Kabetogama fell to values equal to those in Sand Point Lake and, during 2 years, were nearly as low as values in Namakan and Rainy Lakes. In all these instances, summer TSI TP rose sharply, greatly exceeding the corresponding values in Rainy, Namakan, and Sand Point and lending support to the possible occurrence of internal phosphorus loading during summer in Kabetogama Lake.

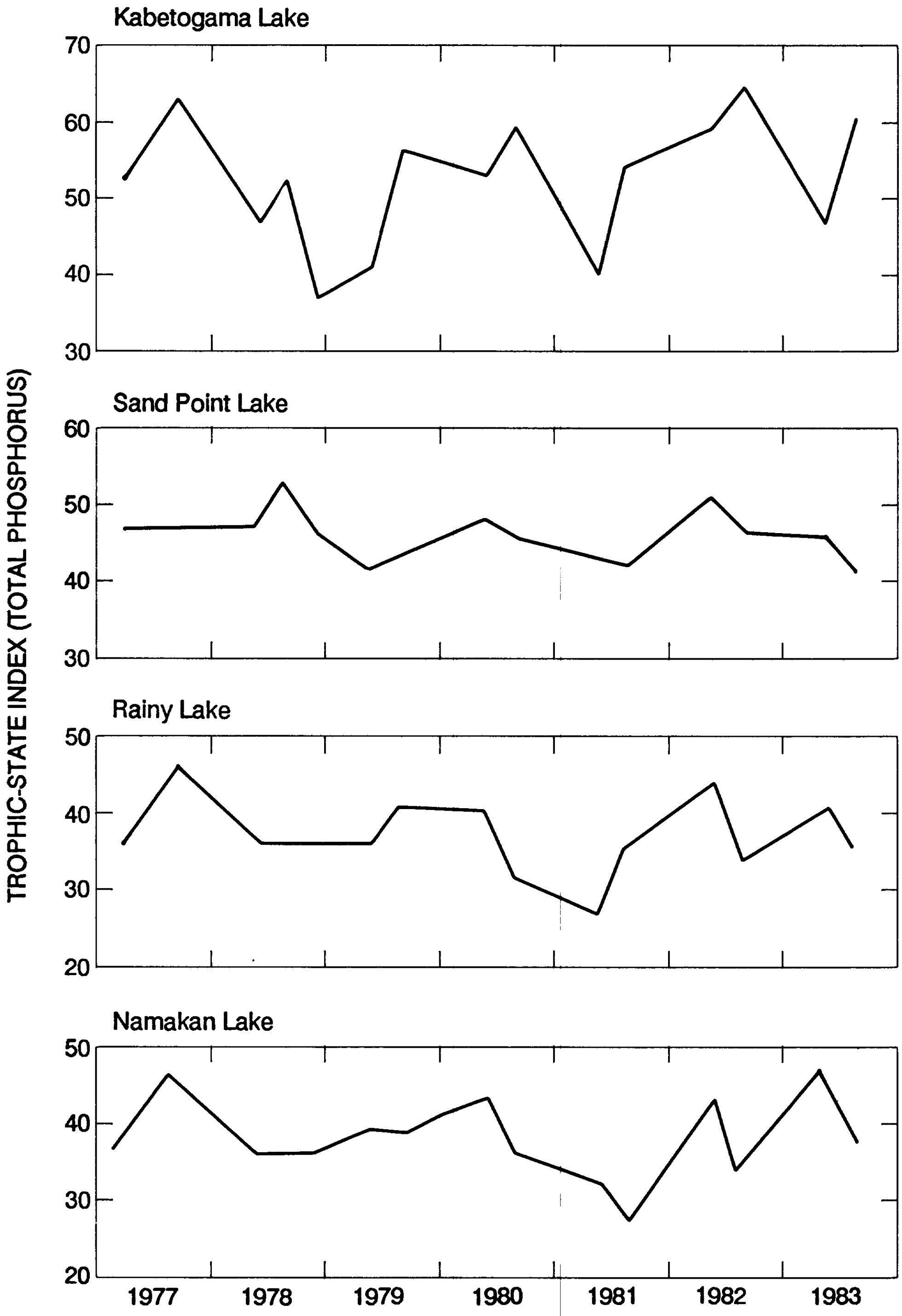


Figure 12.--Total phosphorus trophic-state indices, 1977-83

Long-term trends in TSI are not apparent from the data shown in the graph. Values for Kabetogama Lake, however, exceeded the median value more frequently during the second half of the study period than during the first half.

Some short-term trends affecting all four lakes are shown in the graphs. These are periods of peaks and declines that appear to be synchronous for all the lakes and involve peak values during 1977, 1980, and 1982, and low values during May 1979 and May 1981. These short-term trends suggest external influences common to all the lakes and acting simultaneously, such as climate and weather variables.

TSI SD values for 1977-83 are shown graphically in figure 13. As discussed in the previous section, TSI SD is an imprecise indicator of algal productivity and nutrient levels in these lakes. Transparency is important, nonetheless, in that visitor perception and judgment of water quality in the Park likely is influenced to a greater extent by water clarity than by other factors. Transparency, then, may be the best indicator of water quality from the perspective of a Park visitor.

The TSI SD data for Kabetogama Lake shown in figure 13 reflect the sharp, annual decreases in summer transparency, which correspond to the annual summer increases in chlorophyll *a* productivity. Examining August values only, TSI SD increased gradually during the period of study. From 1977 through 1981 the increase was so small that the change would not be perceptible to a casual observer. The abrupt increase during 1982, however, which represents nearly a halving of the Secchi-disk transparency, likely was noticable.

In Namakan Lake at site 14, there was a 3-year period from November 1978 to August 1981 when transparency steadily increased. The increase in transparency is reflected in the graph of TSI SD shown in figure 13. The 3-year trend was abruptly reversed between August 1981 and May 1982 when transparency decreased sharply. By August 1982, TSI SD had risen to the level that existed at the start of the 3-year decline. TSI TP for the 3-year period does not follow the steadily declining trend and, in fact, shows a significant rise during the middle part of the period (fig. 12). This suggests that the trend in transparency was not related to a declining total-phosphorus supply. Chlorophyll data are not available for the first half of this period, so it is uncertain whether the increase in transparency was closely related to a decline in algal productivity. The period 1980-83 shows that during May 1981, August 1982, and August 1983 transparency was not well correlated with algal productivity, suggesting that the 3-year trend may have been influenced by some other factor such as a change in the amount of organic color.

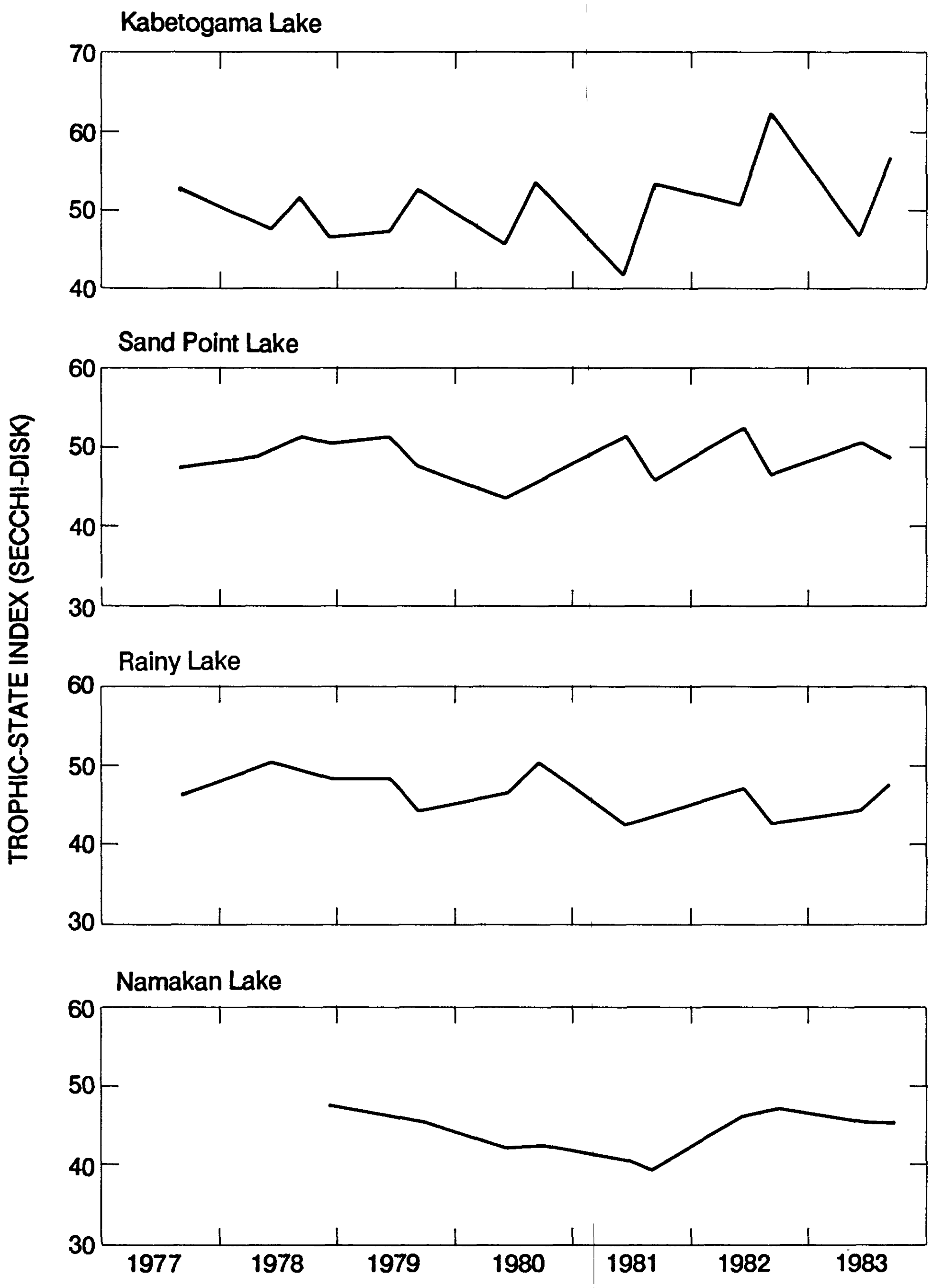


Figure 13.--Secchi-disk trophic state indices, 1977-83

RECONNAISSANCE OF INTERIOR LAKES AND INFLOWS

Interior Lakes

Nineteen interior lakes were sampled from 1982 through 1984. Each lake was sampled twice, once during May and once during August. The purpose of the sampling was to determine water chemistry, trophic state, and physical characteristics on a reconnaissance basis.

Water Chemistry

Water-chemistry investigations included determination of alkalinity, major ions, and nutrient concentrations. Trophic state was determined by analyzing for chlorophyll *a*, total phosphorus, and by measuring Secchi-disk transparency. Determination of physical characteristics included measurement of temperature, specific conductance, and dissolved oxygen in vertical profiles.

The distribution of dissolved-solids concentrations for the interior lakes is shown in table 11. The results range from 16 mg/L for Cruiser Lake to 48 mg/L for Shoepack Lake. Namakan and Rainy had the lowest dissolved solids (49 mg/L mean concentration) of the four large lakes in the Park, but all the interior lakes that were sampled had less dissolved solids than Rainy and Namakan.

Table 12 shows relative proportions, expressed as percentages, of the major cations--calcium, magnesium, sodium, and potassium--for each lake. The data were compiled from the May sampling periods. Data for the large lakes--Rainy, Namakan, Sand Point, Kabetogama, and Black Bay--are shown also for comparison.

Little Trout, Mukooda, and O'Leary closely resemble the large lakes, differing mainly in having lower calcium to magnesium ratios. The other interior lakes, however, had proportionately about twice as much sodium and potassium in comparison to Little Trout, Mukooda, O'Leary, and the large lakes and lower proportions of calcium and magnesium.

The results of total alkalinity determinations for the interior lakes are shown in table 11. For all but three of the interior lakes, alkalinities were in a narrow range between 4.1 and 13 mg/L. Only Little Trout, Mukooda, and O'Leary had alkalinities greater than the mean for Rainy and Namakan, which had the lowest alkalinities of the four large lakes in the Park.

Table 11.--*Dissolved solids and total alkalinity concentrations for interior lakes, from May and August samples collected 1982-84*

[Values are in milligrams per liter]

Lake	Dissolved solids			Alkalinity		
	May	August	Change May to August	May	August	Change May to August
1982						
Locator	32	34	+2	4.9	4.1	-0.8
Shoepack	48	46	-2	4.9	4.1	-.8
Cruiser	17	16	-1	6.6	6.6	0
Oslo	30	32	+2	6.6	6.6	0
O'Leary	42	48	+6	28	30	+2.0
Mukooda	38	44	+6	27	29	+2.0
1983						
Peary	22	35	+13	9.8	13	+3.2
Little Trout	22	28	+6	16	16	0
Lucille	39	24	-15	6.9	8.2	+1.3
Jorgens	18	35	+17	7.9	12	+4.1
Little Shoepack	27	41	+14	6.7	8.2	+1.5
Beast	47	33	-14	5.9	7.4	+1.5
1984						
Quill	41	38	-3	8.2	6.9	-1.3
Loiten	38	36	-2	8.4	8.2	-.2
War Club	42	38	-4	7.0	6.4	-.6
Ryan	46	32	-14	8.5	8.0	-.5
Brown	32	26	-6	7.9	7.4	-.5
Tooth	39	30	-9	11	11	0
Ek	40	32	-8	10	8.2	-1.8

Table 12.--*Major cations, relative proportions expressed as percentage of total cations, from samples collected in interior lakes during May 1982-84*

Lake	Percent calcium	Percent magnesium	Percent sodium	Percent potassium	Calcium to magnesium ratio
Locator	45	33	17	5	1.36
Shoepack	42	33	18	7	1.27
Beast	43	29	21	7	1.48
War Club	48	32	15	5	1.50
Cruiser	49	29	16	6	1.69
Lucille	47	28	21	4	1.68
Little Shoepack	46	28	21	5	1.64
Brown	46	30	18	6	1.53
Oslo	42	33	19	6	1.27
Quill	47	32	15	6	1.47
Ryan	51	30	14	5	1.70
Loiten	47	32	15	6	1.47
Jorgens	45	28	20	6	1.64
Ek	49	31	15	5	1.58
Peary	46	31	18	5	1.48
Tooth	46	35	14	5	1.31
Little Trout	53	34	10	3	1.56
Mukooda	49	39	9	3	1.29
O'Leary	51	38	8	3	1.34
Major lakes and bays, mean values					
Rainy	59	27	12	3	2.21
Namakan	58	26	13	4	2.27
Sand Point	57	30	10	4	1.81
Kabetogama	58	35	6	2	1.66
Black Bay	58	33	7	2	1.79

The MPCA (Minnesota Pollution Control Agency) has used total-alkalinity values as a basis for determining sensitivity to acid precipitation. In their report to the Legislative Commission on Minnesota Resources (Minnesota Pollution Control Agency, 1982), they presented a classification system that combined features of systems developed by Conroy and others (1974) and Glass and Louck (1980). The resulting classification system is as follows:

<u>ACIDIFIED LAKES</u> (A) - Lakes with alkalinity values less than 0.0 are considered to be acidified. The pH of an acidified lake is typically less than 5.0 and such lakes will have severely stressed fish populations. Many species may be absent or, in extreme cases, the lake may be completely without fish. Acidified lakes will be very clear. Many other aquatic organisms such as mollusks, snails, amphibians, and insects may be absent.

<u>NATURALLY ACIDIC</u> (NA) - Highly "colored" lakes may be naturally acidic due to the presence of natural organic acids that are produced in bogs, fens, and peatlands. These organic acids are responsible for the tea-stained color in such lakes. In the absence of reliable historical data, colored lakes (greater than 20 platinum-cobalt units) with alkalinity values less than or equal to 0.0 are classified as naturally acidic (NA) to indicate that their current condition may be natural. However, colored lakes are not immune to the effects of acid deposition. Colored lakes that have a measurable alkalinity are highly sensitive to additional acid inputs.

<u>EXTREMELY SENSITIVE</u> (ES) - Lakes with alkalinity values greater than 0.0 but less than or equal to 5.0 mg/L as $CaCO_3$ (100 μeq/L (micro-equivalents per liter) are considered to be extremely sensitive. The pH and chemical content of these lakes is probably healthy enough to support aquatic species indigenous to the lake. Such lakes will likely lose their alkalinities and become acidified with continued or increased acid loadings. Eposodic pH depression may occur during snowmelt which could lead to stressed fish populations and, in extreme cases, missing year classes.

<u>MODERATELY SENSITIVE</u> (MS) - Moderately sensitive lakes have alkalinity values greater than 5.0 but less than or equal to 10.0 mg/L as $CaCO_3$ (200 μeq/L). Some moderately sensitive lakes likely will be affected by continued long-term acidic deposition at current or increased levels. Some problems may occur in these lakes but aquatic species generally are at less risk than in extremely sensitive lakes.

<u>POTENTIALLY SENSITIVE</u> (PS) - These lakes have alkalinity values greater than 10.0 but less than or equal to 20.0 mg/L as $CaCO_3$ (400 μeq/L). Certain of these lakes may be affected by long-term deposition at current levels, but most may not show any effects unless acid loadings increase in the future.

<u>NON-SENSITIVE</u> (NS) - These lakes have alkalinity values greater than 20.0 mg/L as $CaCO_3$ and are thought to contain enough buffering capacity to neutralize acidic deposition for an indefinte period of time.

Application of the data in table 11 to the criteria given in the classification system reveals that 13 of the interior lakes can be classified moderately sensitive and that two of the lakes, Locator and Shoepack, are extremely sensitive. Of the remaining four lakes, Tooth and Little Trout are potentially sensitive, and only Mukooda and O'Leary can be classified as nonsensitive.

The authors of the MPCA report caution that the classification system will assign improper sensitivities to some lakes, and state that hydrology and soils of an individual lake and its watershed must be considered when classifying a lake. This is demonstrated by comparing historical data for Tooth Lake. During 1973, the Minnesota Department of Natural Resources measured a total alkalinity of 32 mg/L in Tooth Lake, which would classify Tooth as nonsensitive. Alkalinity measurements in 1978 and 1984, however, gave results of 9.1 and 11 mg/L, respectively, placing Tooth Lake in the moderately sensitive to potentially sensitive categories. Similar results for Loiten and Locator are shown in the following data.

Lake	*Year*	*Alkalinity*
Tooth	1973	32 mg/L
	1978	9.1
	1984	11
Loiten	1970	18
	1978	5.6
	1984	8.4
Locator	1970	15
	1978	5.2
	1982	4.9

The data shown above suggest that Tooth, Loiten, and Locator Lakes have undergone significant reductions in total alkalinity since the early 1970's. However, the 1973 data may not be directly comparable to later measurements owing to use of different methods of measuring alkalinity.

Figure 14 shows an empirical relationship between pH and calcium concentration that was developed by Henriksen (1979). Lakes that plot above the line have a lower pH than expected, based on their calcium concentrations. Figure 14 shows that both May and August data for Quill, Loiten, War Club, Ek, and Brown plot above the line. Data for Ryan and Shoepack plot above the line only during May. The shift to higher pH during August in these lakes may be a result of phytoplankton removing CO_2 from the water during photosynthesis, causing a shift in the carbonate equilibrium.

Almer and others (1978) have shown that lakes should have a 1:1 relationship between the sum of calcium plus magnesium and alkalinity. They proposed that lakes having an excess of calcium and magnesium show the effect of excess leaching of these cations from the watershed. Figure 15 shows a plot of alkalinity versus calcium plus magnesium for the interior lakes. All the lakes generally exceeded a 1:1 relationship during May, ranging from about 1.0:1 in Mukooda Lake to 2.3:1 in Locator Lake. The ratios were different in some of the lakes during August. Peary Lake, for example, had a 0.8:1 ratio, while Locator Lake had an even greater ratio during August than during May (2.8:1).

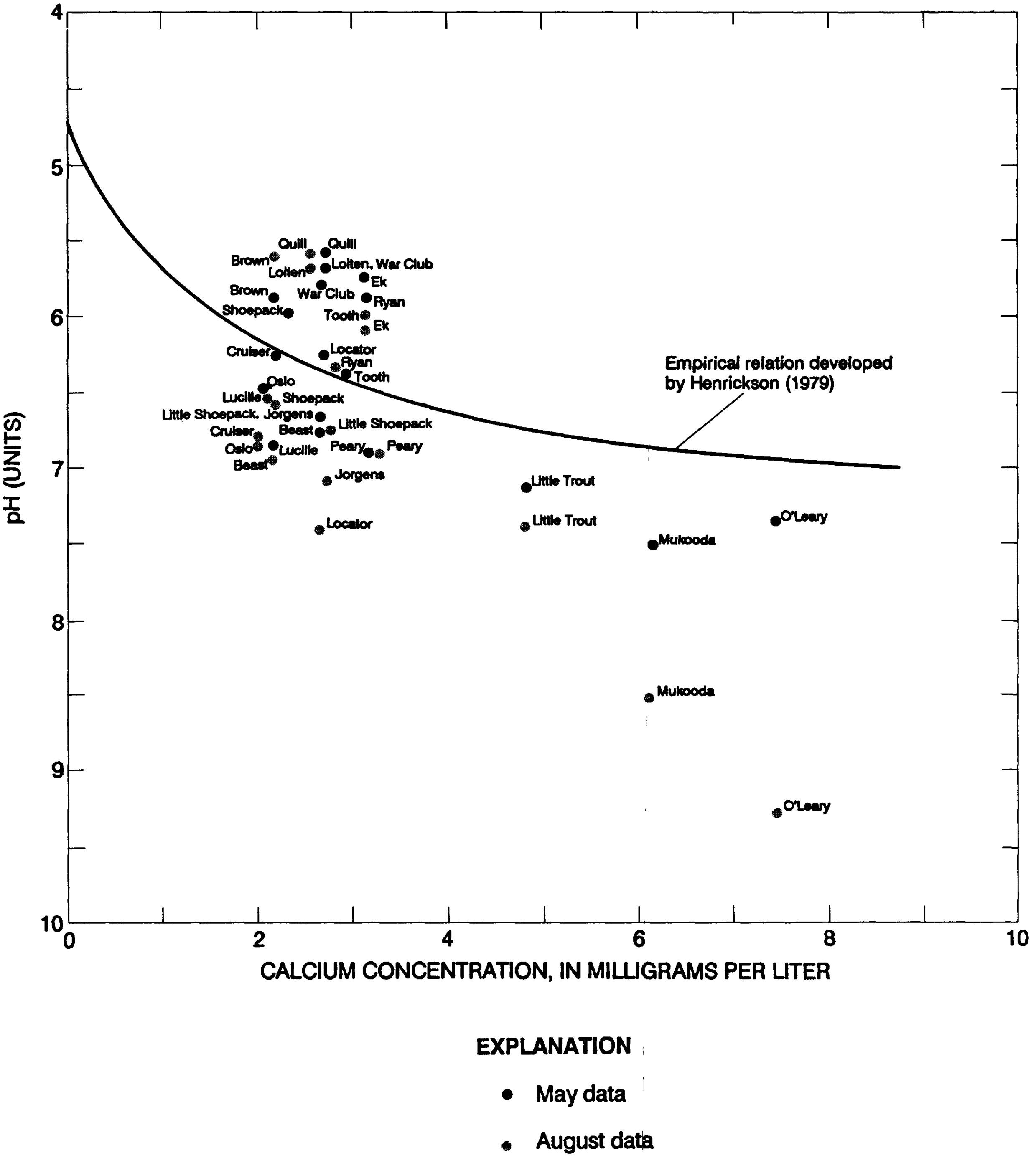


Figure 14.--pH as a function of calcium concentrations, interior lakes

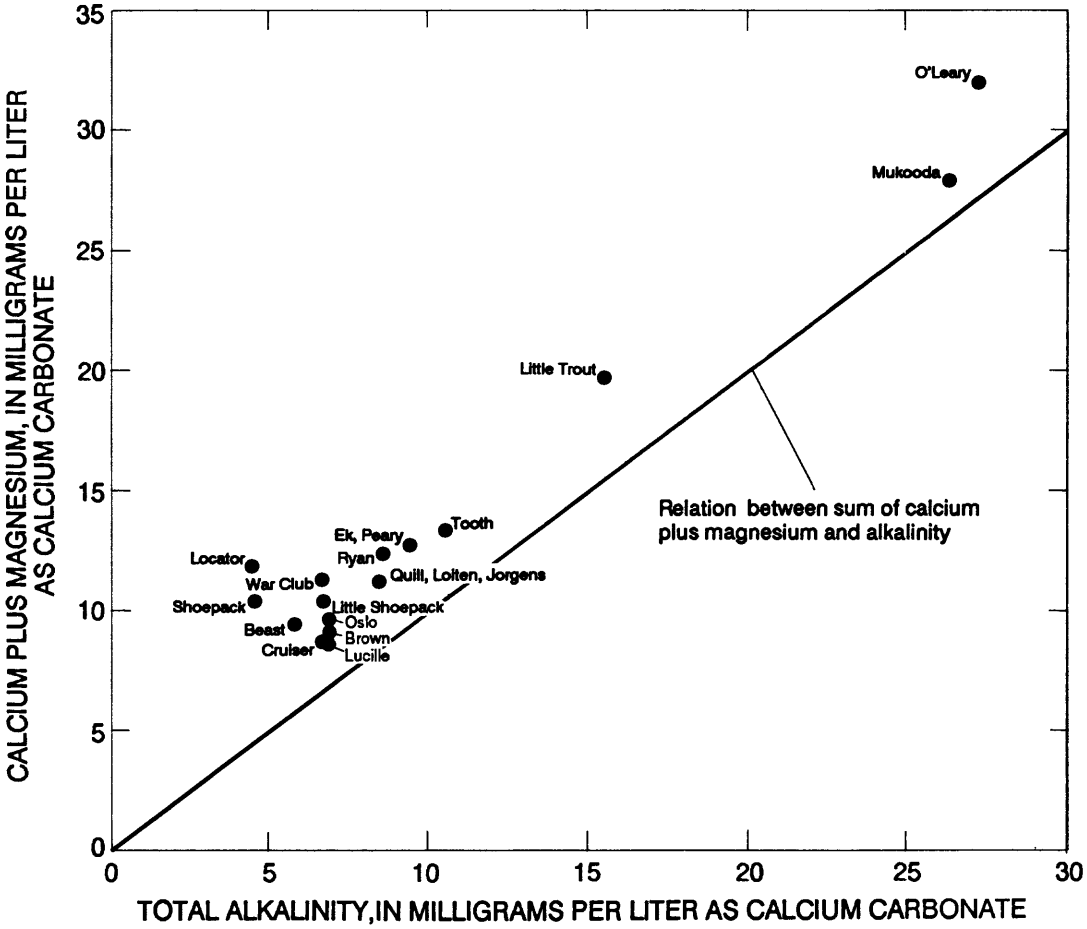


Figure 15.--Relation between alkalinity and the sum of calcium plus magnesium, interior lakes, May data

The ratio of sulfate to alkalinity was computed for each of the interior lakes. These ratios were plotted against the ratios of calcium plus magnesium to alkalinity from figure 15. The results are shown in figure 16. Eight lakes that have high ratios (greater than 0.6) of sulfate to alkalinity coincide with the lakes that have lower than expected pH from figure 14. Six of the eight lakes that have high sulfate to alkalinity ratios also have high (greater than 1.4) calcium plus magnesium to alkalinity ratios. Ek Lake is an exception, having low ratios but lower than expected pH. Ek Lake is a highly colored (55 platinum-coblt units) suggesting the presence of naturally occurring organic acids that could account for its low pH. Figure 17 shows that the interior lakes have an inverse relationship between color and pH.

Examination of the anion ratios showed that, except for Ek Lake, the lakes having the highest proportion of sulfate, nitrate, and chloride coincide with the lakes having lower than expected pH. Table 13 shows that sulfate, nitrate, and chloride comprise more than 44 percent of the anions in the lakes having low pH.

Physical Characteristics

Physical characteristics were determined from vertical profiles of temperature, specific conductance, and dissolved oxygen. Results of the measurements are shown in table 20 (at back of report). The data obtained in the profiles were evaluated to determine the occurrence of thermal stratification, hypolimnetic oxygen depletion, and changes in specific conductance with depth. The results are condensed in table 14.

Table 14 shows that vertical temperature profiles during May ranged from uniform to moderately stratified. The differences in stratification between the lakes during May is a function of the date of sampling. Most of the lakes were sampled during late May, but some were sampled as early as May 2. Evidence of the onset of thermal stratification was observed as early as two weeks after the lakes lost their ice cover.

During August, all the lakes except Lucille and Ryan were sharply stratified. In the sharply stratified lakes, thermal gradients exceeded 3 ^{o}C per meter and were as high as 6 ^{o}C per meter in some of the lakes.

In five of the lakes that were moderately stratified during May, the thermal gradient was sufficient to prevent circulation within the water column. This is shown by depressed (less than 5.0 mg/L) dissolved-oxygen concentrations at lower depths. The minimum dissolved-oxygen concentrations ranged from 1.6 to 10.5 mg/L, indicating varying degrees of oxygen demand and consumption in the bottom layers of water. The occurrence of low dissolved-oxygen values shortly after onset of stratification suggests that the oxygen demand in some of the lakes is high.

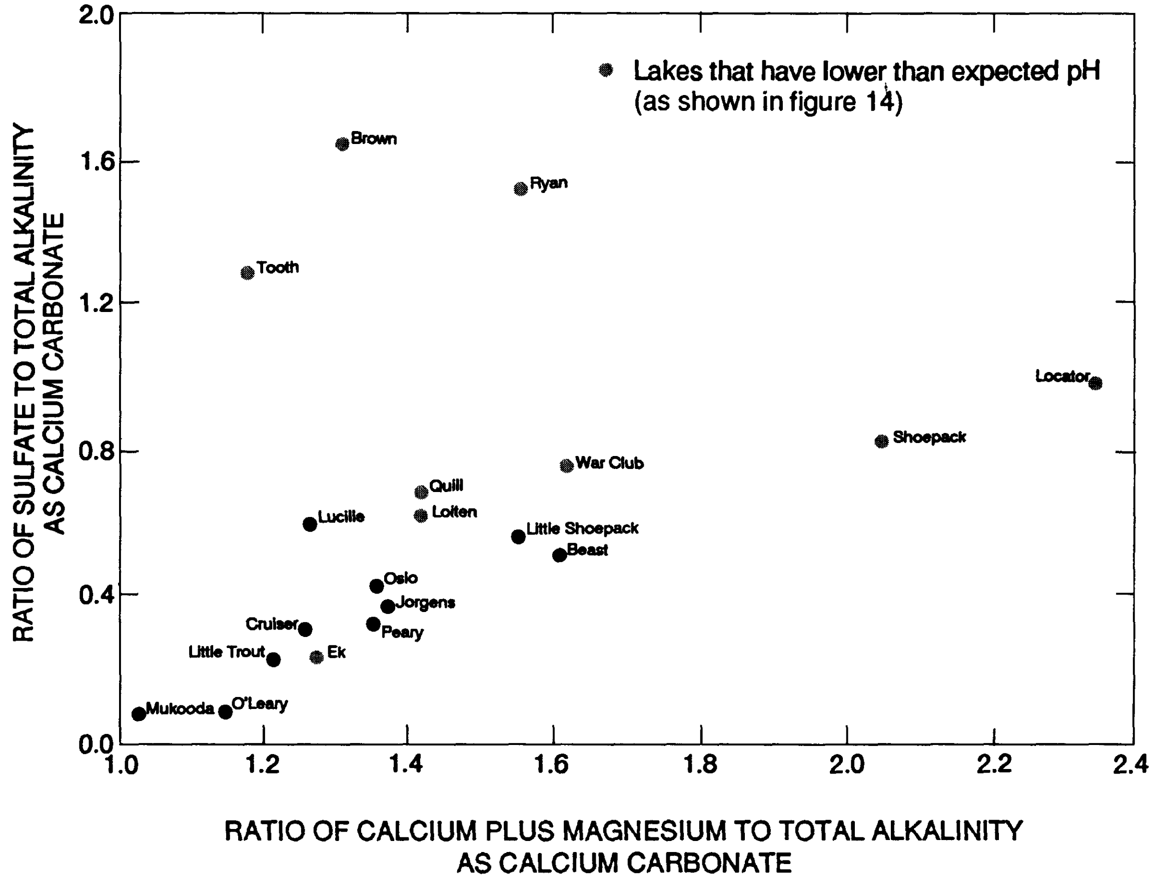


Figure 16.--Ratio of sulfate to alkalinity as a function of the ratio of calcium plus magnesium to alkalinity

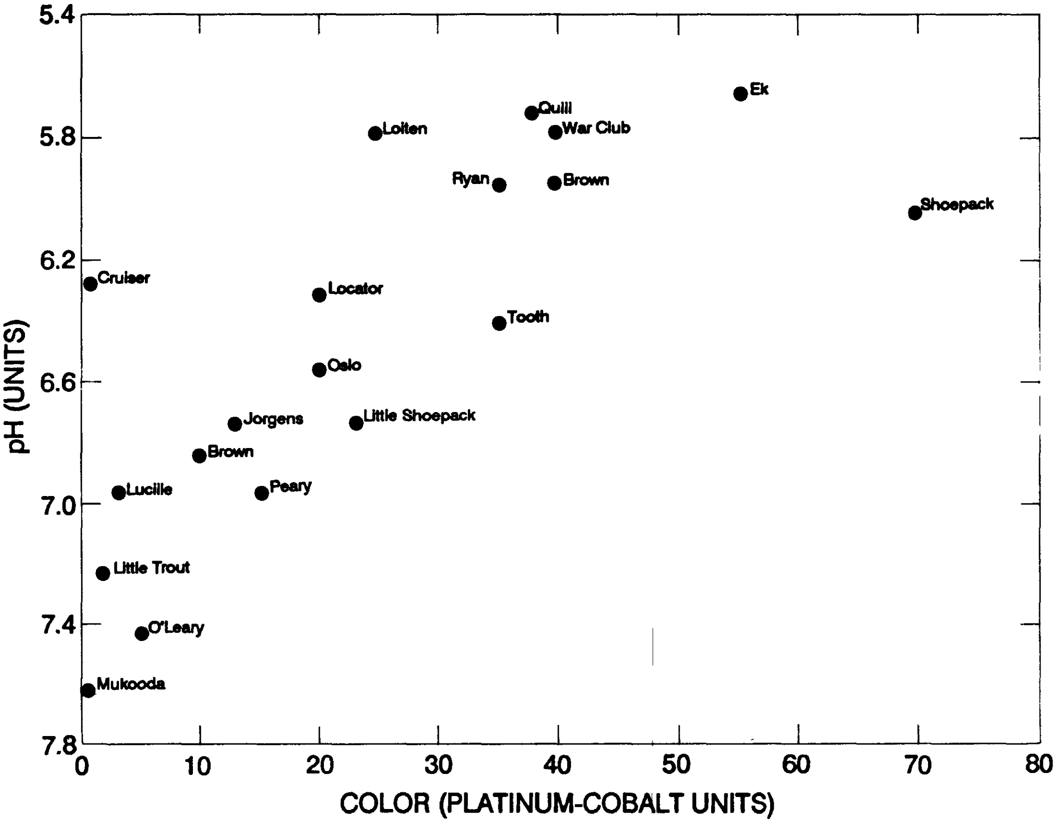


Figure 17.--Inverse relation between pH and color

Table 13.--***Major anions, expressed as percentage of total anions, interior lakes***

[<, less than]

Lake	Percent bicarbonate	Percent chloride	Percent sulfate	Percent nitrate	Percent chloride plus sulfate plus nitrate
Locator[1]	42	12	45	<1	58
Shoepack[1]	47	14	39	<1	53
Beast	66	7	27	<1	34
War Club[1]	25	5	18	52	75
Cruiser	74	3	23	<1	26
Lucille	64	4	32	<1	36
Little Shoepack	62	7	31	<1	38
Brown[1]	24	3	34	39	76
Oslo	59	13	28	<1	41
Quill[1]	56	7	35	2	44
Ryan[1]	34	3	48	15	66
Loiten[1]	27	3	17	53	73
Jorgens	74	6	20	<1	26
Ek[1]	73	7	19	1	27
Peary	73	5	18	4	27
Tooth[1]	49	3	47	1	51
Little Trout	77	3	20	<1	23
Mukooda	92	1	7	<1	8
O'Leary	91	2	7	<1	9

[1] Lakes that have lower than expected pH.

Table 14.--*Summarized results of vertical-profile measurements of temperature, specific conductance, and dissolved oxygen*

Temperature stratification: uniform = less than 1 °C (degrees Celsius) change over the entire vertical, slight = less than 1 °C change per meter, moderate = 1 °C to 3 °C change per meter, sharp = greater than 3 °C change per meter.
Hypolimnetic oxygen: yes = dissolved oxygen concentration in the hypolimnion was depressed, less than 5.0 mg/L (milligrams per liter), no = concentration of oxygen was greater than 5.0 mg/L in the hypolimnion.
Minimum dissolved oxygen concentration: The minimum dissolved oxygen concentration, in mg/L, measured in the vertical.
Specific conductance: The specific conductance at the top of the vertical subtracted from the specific conductance at the bottom of the vertical. Values are in microsiemens per centimeter at 25 degrees Celsius. Three dashes, ---, means that the change in specific conductance was less than 5 microsiemens per centimeter.

Lake	Temperature stratification		Hypolimnetic oxygen		Minimum dissolved oxygen concentration		Change in specific Conductance		Depth at vertical (in feet)		Remarks
	May	August	May	August	May	August	May	August	May	August	
Locator	moderate	sharp	yes[1]	yes	3.5	0.8	---	---	49.0	47.8	Depressed dissolved oxygen (DO) concentrations during May limited to 3 feet from bottom.
Shoepack	moderate	sharp	yes	yes	1.6	.5	+9	+14	21.1	19.0	
Beast	moderate	sharp	yes[1]	yes	4.2	1.8	---	---	58.9	28.5	Oxygen measurements not made below 45 feet during May
War Club	uniform	sharp	no	yes[1]	10.4	1.2	---	+13	37.5	36.8	Depressed DO concentration at top of thermocline.
Cruiser	slight	sharp	no	no	9.6	6.2	---	-6	88.5	90.0	
Lucille	uniform	slight	no	yes[1]	7.4	1.0	---	+6	22.0	20.5	Depressed DO concentrations limited to 3 feet from bottom.
Little Shoepack	moderate	sharp	yes	yes	1.6	.5	+11	+16	21.1	19.0	
Brown	slight	sharp	no	yes	10.4	1.2	---	+30	26	27.5	
Oslo	moderate	sharp	no	yes	6.0	.5	---	+35	38.2	45.8	
Quill	slight	sharp	no	yes	10.0	2.2	---	+23	38.2	45.8	
Ryan	slight	slight	no	yes[1]	10.1	3.3	---	---	13.3	13.2	Depressed DO concentrations limited to 2.3 feet from bottom.
Loiten	slight	sharp	no	yes	6.4	2.5	---	---	47.2	42.0	
Jorgens	moderate	sharp	yes[1]	yes	4.8	.5	---	+21	20.2	20.5	Hypolimnetic depressed DO concentrations during May limited to 3 feet from bottom.
Ek	slight	sharp	no	yes	10.0	1.0	---	+60	18.1	22.1	
Peary	slight[1]	sharp[1]	no	yes	5.8	.6	---	+71	19.8	18.5	May temperatures uniform to depth of 16.4 feet. Sharp gradient limited to 3 feet from bottom during August.
Tooth	slight	sharp	no	yes	8.9	1.5	---	+31	38.4	41.9	
Little Trout	moderate	sharp	no[1]	no[1]	8.3	7.2	---	-7	>62.0	>62.0	Oxygen not measured below 62 feet. Upper hypolimnion greater than 5.0 mg/L dissolved oxygen.
Mukooda	moderate	sharp	no	yes[1]	10.5	3.0	---	-12	73.0	73.0	Depressed DO concentrations limited to lower 6 feet, upper part of hypolimnion oxygenated.
O'Leary	moderate	sharp	no	yes	5.4	1.1	---	---	52	35.6	

[1] Refer to remarks column for explanation.

During August, only Cruiser and Little Trout had hypolimnetic dissolved-oxygen concentrations in excess of 5.0 mg/L. Low concentrations in some of the other lakes were limited to the bottom 3.3 ft of the water column near the sediment-water interface, but in others low concentrations were found throughout the hypolimnion and even extended into the thermocline. In War Club Lake, for example, dissolved-oxygen concentrations were below 5.0 mg/L at the top of the thermocline and declined sharply to 1.3 mg/L within the thermocline.

Specific conductance was uniform (less than 5 μS/cm change) throughout the water columns during May except in Shoepack and Little Shoepack Lakes. During August, however, 11 of the lakes had a rise in specific conductance in their hypolimnions that was most pronounced near the sediment-water interface. The rise in specific conductance indicates that the microzone at the sediment-water interface had become anoxic. The rise in specific conductance likely is a reflection of the release of iron, manganese, phosphate, calcium carbonate, carbon dioxide, ammonia, and sulfide at the sediment-water interface. The release occurs as a result of a lowering of the redox potential in the micro-zone in response to the development of anoxic conditions in the overlying water.

Nutrients

The results of analyses for nutrients are shown in table 15. Examination of the values for spring (May) total phosphorus shows that concentrations in the interior lakes varied from 0.003 mg/L to 0.031 mg/L. This range of values exceeded the range of mean spring values for the large lakes, 0.011 mg/L (Rainy) to 0.026 mg/L (Kabetogama). This is significant in that, based on spring total-phosphorus concentrations, lakes such as O'Leary, Shoepack, and Ek could be expected to be as productive as Sand Point and Kabetogama, while others, particularly Ryan, Quill, and Loiten, would be expected to have lower productivity than Rainy and Namakan.

Examination of the August data, however, shows that the interior lakes are subject to processes that, in some of the lakes, greatly increase or decrease total-phosphorus concentrations, affecting the amount of phosphorus available in the epilimnion during summer.

The data in table 15 show that 12 of the lakes underwent a reduction in total-phosphorus between May and August, while four of the lakes underwent an increase. Only two of the lakes, Little Shoepack and Cruiser, remained at nearly the same concentrations.

Determination of the processes that cause the observed changes in total-phosphorus concentration requires intensive data collection beyond the scope of this study. This study does, however, provide evidence that changes in concentration are related to the presence or absence of sharp thermal stratification, which, in turn is regulated by depth, lake-basin shape, and basin orientation.

Table 15.--*Results of analyses for nutrients in interior lakes, 1982-84, and mean results for large lakes, 1977-83*

[Values shown are in milligrams per liter]

NUTRIENTS IN INTERIOR LAKES, 1982-84

Lake	Total phosphorus		Nitrite plus nitrate nitrogen, dissolved, as N		Ammonia plus organic nitrogen, total, as N		Total nitrogen		Phosphorus, dissolved	
	May	August	May	August	May	August	May	August	May	August
Locator	0.014	0.011	0.06	<0.01	0.50	0.30	0.56	0.30	0.008	<0.001
Shoepack	.021	.014	.14	.02	.69	.70	.83	.72	.011	.001
War Club	.009	<.001	4.20	.033	.40	.80	4.60	.83	.004	<.001
Beast	.007	.014	<.01	<.01	.30	.40	.30	.40	<.001	.003
Little Shoepack	.019	.018	<.01	<.01	.50	.40	.50	.40	.006	.014
Ryan	.003	.040	1.10	.013	.50	.80	1.60	.81	.003	<.001
Quill	.004	<.001	.067	<.01	.40	1.10	.47	1.10	.002	<.001
Loiten	.003	<.001	4.6	.031	.40	.60	5.00	.63	<.001	<.001
Jorgens	.015	.020	.037	<.01	.30	.50	.34	.50	.002	.017
Oslo	.017	.008	.10	<.01	.94	.50	1.04	.50	.007	<.001
Peary		.018	<.01	.180		.30		.48		.015
Brown	.006	<.001	3.7	<.01	.30	.50	4.00	.50	<.001	<.001
Ek	.020	.011	.053	<.01	.70	.90	.75	.90	.002	<.001
Lucille	.008	.022	<.01	<.01	.50	.20	.50	.20	.006	.004
Cruiser	.008	.008	.01	<.01	.34	.50	.35	.50	<.001	.002
Little Trout	.016	.009	.01	<.01	.30	.10	.31	.10	<.001	.005
Tooth	.010	.004	.059	<.010	.40	.40	.46	.40	<.001	<.001
O'Leary	.031	.013	<.01	<.01	.50	.30	.50	.30	<.001	<.001
Mukooda	.016	.010	<.01	<.01	.52	.50	.52	.50	<.001	<.001

MEAN VALUES FOR PHOSPHORUS AND NITRITE PLUS NITRATE CONCENTRATIONS IN LARGE LAKES, 1977-83

Lake	Total phosphorus		Nitrite plus nitrate nitrogen, dissolved, as N	
	May	August	May	August
Rainy	0.011	0.011	0.051	0.047
Namakan	.014	.012	.070	.062
Sand Point	.019	.018	.042	.022
Kabetogama	.026	.047	.011	.083

In stratified lakes, phosphorus is lost from the epilimnion by means of sedimentation of particulate matter. The presence of a strong thermal gradient prevents recirculation of deposited phosphorus. During periods of stratification, phosphorus concentrations in the epilimnion can only be maintained or increased by recycling from sediments in the shallow-water littoral zone, inflow, or by atmospheric deposition.

Of the four lakes that showed spring to summer increases in total-phosphorus concentrations, two lakes, Lucille and Ryan, were only slightly stratified during summer, suggesting that recirculation and, consequently, recycling of phosphorus may have occurred during the summer. Jorgens Lake, which also showed a gain in total phosphorus during summer, was stratified during August, but is less than 15 ft deep over much of its basin and has an east-west orientation, making is susceptible to destratification by wind. Beast Lake also showed an increase in total phosphorus during summer. It is unlikely that Beast Lake destratifies, owing to its depth (75 ft), but approximately one-third of its basin consists of a bay that is 15 ft or less in depth, providing a potentially large littoral zone where phosphorus recycling can occur. This bay also receives inflow from a stream that may be a source of phosphorus during summer.

The majority of the interior lakes showed a decrease in total-phosphorus concentrations between spring and summer. In four of the lakes, War Club, Quill, Loiten, and Brown, the loss caused the total-phosphorus concentrations to decline to less than 0.001 mg/L.

The observed declines in total-phosphorus concentrations suggest that most of the interior lakes undergo a net loss of this essential nutrient from their epilimnions during the summer period. The loss occurs when other conditions for primary productivity, such as light and temperature, are optimum. The effects of the loss will be discussed in the section that describes biological productivity in the interior lakes.

The net loss suggests that inputs of phosphorus from runoff, ground water, and atmospheric deposition are not sufficient to maintain total-phosphorus concentrations at levels observed shortly after spring turnover. This, in turn, suggests that processes of internal cycling are the main factors controlling the availability of total phosphorus during the late spring and summer growing season. Internal cycling also may control total-phosphorus concentrations in the epilimnion during fall, winter, and early spring. Further investigation, involving more frequent sampling during all seasons of the year, will be necessary to determine the relative importance of internal versus external phosphorus inputs on an annual basis.

Dissolved-phosphorus concentrations also decreased between spring and summer in most of the lakes. A decrease would be expected as algal populations develop and begin utilizing the soluble inorganic phosphorus contained in the dissolved part. Separate determinations of soluble inorganic and soluble organic phosphorus were not made, so the proportion of soluble inorganic phosphorus can not be determined from the data.

Only two lakes, Little Shoepack and Jorgens, showed significant increases in dissolved phosphorus between spring and summer. In these lakes, approximately 80 percent of the phosphorus was in dissolved form during August. Peary Lake also had 83 percent of its phosphorus in dissolved form in August, but data were not available for comparison with concentrations in May. All three lakes have extensive shallow areas containing emergent and submergent vegetation. The high proportion of dissolved phosphorus observed in these lakes may be related to release of phosphorus by the aquatic plants and by the feeding activity of benthic invertebrates in the extensive littoral areas of these lakes.

Total nitrogen concentrations in the interior lakes generally ranged from 0.30 to 0.90 mg/L. Four lakes, however, War Club, Ryan, Loiten, and Brown, had spring total-nitrogen values that were much higher, ranging from 1.6 to 5.0 mg/L. The higher values resulted from a much higher proportion of nitrite plus nitrate nitrogen. All four of these lakes, along with Ek, Tooth, and Quill, were sampled on May 2, less than 14 days after loss of an ice cover, while the other interior lakes were sampled during late May. The nitrite plus nitrate values for Ek, Tooth, and Quill, while much lower than War Club, Ryan, Loiten, and Brown, are higher than values for most of the lakes that were sampled in late May. High values may occur following spring circulation in all the lakes, but were not detected when sampling took place after the onset of nitrate assimilation by algae and macrophytes and denitrification by bacteria. Nitrate assimilation by photosynthesis can exceed sources of nitrate income and generation, reducing nitrate to below detectable concentrations (Wetzel, 1975). During May, 47 percent, and during August, 74 percent, of the lakes had nitrite plus nitrate concentrations at or below the detection limit (0.01 mg/L). Nitrite plus nitrate lost between the spring and summer sampling periods was not compensated by a buildup of organic nitrogen within the epilimnion. This was most obvious in War Club, Ryan, Loiten, and Brown Lakes where spring nitrite plus nitrate values were very high relative to the other lakes. This suggests that the presence of high amounts of nitrite plus nitrate at spring overturn is a short-term phenomenon and that the nitrogen present in that form is removed from the trophogenic zone. It also is possible that nitrogen input from external sources is low during the period from late May through August, that excess nitrogen is transferred from the epilimnion to the hypolimnion and sediments, or it is returned to the atmosphere. This is evidenced by summer declines in total nitrogen that were observed in all the lakes except Beast, Jorgens, Cruiser, Quill, and Ek.

Biological Productivity and Trophic State

Trophic-state indices (TSI) were computed from the values obtained for chlorophyll *a*, Secchi-disk transparency, and total phosphorus. Carlson's (1977) index was used for this purpose.

Table 16 shows chlorophyll *a*, total phosphorus, and Secchi-disk values along with corresponding TSI values. The median TSI values for all the interior lakes is shown below:

	TSI CHL	TSI TP	TSI SD
May	39	39.5	45
August	38	39	45

Table 16.--*Total phosphorus, transparency, and chlorophyll a data for interior lakes with corresponding trophic-state indices*

[TSI, Trophic State Index; chlorophyll a in micrograms per liter, transperency in feet, total phosphorus in milligrams per liter]

Lake	Chlorophyll a		Transperency		Total phosphorus		TSI based upon chlorophyll a conentration		TSI based upon transparency Seechi-disk		TSI based upon total phosphorus concentration	
	May	August	May	August	May	August	May	August	May	August	May	August
Locator	5.0	<0.1	9.2	10.2	0.014	0.011	46	<8[a]	45	44	42	39
Shoepack	4.7	2.2	5.6	4.9	.021	.014	46	38	52	54	48	42
War Club	2.1	2.1	9.5	6.6	.009	<.001	38	38	45	50	36	<4[a]
Beast	3.6	4.2	9.5	7.2	.007	.014	43	45	45	49	32	42
Little Shoepack	5.2	10	6.6	5.9	.019	.018	47	53	50	52	47	46
Ryan	1.5	2.1	12.8	10.5	.003	.040	34	38	40	43	20	57
Quill	.9	1.8	9.8	11.8	.004	<.001	30	36	44	42	24	<4[a]
Loiten	.9	1.3	11.5	14.8	.003	<.001	30	33	42	38	20	<4[a]
Jorgens	1.6	3.9	10.2	8.2	.015	.020	35	44	44	47	43	47
Oslo	6.0	1.0	7.9	9.8	.017	.008	48	31	47	44	45	34
Peary	2.4	3.4	8.9	6.9	---	.018	39	43	46	49	---	46
Brown	2.7	2.6	6.9	9.5	.006	<.001	40	40	49	45	30	<4[a]
Ek	5.4	2.9	4.9	5.2	.020	.011	47	41	54	53	47	39
Lucille	2.5	3.6	16.7	10.2	.008	.022	39	43	36	44	34	49
Cruiser	2.3	<.1	16.4	26.2	.008	.008	39	<8[a]	37	30	34	34
Little Trout	1.3	1.4	18.0	15.4	.016	.009	33	34	35	38	44	36
Tooth	1.1	1.9	10.8	9.5	.010	.004	32	37	43	45	37	24
O'Leary	6.5	4.9	9.8	9.2	.031	.013	49	46	44	45	54	41
Mukooda	3.3	1.9	9.5	14.8	.016	.010	42	37	45	38	44	37

[a] TSI values of less than 8 for chlorophyll a and less than 4 for total phosphorus suggest that the corresponding chlorophyll a and total-phosphorus concentrations are erroneous.

The median TSI values indicate that overall trophic state for the lakes as a whole remained constant from May to August although the TSI for individual lakes changed considerably during the same period (table 16).

Comparison of TSI CHL and TSI TP values for individual lakes shows that TSI TP overestimates trophic state for seven lakes and underestimates trophic state for five lakes. This may be attributable, in part, to the weak relationship between total phosphorus concentrations and chlorophyll *a* concentrations for this group of lakes. The relationship is shown in figure 18 along with the regression line developed by Carlson (1977) for the trophic-state index.

The median TSI values also show that, overall, TSI SD overestimates productivity in comparison to estimates derived from calculation of TSI CHL and TSI TP. This also is shown by comparing TSI SD with TSI CHL for the individual lakes. During August, 17 of the 19 lakes had TSI SD values that were greater than their TSI CHL values. The relationship of chlorophyll *a* concentrations to Secchi-disk transparency is shown in figure 19. The regression line developed by Carlson (1977) is shown for comparison. Figure 19 shows that most of the interior lakes have less transparency than would be expected using Carlson's regression. It is likely that the organic color present in many of the interior lakes reduced Secchi-disk readings. Figure 19 shows that the lakes tend to plot farther from Carlson's regression line when they have higher color. Figure 20 shows that Secchi-disk readings have an increasing tendency to overestimate chlorophyll *a* as lake color increases.

Figure 21 shows the distribution of TSI CHL values for the interior lakes. Comparison of the results from May and August shows that productivity increased in 10 lakes, decreased in 5, and remained the same in 2. Cruiser and Locator Lakes are not included in this comparison because their August chlorophyll *a* values are believed to be erroneously low. It is reasonable, however, to use TSI SD to estimate chlorophyll *a* concentrations in Cruiser Lake because the lake is not highly colored. The large increase in transparency from 16.4 ft to 26.2 ft in Cruiser Lake during May through August strongly suggests that it also had a reduction on chlorophyll *a* concentration.

The five lakes that had reductions in TSI CHL (Shoepack, Ek, Oslo, O'Leary, and Mukooda) had a mean TSI CHL that declined from 46 during May to 38 during August. Individually, the magnitude of change ranged from a low of 3 TSI units in O'Leary Lake to 17 units in Oslo Lake. These results should be used with caution because they are based on two samples during just one season of data collection for each lake. Nonetheless, the results are worthy of further examination if one considers their implications.

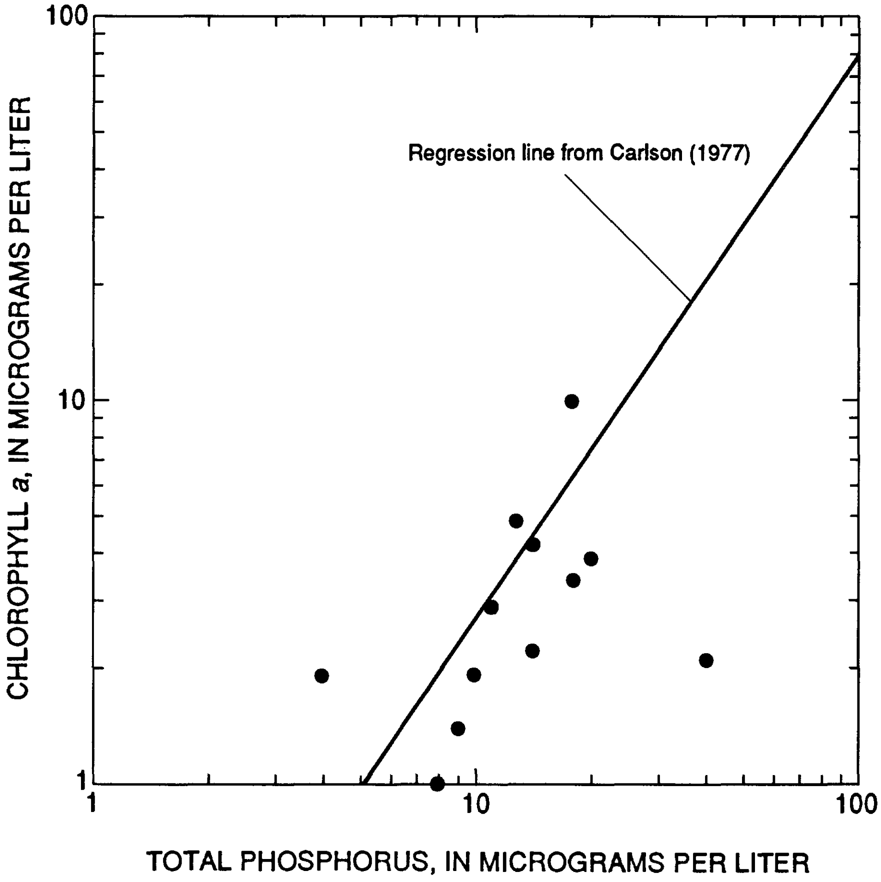


Figure 18.--Relation between chlorophyll *a* and total phosphorus for interior lakes during August, 1982-84

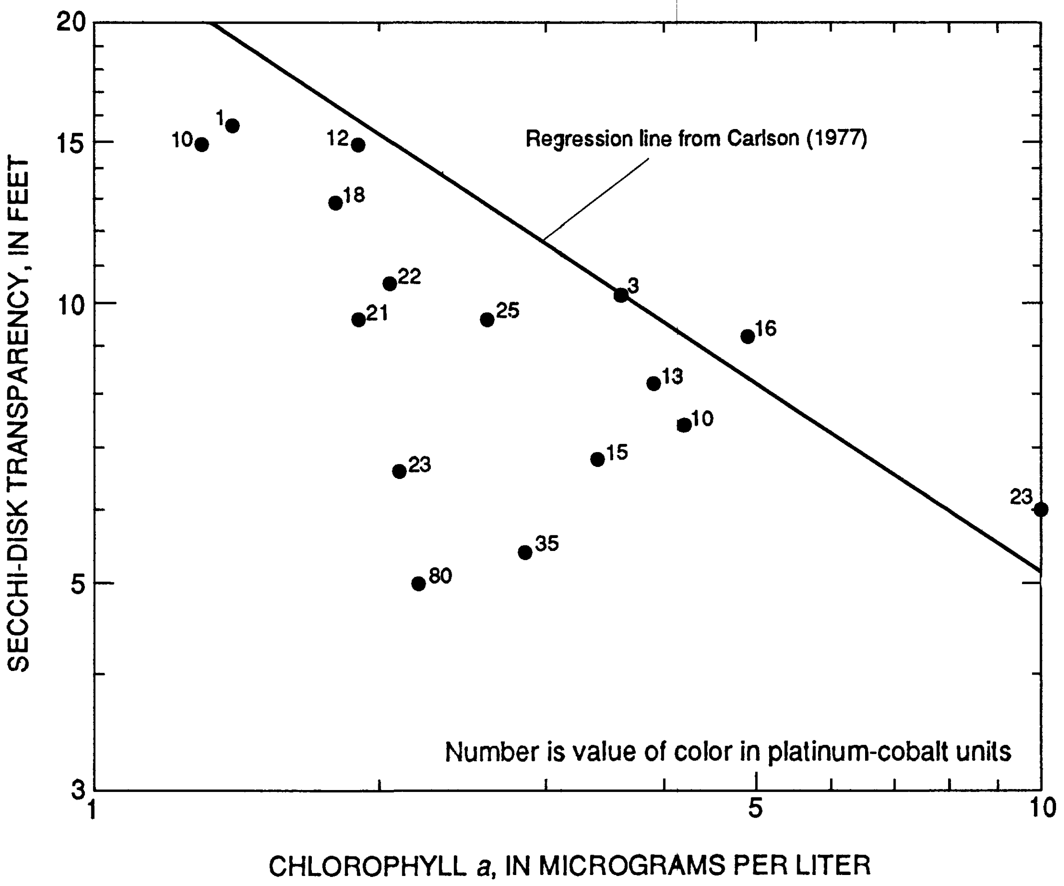


Figure 19.--Relation between Secchi disk transparency and chlorophyll *a* for interior lakes

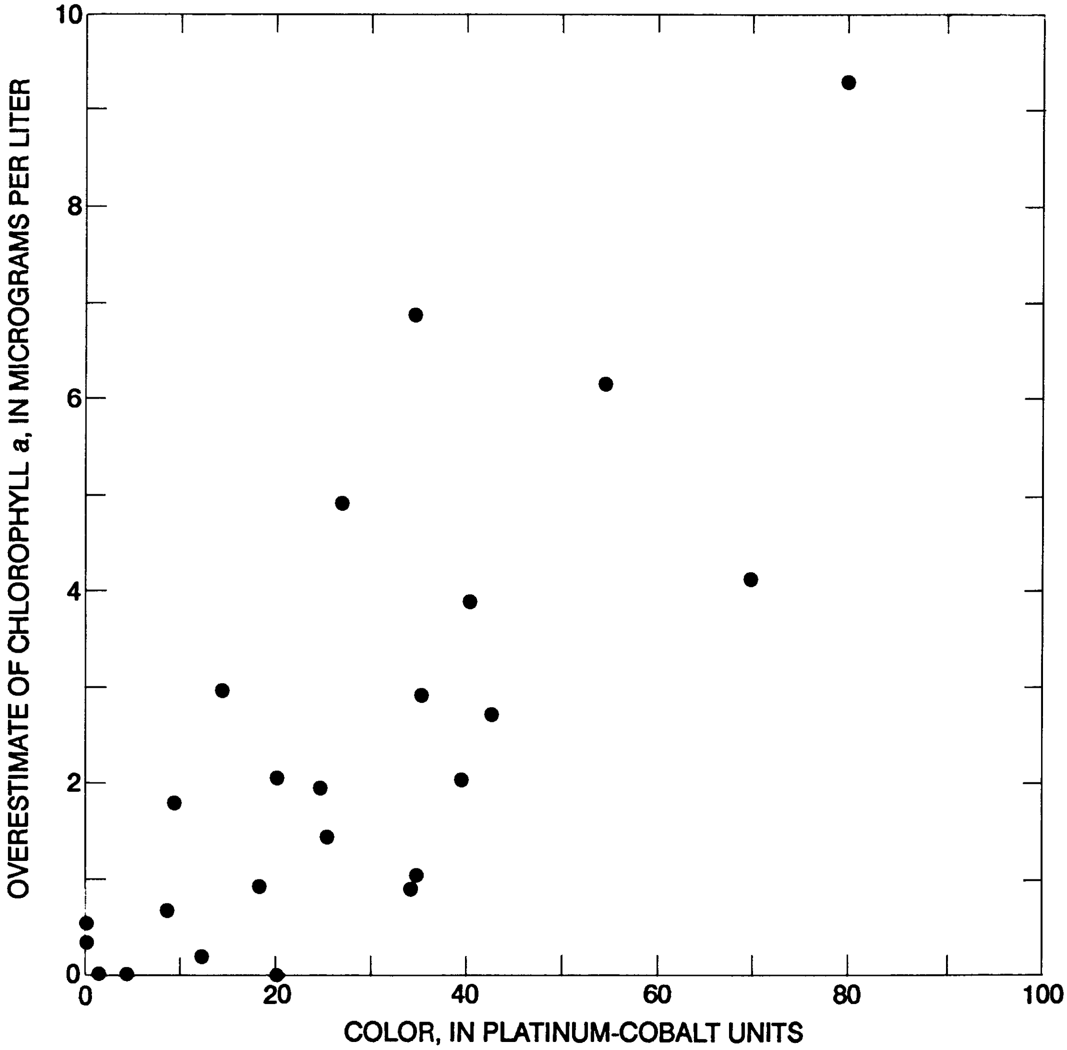


Figure 20.--Effect of color on estimates of chlorophyll *a* concentration determined by Secchi disk

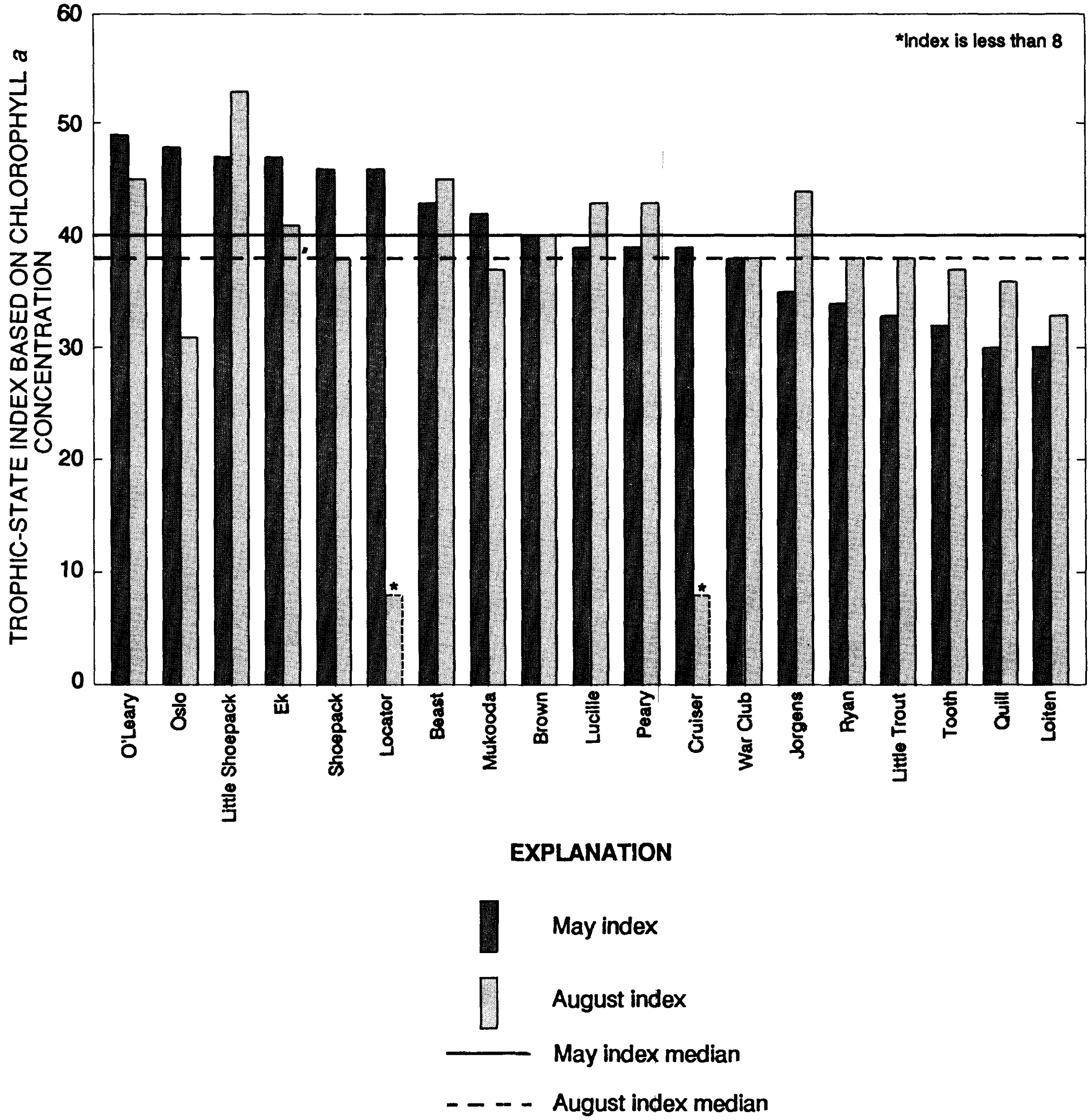


Figure 21.--Distribution of May and August trophic-state indices for interior lakes, based on chlorophyll *a* concentration

One hypothesis is that productivity drops in these lakes because of nutrient limitation during August. A check of the TSI TP values shows that for each of these lakes TSI TP is, in fact, lower during August. It should be noted, however, that Tooth Lake, which underwent an increase in TSI CHL, also had lower concentrations of total phosphorus during August. Another anomalous condition is shown by Ryan Lake, where TSI TP increased from 20 to 57, but TSI CHL changed only slightly, rising from 34 to 38. The lack of a consistent relationship between the TSI CHL and the concentration of total phosphorus in several of the interior lakes suggests that (1) the amount of data collected is inadequate to define the phosphorus-chlorophyll *a* relationships or (2) one or more factors or conditions are holding chlorophyll *a* production below the potential indicated by the total-phosphorus concentrations.

Considering (1) above, the data set is limited to only one sample for each season and any error in sampling or analytical techniques could have considerable impact on the results. For example, total-phosphorus concentrations are so low in several of the lakes that sampling and analytical procedures are near the limits of precision and accuracy. Assuming the results are accurate, concentrations sampled may not be representative of concentrations throughout the season.

Statement (2) above is supported by information portrayed in figure 18, where data for most of the lakes plot to the right of Carlson's regression line, indicating that chlorophyll *a* production does not reach the potential indicated by the total-phosphorus concentrations. Included in this group of lakes are Shoepack, Mukooda, and Oslo, three of the five lakes that underwent reductions in trophic state between May and August. This may indicate that observed seasonal declines in productivity are not caused solely by reductions in total phosphorus, but are also affected by factors that may include limited availability of trace-element nutrients, zooplankton grazing, or lack of phosphorus in a biologically active form.

Inflows

During 1982, reconnaissance sampling was conducted in the Namakan River and Ash River to determine the quality of water entering the Park. The Namakan River was sampled because it is the largest source of inflow to the Park. The Ash River was sampled because previous sampling at the mouth of the Ash River (site 12 in Sullivan Bay) had shown that its quality was less than the receiving waters in Kabetogama Lake.

Namakan River

The Namakan River is gaged approximately 16 mi (miles) upstream of Namakan Lake near the outlet of Lac La Croix. The average discharge, based on 61 years of record, is 3,820 ft^3/s (cubic feet per second). Peak flow for the period of record was 28,200 ft^3/s, May 31 to June 2, 1950. The Namakan River was sampled during May and August 1982 about 2,000 ft upstream from the point of entry into Namakan Lake (site 20). The results of the analyses are shown with data from Namakan Lake site 14 in table 17. Water in the Namakan River at the time of sampling had better quality than other areas in the Park. The Namakan River and Namakan Lake at site 14, about 8 mi from the mouth of the Namakan River,

Table 17.--*Comparative water-quality data for Namakan River and Namakan Lake*

[µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; cells/mL, cells per milliliter, <, less than]

	Namakan River 1982		Namakan Lake site 14 1982		Namakan Lake site 14 mean values 1979-83	
	May	August	May	August	May	August
Specific conductance (µS/cm)	35	43	46	41	48	42
pH	7.0	7.6	6.9	7.6	7.0	6.8
Transparency (feet)	7.9	9.8	8.9	8.2	10.5	10.5
Dissolved oxygen (mg/L)	11.1	8.8	---	7.8	9.4	7.6
Total alkalinity (mg/L)	12	12	15	13	16	14
Dissolved solids (mg/L)	36	50	41	38	53	44
Nitrite plus nitrate (mg/L)	.05	.13	.12	.07	.07	.06
Ammonia plus organic nitrogen (mg/L)	.47	<.10	.61	<.10	.63	.70
Total phosphorus (mg/L)	.017	.012	.018	.012	.014	.012
Dissolved phosphorus (mg/L)	.017	.003	.007	.001	.007	.003
Chlorophyll *a* (µg/L)	4.40	1.10	5.60	1.00	3.80	2.03
Phytoplankton cell count (cells/mL)	1100	240	1500	1500	2400	20,800[a]

[a] Mean value affected by high cell count during August 1979 (94,000 cells/mL).

had similar concentrations of dissolved solids and nutrients and similar pH, alkalinity, and total algal productivity. This is significant because data collected during this study have shown that water-quality conditions in Namakan Lake are among the best of the four large lakes in the Park. The data indicate that quality of the water entering the Park from the Namakan River is maintained throughout Namakan Lake.

Ash River

Reconnaissance sampling of the Ash River was conducted during August 1982. Samples were collected at four sites along a 3-mi reach from Ash River Falls to the mouth of the Ash River at Sullivan Bay. The river was flowing at 2.9 ft^3/s during sampling and the entire study reach below Ash River Falls was pooled by backwater from Sullivan Bay.

Each sample was composited from samples taken near the midpoint of three evenly-spaced verticals in the stream. The resulting data should be representative of the entire water-sediment mixture in the stream. Depths were less than 1.0 ft at Ash River Falls, so sample bottles were filled by lowering them at a constant rate in a single vertical above the falls near midchannel.

The sampling was intended to determine the quality of inflow immediately above Ash River Falls and determine if the quality of Ash River is affected by the residential and commerical area downstream of the pooled reach.

Results of sample analysis are shown in table 18 along with results for Kabetogama Lake and Namakan Lake. Comparison of the results for Ash River at Ash River Falls with receiving waters in Kabetogama Lake and Namakan Lake shows that Ash River inflow differs from the receiving waters in several important aspects. Dissolved-solids, indicated by specific-conductance in table 18, was much higher in Ash River compared to the receiving waters. Alkalinity also was much higher in the Ash River. Total-phosphorus concentration in the inflow was very high relative to Namakan Lake, but only slightly higher than the mean summer concentration in Kabetogama Lake. Total nitrogen, primarily organic nitrogen, was lower than mean values for the receiving waters. There was virtually no nitrite plus nitrate nitrogen in the inflow, but as much as 0.040 mg/L ammonia nitrogen was found in the study reach.

To determine the extent inflow is altered as it passes through the pooled reach, data from sites 27, 28, 29, and 12 (table 18) were compared and evaluated. The pooled reach occurs between sites 28, 29 and 12.

The specific-conductance and alkalinity values remained nearly constant throughout the reach downstream to site 12 where both values drop substantially, probably in response to mixing with the waters of Sullivan Bay.

Total-phosphorus concentrations generally declined within the reach. The most noticable change in phosphorus concentration was the decline in dissolved phosphorus. At Ash River Falls, 60 percent of the total phosphorus was in dissolved form. In the downstream parts of the reach, dissolved phosphorus comprised only 5 to 15 percent of the total phosphorus.

There was approximately a threefold increase in total nitrogen between Ash River Falls and site 29. Nearly all of this increase was organic nitrogen.

Algal productivity, as indicated by chlorophyll *a* concentrations, showed a large increase between Ash River Falls and site 28. This response would be expected as the river changes from a narrow, swift-flowing, tree-shaded stream above the falls to a broad, pooled, sun-exposed channel immediately downstream of the falls. Much of the change in water quality observed in the pooled reach likely is related to the change in flow and channel characteristics and the increase in algal productivity. In the reach below the falls, utilization of the large quantity of dissolved phosphorus available in the river probably accounts for the drop in dissolved phosphorus observed in the pooled reach. Similarly, the increase in organic nitrogen in the pooled reach may result from increased productivity. There was not, however, a direct relationship between the increase in organic nitrogen and chlorophyll *a* concentrations.

Organic-nitrogen concentrations and algal productivity increase upstream from the developed residential and commerical part of the reach. This suggests that the combination of nutrient-rich water at Ash River Falls and the changes in stream characteristics below the falls are sufficient to cause increased algal productivity and lowered transparency, without nutrient input from anthropogenic sources in the developed area downstream.

Table 18.--*Results of reconnaissance sampling, August 1982*

[°C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; µg/L, micrograms per liter; ---, not measured; <, less than]

	Ash River at Ash River Falls, site 27	Ash River above mouth of Gannon Creek, site 28	Ash River below mouth of Gannon Creek, site 29	Ash River at entrance to Sullivan Bay, site 12	Kabetogama Lake, site 17	Namakan Lake, site 14	1979-83 August means: near Gappas Landing, site 9 and Kabetogama Lake, site 17	1979-83 August means: Namakan Lake, site 14
Specific conductance (µS/cm)	207	209	213	158	89	41	88	42
pH	8.2	8.8	8.7	9.4	9.6	7.6	8.0	7.0
Temperature (°C)	23.5	22.0	20.5	24.0	21.6	21.5	21.4	21.3
Dissolved oxygen (mg/L)	7.9	10.5	6.5	11.9	11.0	7.8	9.1	7.6
Dissolved oxygen (percent saturation)	96	125	75	146	131	91	108	89
Total alkalinity (mg/L)	110	113	108	81	41	13	43	14
Total sulfide (mg/L)	<.5	<.5	<.5	<.5	---	---	---	---
Suspended solids (mg/L)	1	2	3	3	---	---	---	---
Nitrite plus nitrate nitrogen (mg/L)	<.01	---	<.01	<.01	<.01	.07	.07	.06
Total ammonia nitrogen (mg/L)	.030	.040	.040	.010	---	---	---	---
Total organic nitrogen (mg/L)	.37	.46	1.2	.89	---	---	---	---
Total ammonia plus organic nitrogen (mg/L)	.40	.50	1.2	.90	.80	<.10	.66	.70
Total phosphorus (mg/L)	.053	.042	.037	.046	.063	.012	.045	.012
Dissolved phosphorus (mg/L)	.032	---	.002	.007	.003	.001	.009	.003
Chlorophyll _a_ (µg/L)	.900	14.0	7.80	9.50	42.0	1.00	26.0	2.03
Transparency (feet)	3.3	2.8	2.8	2.8	3.0	8.2	4.6	10.5

Vertical profiles of temperature and dissolved-oxygen concentrations were obtained at sites 28, 29, and 12. The results are shown in table 19. The data from site 28 and 29 show a temperature gradient, but temperatures at site 12 were nearly uniform. A profile also was obtained in the Ash River about 1,000 ft upstream from site 12 at the end of the Ash River channel. The profile at this site was similar to the one at site 29, verifying that the entire pooled reach of the Ash River channel has a vertical temperature gradient.

The dissolved-oxygen data show a decline in concentration with depth at each site. Concentrations near the bottom of the channel were less than 5.0 mg/L (from 43 to 51 percent of saturation) at sites 28, 29, and the auxillary profile site mentioned above. At site 12, the concentration near the bottom was 10.6 mg/L (126 percent saturation), indicating that the depressed oxygen conditions are alleviated as the water enters Sullivan Bay, and possibly augmented by photosynthetic activity.

Table 19.--*Temperature and dissolved-oxygen profiles, Ash River*

Depth (feet)	Temperature (degrees Celsius)	Dissolved oxygen (milligrams per liter)
Site 28, Ash River above mouth of Gannon Creek		
1.0	24.5	11.5
1.6	24.0	12.6
3.3	23.0	12.6
4.9	22.0	10.5
6.6	21.0	8.6
8.2	20.0	7.2
9.8	19.5	4.5
Site 29, Ash River below mouth of Gannon Creek		
1.0	24.5	12.0
1.6	23.5	12.2
3.3	22.0	11.4
6.6	20.5	6.5
8.2	20.0	5.9
9.8	20.0	5.5
11.5	19.5	3.9
Site 12, Ash River at entrance to Sullivan Bay		
1.0	24.5	11.9
1.6	24.0	12.0
3.3	24.0	11.8
4.9	24.0	11.8
6.6	23.0	10.6

The need for further investigation of the Ash River inflows is suggested by results from the reconnaissance sampling. The temperature gradient and the observed oxygen decline suggest that, at times, the bottom layer of water could become anoxic if the temperature gradient prevents mixing. The onset of anoxic conditions could result in a buildup of ammonia and sulfide and the release of soluble phosphorus. Frequent monitoring of temperature and dissolved oxygen in vertical profiles will be required to determine whether oxygen consumption and thermal stratification combine to bring about anoxic conditions. If anoxic conditions develop, discrete samples collected from the bottom layer of water will determine the extent of buildup of ammonia, sulfide, and soluble phosphorus.

More detailed sampling during summer and determination of nutruent loading during periods of heavy runoff such as during spring snowmelt will help evaluate the impact of the Ash River on receiving waters.

SUMMARY

Water-quality investigations undertaken during this study established a baseline of water-quality data for Kabetogama, Sand Point, Namakan, and Rainy Lakes in Voyageurs National Park in northern Minnesota. The data, collected from March 1977 to August 1983, were used to determine limnological characteristics of each lake and indicated seasonal and short-term changes in chemistry, trophic state, and stratification.

The data indicate substantial differences in dissolved-solids content, nutrient concentrations, algal productivity, occurrence and persistence of stratification, and transparency between each of the four largest lakes.

Sand Point, Namakan, and Rainy Lakes, located along the eastern and northern boundaries of the Park, generally had similar water-quality characteristics. These lakes have, low dissolved solids and alkalinity, high transparency, low algal productivity, and high organic color compared to other large water bodies in the Park. These lakes undergo dimictic stratification and share a common flow system dominated by large quantities of inflow from the Namakan and Vermilion Rivers.

Kabetogama Lake, located along the western and southern boundary of the Park, had substantially different quality from that of Sand Point, Namakan, and Rainy Lakes. Kabetogama Lake had higher dissolved-solids content, alkalinity, and nutrients, had summer algal blooms that reduced transparency, was polymictic rather than dimictic, and is much shallower than Sand Point, Namakan, and Rainy Lakes.

Two large embayments, Sullivan Bay in Kabetogama Lake and Black Bay in Rainy Lake, also located along the western and southern boundaries of the Park, comprised a third group of water bodies that differed greatly from their respective main lakes. These embayments are shallow, polymictic, turbid, and had the highest levels of dissolved-solids content, alkalinity, nutrients, and algal productivity found in lakes in the Park.

Total phosphorus concentrations declined between spring and summer in the less-productive lakes (Sand Point, Namakan, and Rainy) and trophic-state indices calculated from the chlorophyll *a* also declined. The more productive water bodies (Kabetogama Lake, Black Bay, and Sullivan Bay) had strong increases in both algal productivity and total-phosphorus concentrations during summer. The increase in total-phosphorus concentrations may result from the polymictic stratification common to all of the more productive water bodies. Frequent mixing may enhance internal cycling of phosphorus from sediments in the productive lakes, while the dimictic pattern found in the deeper, less-productive lakes may serve to isolate their upper waters from this potential source of phosphorus.

Secchi-disk transparency, commonly used as an indicator of trophic state, was limited by factors other than algal-cell density in Namakan, Sand Point, and Rainy Lakes. Natural color in these lakes decreases transparency. In Black Bay and Sullivan Bay resuspended bottom material limits transparency.

Indicators did not reveal a trend in trophic state during the 7-year study. Some 2 to 3 year trends were observed that consisted of peaks and declines in trophic state that were synchronous for all the lakes. These probably resulted from influences of climate and weather.

Waters in the large lakes and embayments met nearly all criteria established by the U.S. Environmental Protection Agency for protection of freshwater aquatic life, drinking water, and recreation. Drinking-water criteria were exceeded at some sites because of oil and grease and phenols. Sulfide concentrations in Black Bay and Sullivan Bay exceeded criteria for protection of aquatic life. Criteria for protection of aquatic life also were not met in Sullivan Bay because of the presence of ammonia. PCB concentrations at site 19 in Kabetogama Lake exceeded recommended concentrations for protection of aquatic life.

Nineteen small lakes located in the Park interior were sampled on a reconnaissance basis to determine their major-ion chemistry, physical properties, and trophic state.

All except two interior lakes experienced sharp thermal stratification during summer. Only two of the stratified lakes maintained hypolimnetic oxygen at concentrations greater than 5.0 mg/L. Onset of stratification and depression of dissolved oxygen was evident in many of the lakes during spring, occurring as early as two weeks after the ice melted.

Dissolved-solids concentrations were lower in the interior lakes than in the large lakes, ranging from 17 to 47 mg/L. Total alkalinity concentrations for all but three interior lakes ranged from 4 to 11 mg/L, much lower than alkalinity measured in the large lakes. Criteria developed by the MPCA show that two of the interior lakes were extremely sensitive to acid precipitation, 13 were as moderately sensitive, two were potentially sensitive, and two were nonsensitive. Eight of the interior lakes had lower pH than would be expected based on their calcium concentrations. Seven of these had higher anionic proportions of nitrate, sulfate, and chloride than the other interior lakes.

Data indicate that large changes in total-phosphorus concentrations and algal productivity occur between spring and summer. The changes severely lower algal productivity in some lakes. Although limited in scope, the data indicate that most of the interior lakes have low nutrient input, especially during summer, and that internal cycling is limited by early onset of sharp thermal stratification.

The Namakan River is the largest single source of inflow to the Park, and had water-quality similar to Namakan Lake. Their quality generally was the best found in the Park. They had moderate levels of dissolved solids, nutrient concentrations, algal productivity, and high transparency.

The Ash River generally had poorer water-quality than receiving waters in the Park. Dissolved-solids and total-phosphorus concentrations were higher than the receiving waters and transparency was low because of high algal productivity. A temperature gradient, reduced dissolved-oxygen concentrations, and the presence of sulfides and ammonia were measured in the 3-mi-long pooled reach above the mouth.

The Ash River affects the quality of Sullivan Bay during low flow, but at high flow the Ash River may affect water quality in the main part of Kabetogama Lake. It also could affect the western part of Namakan Lake.

A series of samples collected along the 3-mi pooled reach of the Ash River during low flow indicated that commercial and residential development is not degrading the quality of the Ash River. The high concentrations of total-phosphorus and high algal productivity were present upstream from the development.

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Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*

[°C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; ---, not sampled]

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
KABETOGAMA LAKE, SITE 8								
May 24, 1978	1.0	12.0	---	10.4	9.0	10.0	---	9.8
	3.0	11.0	82	10.5	12.0	10.0	---	9.6
	6.0	10.5	---	10.2				
August 16, 1978	1.0	20.3	84	8.1	9.0	20.3	84	8.0
	3.0	20.3	84	8.1	11.0	20.3	84	8.0
	6.0	20.3	84	8.1				
November 7, 1978	1.0	6.5	---	11.0	9.0	6.5	---	10.7
	3.0	6.5	90	10.8	14.0	6.5	---	10.8
May 30, 1979	3.0	10.4	91	9.9	9.0	9.9	91	10.0
	6.0	10.3	91	10.2				
August 14, 1979	3.0	19.0	88	7.9	9.0	19.0	89	7.8
	6.0	19.0	89	7.9				
August 6, 1980	1.0	20.7	86	7.2	5.0	20.6	86	7.1
	2.0	20.8	86	7.2	6.0	20.4	86	7.1
	3.0	20.7	85	7.2	7.0	20.4	86	7.1
	4.0	20.6	86	7.1	8.0	20.2	86	7.1
August 20, 1981	0.5	20.6	89	7.4	6.0	20.7	90	7.0
	3.0	20.7	90	7.2				
KABETOGAMA LAKE, SITE 9								
May 24, 1978	1.0	12.0	---	10.7	15.0	10.0	---	9.7
	3.0	12.0	82	10.7	18.0	10.0	---	9.6
	6.0	12.0	---	10.7	21.0	10.0	---	9.4
	9.0	12.0	---	10.7	24.0	10.0	---	9.1
	12.0	11.0	---	10.8	27.0	10.0	---	9.0
August 16, 1978	1.0	20.5	83	7.9	15.0	20.5	78	7.8
	6.0	20.5	78	7.8	18.0	20.5	78	7.8
	12.0	20.5	78	7.8	24.0	20.4	78	7.5
November 7, 1978	1.0	6.5	---	10.7	15.0	6.5	---	10.7
	3.0	6.5	91	10.7	21.0	6.5	---	10.7
	9.0	6.5	---	10.7	27.0	6.5	---	10.8
May 31, 1979	3.0	11.5	91	9.4	18.0	9.7	92	8.6
	6.0	11.5	91	9.3	21.0	9.1	91	8.6
	9.0	11.0	91	9.1	24.0	9.0	90	8.5
	12.0	10.6	91	9.0	27.0	8.8	90	8.1
	15.0	10.4	91	8.6				
August 14, 1979	3.0	19.5	89	8.2	21.0	19.0	90	7.7
	9.0	19.5	90	8.0	25.0	19.0	90	7.8
	15.0	19.0	90	7.8				
KABETOGAMA LAKE, SITE 10								
May 24, 1978	1.0	16.0	---	10.6	6.0	15.0	---	10.6
	3.0	16.0	60	10.8				
August 16, 1978	1.0	21.0	77	8.6	6.0	21.0	77	8.6
	3.0	21.0	77	8.6	8.0	21.0	77	8.5
November 7, 1978	1.0	7.0	---	10.8	11.0	7.0	---	10.6
	6.0	7.0	95	10.8				
May 30, 1979	3.0	9.2	72	10.1	9.0	8.4	76	9.6
	6.0	8.7	74	10.2	12.0	8.2	78	---
August 14, 1979	3.0	20.0	76	8.0	9.0	20.0	77	8.0
	6.0	20.0	77	8.0	11.0	20.0	77	7.9

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (μS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (μS/cm)	Dissolved oxygen (mg/L)
				KABETOGAMA LAKE, SITE 11				
May 14, 1978	1.0	16.0	---	10.7	12.0	11.5	---	10.9
	3.0	16.0	---	10.8	15.0	10.5	---	10.9
	6.0	14.5	---	11.0	18.0	10.0	---	10.7
	9.0	13.0	---	11.0	20.0	9.0	---	10.6
August 16, 1978	1.0	20.8	78	8.1	18.0	20.9	77	8.0
	6.0	20.9	77	8.0	23.0	20.9	77	8.0
	12.0	20.9	77	8.1				
November 7, 1978	1.0	7.0	---	10.4	21.0	7.0	---	10.3
	3.0	7.0	---	10.4	27.0	7.0	---	10.3
	9.0	7.0	97	10.3	33.0	7.0	---	10.2
	15.0	7.0	---	10.3	39.0	7.0	---	10.2
May 30, 1979	3.0	11.2	66	9.5	27.0	7.5	88	9.3
	9.0	10.0	73	9.4	33.0	7.5	88	9.5
	15.0	7.9	84	9.1	36.0	7.5	88	9.5
	21.0	7.6	87	9.2				
August 14, 1979	3.0	20.0	79	7.7	24.0	20.0	---	7.4
	6.0	20.3	80	7.6	27.0	20.0	78	7.4
	9.0	20.3	80	7.5	30.0	20.0	---	7.3
	12.0	20.0	---	7.5	33.0	20.0	78	7.3
	15.0	20.0	80	7.5	36.0	20.0	78	7.3
	18.0	20.0	---	7.5	38.0	20.0	78	7.2
	21.0	20.0	79	7.4				
May 14, 1980	0.5	10.5	---	9.7	18.0	10.0	---	9.4
	3.0	10.5	---	9.7	21.0	10.0	---	9.4
	6.0	10.0	---	9.6	24.0	10.0	---	9.3
	9.0	10.0	78	9.6	27.0	9.5	---	9.3
	12.0	10.0	---	9.6	30.0	9.0	---	9.1
	15.0	10.0	---	9.4	33.0	9.0	---	8.8
August 4, 1980	1.0	22.7	70	8.0	21.0	22.1	74	7.5
	3.0	22.7	70	8.0	24.0	22.1	76	7.5
	6.0	22.7	70	8.0	27.0	21.7	78	6.7
	9.0	22.7	70	8.0	30.0	21.2	81	4.7
	12.0	22.6	70	8.0	33.0	19.9	82	2.4
	15.0	22.5	70	7.9	36.0	19.3	84	1.8
	18.0	22.3	73	7.7	39.0	19.2	84	1.5
May 6, 1981	0.5	10.1	61	10.9	19.7	8.2	55	10.9
	3.3	9.7	61	11.0	23.0	7.9	55	11.0
	6.6	9.3	60	11.0	26.2	7.2	58	11.1
	9.8	9.1	60	11.0	29.5	6.9	58	11.1
	13.1	8.8	58	11.1	32.8	6.6	62	10.9
	16.4	8.4	56	11.0	36.1	6.4	63	10.9
August 19, 1981	0.5	22.8	78	8.3	21.0	21.7	76	5.5
	3.0	22.7	78	8.2	24.0	21.6	79	5.0
	6.0	22.4	77	7.8	27.0	21.2	70	4.0
	9.0	22.3	77	7.9	30.0	20.5	77	2.8
	12.0	22.3	77	7.9	33.0	19.8	80	1.9
	15.0	22.3	76	7.4	36.0	19.4	83	1.4
	18.0	22.1	72	6.7				
May 17, 1982	0.5	11.9	102	10.5	19.7	9.5	87	7.8
	3.3	11.9	101	10.2	23.0	9.0	87	7.3
	6.6	10.5	89	10.0	26.2	8.6	87	7.5
	9.8	10.2	85	9.8	29.5	8.5	87	9.7
	13.1	10.1	84	8.8	32.8	8.4	87	12.7
	16.4	10.0	84	8.2	36.1	8.3	87	13.9
August 18, 1982	0.5	22.3	74	11.2	23.0	20.0	74	5.2
	3.3	22.3	74	11.2	26.2	19.8	80	5.1
	6.6	22.3	70	9.9	29.5	19.7	83	5.2
	9.8	21.9	72	9.2	32.8	19.6	83	4.8
	13.1	21.8	72	8.6	36.1	19.5	84	4.3
	16.4	20.9	64	6.7	38.7	19.5	85	4.0
	19.7	20.3	60	5.9				

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
				KABETOGAMA LAKE, SITE 11--Continued				
May 25,	0.5	12.7	76	10.3	19.7	12.0	84	9.0
1983	3.3	12.6	76	11.5	23.0	12.0	83	3.4
	6.6	12.5	77	11.2	26.2	11.9	83	2.8
	9.8	12.3	80	10.0	29.5	11.6	83	2.5
	13.1	12.2	80	9.8	32.8	11.3	80	2.4
	16.4	12.1	81	9.4				
August 23,	1.0	24.9	70	8.4	23.0	23.1	68	6.4
1983	3.3	24.1	67	8.0	26.2	23.1	71	6.6
	6.6	24.0	67	7.4	29.5	22.9	75	6.3
	9.8	23.2	68	6.6	32.8	22.4	81	4.0
	13.1	23.2	67	6.5	36.1	22.2	84	3.1
	16.4	23.2	66	6.4	39.4	21.8	87	3.5
	19.7	23.1	67	6.4	41.0	21.6	90	1.6
				KABETOGAMA LAKE, SITE 17				
May 14,	0.5	9.0	---	10.4	18.0	8.5	---	9.7
1980	3.0	9.0	---	10.4	21.0	8.5	---	9.6
	6.0	9.0	---	10.4	24.0	8.5	---	9.5
	9.0	8.5	105	10.2	27.0	8.5	---	9.4
	12.0	8.5	---	9.9	30.0	8.0	---	8.8
	15.0	8.5	---	9.7				
August 6,	1.0	21.0	85	7.3	18.0	20.7	85	7.0
1980	3.0	21.0	84	7.3	21.0	20.7	85	7.0
	6.0	20.8	85	7.2	24.0	20.7	85	7.0
	9.0	20.8	85	7.2	27.0	20.7	85	7.0
	12.0	20.8	85	7.0	30.0	20.7	84	7.0
	15.0	20.7	85	7.0	32.0	20.7	84	7.0
May 6,	0.5	11.8	85	10.2	19.7	8.0	83	10.8
1981	3.3	9.5	85	10.6	23.0	7.9	82	10.9
	6.6	8.9	84	10.6	26.2	7.4	81	10.9
	9.8	8.7	84	10.7	29.5	6.8	82	10.9
	13.1	8.5	83	10.7	32.8	6.7	82	10.6
	16.4	8.4	83	10.7				
August 20,	0.5	21.4	89	8.2	18.0	21.4	88	8.1
1981	3.0	21.4	89	8.3	21.0	21.4	88	8.2
	6.0	21.4	89	8.2	24.0	21.4	88	8.0
	9.0	21.4	89	8.3	27.0	21.3	88	8.1
	12.0	21.4	89	8.0	30.0	20.5	95	3.6
	15.0	21.4	89	8.1	33.0	20.3	96	2.9
May 17,	0.5	10.3	85	12.1	19.7	9.6	83	12.0
1982	3.3	10.3	85	12.0	23.0	9.6	83	12.1
	6.6	10.3	85	12.1	26.2	9.5	83	12.0
	9.8	9.9	84	11.9	29.5	9.4	82	12.1
	13.1	9.7	84	12.0	32.8	9.4	82	11.9
	16.4	9.7	83	12.1				
August 18,	0.5	21.6	90	11.0	19.7	20.8	88	8.6
1982	3.3	21.6	89	11.0	23.0	20.4	88	8.0
	6.6	21.6	89	10.8	26.2	20.1	88	7.2
	9.8	21.6	89	10.6	29.5	19.8	88	6.7
	13.1	21.1	88	9.2	31.5	19.6	87	6.1
	16.4	21.1	88	9.2				
May 25,	0.5	11.2	87	10.0	16.4	11.2	87	9.4
1983	3.3	11.3	87	10.2	19.7	11.2	86	7.4
	6.6	11.3	87	10.9	23.0	11.2	86	7.2
	9.8	11.2	87	11.0	26.2	11.2	86	6.8
	13.1	11.2	87	9.8	29.5	11.2	86	6.4
August 23,	1.0	24.4	89	11.2	19.7	22.3	86	7.1
1983	3.3	23.8	89	11.3	23.0	22.2	86	6.8
	6.6	23.4	87	10.7	26.2	22.2	85	6.7
	9.8	23.4	86	10.4	29.5	22.2	85	6.8
	13.1	22.4	85	7.9	32.8	22.1	86	6.2
	16.4	22.3	86	7.2				

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
				KABETOGAMA LAKE, SITE 18				
May 14, 1980	0.5	11.5	---	9.8	18.0	10.5	---	8.9
	3.0	11.5	---	9.6	21.0	10.0	---	8.6
	6.0	11.0	---	9.5	24.0	10.0	---	7.4
	9.0	11.0	107	9.6	27.0	7.0	---	3.2
	12.0	11.0	---	9.2	28.5	6.0	---	3.0
	15.0	10.5	---	9.2				
August 6, 1980	1.0	22.6	82	7.2	21.0	21.6	81	6.6
	3.0	22.2	82	7.2	24.0	21.6	81	6.5
	6.0	21.9	82	7.1	27.0	20.5	81	3.0
	9.0	21.8	82	6.9	30.0	14.9	104	1.8
	12.0	21.8	82	6.8	33.0	11.8	122	2.0
	15.0	21.7	82	6.6	35.0	10.9	133	2.1
	18.0	21.7	81	6.6				
May 6, 1981	0.5	10.7	77	10.4	19.7	6.8	77	10.3
	3.3	10.6	77	10.5	23.0	6.6	77	10.2
	6.6	10.0	77	10.4	26.2	6.5	77	9.7
	9.8	9.1	76	10.2	29.5	6.2	76	9.6
	13.1	7.5	78	10.5	32.8	5.9	74	8.2
	16.4	7.1	77	10.5	35.0	5.9	74	7.3
August 20, 1981	0.5	22.9	88	8.9	21.0	21.7	86	4.7
	3.0	22.9	88	8.7	24.0	21.1	86	3.0
	6.0	22.9	88	8.5	27.0	19.4	83	1.5
	9.0	22.9	88	8.5	30.0	17.6	101	1.5
	12.0	22.9	87	8.4	33.0	14.0	116	1.7
	15.0	22.9	87	8.4	36.0	12.9	138	1.7
	18.0	22.5	87	7.4				
May 17, 1982	0.5	10.6	78	---	19.7	9.8	81	---
	3.3	10.5	78	---	23.0	9.3	81	---
	6.6	10.5	78	---	26.2	8.7	83	---
	9.8	10.3	78	---	29.5	8.4	85	---
	13.1	10.2	77	---	32.8	8.2	84	---
	16.4	10.1	80	---				
August 18, 1982	0.5	23.4	90	12.2	19.7	20.5	85	5.7
	3.3	23.3	89	12.0	23.0	20.3	85	5.2
	6.6	23.1	88	11.6	26.2	20.1	84	4.2
	9.8	22.6	86	10.5	29.5	19.4	85	2.5
	13.1	21.7	83	8.5	32.8	14.6	115	0.4
	18.4	21.0	83	6.8	36.1	11.6	134	0.3
May 25, 1983	0.5	13.0	86	10.1	19.7	12.1	87	6.0
	3.3	13.0	86	9.8	23.0	11.0	86	5.4
	6.6	13.0	86	10.0	26.2	10.8	85	5.0
	9.8	13.0	86	9.6	28.5	9.6	83	4.2
	13.1	13.0	86	8.0	32.8	9.1	82	3.4
	16.4	12.5	86	6.8				
August 23, 1983	1.0	25.7	85	9.4	19.7	23.4	82	6.5
	3.3	24.5	84	9.3	23.0	23.3	82	5.0
	6.6	23.8	83	8.2	26.2	22.9	81	4.4
	9.8	23.7	82	7.6	29.5	19.4	100	0.5
	13.1	23.6	82	7.3	32.8	15.2	123	0.6
	16.4	23.6	82	7.1	34.4	13.0	144	0.6
				KABETOGAMA LAKE, SITE 19				
August 6, 1980	1.0	21.1	87	7.9	8.0	20.6	87	7.5
	2.0	21.0	87	7.9	9.0	20.7	87	7.4
	3.0	20.9	88	7.9	10.0	20.6	87	7.4
	4.0	20.7	88	7.9	11.0	20.6	87	7.4
	5.0	20.7	88	7.8	12.0	20.6	87	7.4
	6.0	20.7	87	7.7	13.0	20.6	87	7.4
	7.0	20.7	87	7.6				
August 20, 1981	0.5	21.0	92	7.5	12.0	20.9	91	7.3
	3.0	21.0	92	7.3	15.0	20.9	91	7.2
	6.0	21.0	91	7.4	18.0	20.8	90	7.3
	9.0	20.9	91	7.5				

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
RAINY LAKE BELOW KETTLE FALLS, SITE 3								
May 23,	1.0	12.0	---	11.6	9.0	9.0	---	12.0
1978	3.0	10.0	46	12.1	12.0	9.0	---	11.9
	6.0	9.0	---	12.0				
August 15,	1.0	20.8	41	8.2	9.0	20.8	35	8.2
1978	3.0	20.8	41	8.2	12.0	20.8	35	8.1
	6.0	20.8	41	8.2				
November 8,	1.0	7.5	---	10.4	12.0	7.5	---	10.6
1978	6.0	7.5	44	10.6	13.0	7.5	---	10.6
May 31,	3.0	11.6	41	9.3	24.0	11.6	40	6.6
1979	6.0	11.6	41	9.3	27.0	11.6	40	7.1
	9.0	11.6	40	8.8	30.0	11.6	40	6.5
	12.0	11.6	40	8.3	33.0	11.6	40	5.7
	15.0	11.6	40	7.8	36.0	11.6	40	7.0
	18.0	11.6	40	7.3	39.0	11.6	40	6.2
	21.0	11.6	40	6.9				
August 15,	3.0	20.0	41	---	27.0	19.0	42	---
1979	9.0	19.5	42	---	33.0	19.0	42	---
	15.0	19.5	42	---	36.0	18.0	43	---
	21.0	19.5	42	---				
RAINY LAKE IN KETTLE CHANNEL, SITE 4								
May 23, 1978	4.0	10.5	46	11.7	8.0	10.0	---	11.5
August 15,	1.0	20.8	41	8.2	6.0	20.7	35	8.2
1978	3.0	20.7	35	8.2	8.0	20.6	30	8.2
November 8,	1.0	7.0	---	11.1	7.0	6.0	---	11.3
1978	4.0	6.5	45	11.2				
May 31, 1979	3.0	11.3	41	8.7	6.0	11.3	41	8.0
August 15, 1979	3.0	19.0	41	---	6.0	18.5	42	---
RAINY LAKE AT BRULE NARROWS, SITE 5								
May 23,	1.0	10.0	---	12.8	15.0	7.0	---	12.6
1978	3.0	10.0	---	12.9	18.0	6.5	---	12.4
	6.0	9.5	41	13.0	21.0	5.5	---	12.1
	9.0	7.5	---	12.9	23.0	5.0	---	11.8
	12.0	7.0	---	12.7				
August 15,	1.0	21.0	40	8.2	12.0	20.7	41	8.2
1978	3.0	21.0	40	8.2	15.0	20.6	41	8.1
	6.0	21.0	40	8.2	18.0	20.0	41	7.9
	9.0	20.9	41	8.2	20.0	19.6	42	7.8
November 8,	1.0	7.5	---	10.8	12.0	7.5	---	10.9
1978	6.0	7.5	46	10.9				
May 31,	3.0	9.8	45	8.7	15.0	8.8	43	8.2
1979	6.0	9.7	43	8.6	18.0	8.8	43	7.4
	9.0	9.1	43	8.6	21.0	8.8	43	7.5
	12.0	9.1	43	8.3	24.0	8.7	43	8.5
August 15,	3.0	18.0	43	---	15.0	16.5	44	---
1979	9.0	17.5	44	---	17.0	16.5	44	---
May 13,	0.5	6.5	---	11.5	12.0	6.5	---	11.4
1980	3.0	6.5	---	11.4	15.0	6.0	---	11.4
	6.0	6.5	---	11.4	18.0	6.0	---	11.4
	9.0	6.5	58	11.4				

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
				RAINY LAKE AT BRULE NARROWS, SITE 5--Continued				
August 5, 1980	1.0	20.5	---	8.2	6.0	20.0	49	8.2
	3.0	20.0	---	8.2				
May 5, 1981	0.5	5.2	41	11.9	13.1	5.2	40	12.1
	3.3	5.2	41	12.2	16.4	5.2	40	12.1
	6.6	5.1	40	12.2	19.7	5.1	40	12.2
	9.8	5.2	40	12.2				
August 18, 1981	0.5	20.8	45	7.5	12.0	20.8	45	7.2
	3.0	20.8	45	7.3	15.0	20.7	45	7.3
	6.0	20.8	45	7.3	18.0	20.7	44	7.2
	9.0	20.8	45	7.2	21.0	20.7	44	7.3
May 19, 1982	0.5	7.2	41	12.5	9.8	6.6	41	12.4
	3.3	7.4	41	12.5	13.1	6.4	40	12.5
	6.6	7.2	43	12.5	16.4	6.3	40	12.5
August 16, 1982	0.5	21.0	43	10.2	9.8	19.7	42	9.7
	3.3	20.9	43	10.1	13.1	19.5	41	9.5
	6.6	20.8	42	10.0	15.1	19.5	42	9.6
May 23, 1983	0.5	8.2	42	11.4	9.8	7.8	41	11.3
	3.3	8.0	42	11.4	13.1	7.8	41	11.2
	6.6	7.9	42	11.3	16.4	7.8	41	11.3
August 22, 1983	1.0	21.5	46	8.1	13.1	21.0	45	8.0
	3.3	21.5	46	8.1	16.4	20.1	44	7.8
	6.6	21.4	46	8.1	19.7	19.7	44	7.7
	9.8	21.3	46	8.0				
				NAMAKAN LAKE, SITE 14				
November 7, 1978	1.0	8.0	---	9.9	18.0	8.0	---	9.9
	3.0	8.0	---	10.0	30.0	8.0	---	9.8
	6.0	8.0	44	9.9	42.0	8.0	---	9.8
	12.0	8.0	---	9.9				
May 29, 1979	3.3	13.8	39.5	10.0	6.6	13.9	39.5	10.0
August 14, 1979	3.0	20.5	41	8.3	51.0	12.5	41	---
	9.0	20.5	41	8.3	54.0	11.5	41	6.8
	15.0	20.5	41	8.2	57.0	11.5	41	---
	21.0	20.5	41	8.2	60.0	11.0	41	7.0
	27.0	20.5	41	8.1	66.0	10.0	42	7.0
	33.0	20.0	40	8.2	72.0	9.5	42	7.1
	36.0	20.0	39	8.2	78.0	9.3	42	7.2
	42.0	18.0	40	7.7	84.0	9.0	42	7.3
	45.0	15.0	40	6.8	90.0	9.1	42	7.3
	48.0	13.0	41	6.9				
May 14, 1980	0.5	7.0	---	10.6	27.0	6.0	---	10.4
	3.0	7.0	---	10.6	30.0	6.0	---	10.4
	6.0	7.0	---	10.6	33.0	6.0	---	10.4
	9.0	6.5	---	10.6	36.0	6.0	---	10.3
	12.0	6.5	68	10.4	39.0	6.0	---	10.1
	15.0	6.5	---	10.4	42.0	6.0	---	10.2
	18.0	6.5	---	10.4	45.0	6.0	---	10.2
	21.0	6.0	---	10.4	48.0	5.5	---	10.2
	24.0	6.0	---	10.4				
August 7, 1980	1.0	21.2	43	8.0	33.0	19.3	41	7.6
	3.0	21.0	42	7.9	35.0	18.9	41	7.5
	9.0	20.4	42	7.9	37.0	18.3	41	7.5
	15.0	20.1	42	7.8	39.0	15.8	40	7.4
	21.0	20.0	42	7.7	45.0	12.5	40	7.9
	27.0	19.7	41	7.7	51.0	11.1	40	8.2
	29.0	19.6	41	7.6	57.0	9.9	40	8.3
	31.0	19.5	41	7.6	60.0	9.7	39	8.3

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
NAMAKAN LAKE, SITE 14--Continued								
May 6, 1981	0.5	7.8	41	10.8	36.1	6.7	39	10.8
	3.3	7.6	41	10.9	39.4	6.3	39	10.9
	6.6	7.4	41	10.9	42.6	6.1	39	10.9
	9.8	7.3	41	10.9	45.9	6.1	39	10.9
	13.1	7.3	41	10.9	49.2	5.8	39	11.0
	16.4	7.2	40	11.0	52.5	5.6	38	10.9
	19.7	7.2	40	10.9	55.8	5.4	38	10.8
	23.0	7.2	40	10.8	59.1	5.3	39	11.0
	26.2	7.2	40	10.8	62.3	5.2	39	11.0
	29.5	7.1	40	10.8	65.6	5.1	38	11.0
	32.8	7.0	39	10.9	68.9	4.9	39	11.2
August 19, 1981	0.5	21.8	43	7.2	33.0	20.0	42	5.9
	3.0	21.8	43	7.2	36.0	18.1	42	5.3
	6.0	21.7	43	6.9	39.0	16.7	42	5.6
	9.0	21.7	43	6.9	42.0	15.8	42	5.6
	12.0	21.7	43	6.8	45.0	14.1	42	5.8
	15.0	21.7	42	6.9	48.0	13.6	42	6.3
	18.0	21.7	42	6.8	51.0	13.3	41	6.5
	21.0	21.6	42	6.8	54.0	12.8	41	7.0
	24.0	21.4	42	6.2	57.0	11.7	41	7.2
	27.0	21.2	42	6.4	60.0	10.7	41	7.2
	30.0	20.7	42	5.9				
May 17, 1982	0.5	8.2	46	---	36.1	7.3	45	---
	3.3	8.2	46	---	39.4	7.2	45	---
	6.6	8.1	46	---	42.6	7.2	45	---
	9.8	7.9	46	---	45.9	7.2	45	---
	13.1	7.9	46	---	49.2	7.1	45	---
	16.4	7.8	46	---	52.5	7.1	45	---
	19.7	7.6	46	---	55.8	7.1	45	---
	23.0	7.5	45	---	59.1	7.0	44	---
	26.2	7.5	45	---	62.3	6.9	44	---
	29.5	7.4	45	---	65.6	6.9	44	---
	32.8	7.3	45	---				
August 18, 1982	0.5	22.0	41	8.1	36.1	19.2	40	6.8
	3.3	21.8	41	8.0	39.4	19.0	40	6.7
	6.6	21.5	41	7.8	42.6	18.3	40	6.6
	9.8	20.8	40	7.8	45.9	17.3	40	6.3
	13.1	20.4	40	7.3	49.2	15.1	40	6.2
	16.4	20.4	40	7.3	52.5	14.6	39	6.2
	19.7	20.1	40	7.2	55.8	13.4	39	6.2
	23.0	20.0	40	7.2	59.1	12.6	38	6.4
	26.2	19.7	40	7.0	62.3	12.3	37	6.3
	29.5	19.6	40	7.0	65.6	11.2	37	6.3
	32.8	19.3	40	6.9				
May 25, 1983	0.5	10.1	46	11.4	32.8	9.3	43	---
	3.3	10.1	46	11.7	36.1	9.2	43	---
	6.6	10.1	46	10.2	39.4	9.0	42	---
	9.8	10.0	45	10.0	42.6	8.7	42	---
	13.1	10.0	45	10.0	45.9	8.3	42	---
	16.4	10.0	45	---	49.2	8.0	41	---
	19.7	10.0	44	---	52.5	7.6	41	---
	23.0	9.6	44	---	55.8	7.4	40	---
	26.2	9.4	44	---	59.1	7.4	40	---
	29.5	9.4	44	---				
August 23, 1983	1.0	23.4	41	7.7	36.1	21.2	40	6.5
	3.3	22.9	41	7.6	39.4	19.5	41	6.1
	6.6	22.8	41	7.6	42.6	17.7	41	6.0
	9.8	22.8	41	7.5	45.9	16.7	41	6.2
	13.1	22.8	41	7.5	49.2	15.9	41	6.3
	16.4	22.8	41	7.5	52.5	14.4	40	6.6
	19.7	22.8	40	7.5	55.8	13.2	40	6.9
	23.0	22.8	40	7.5	59.1	12.3	40	7.1
	26.2	22.6	40	7.3	62.3	11.6	40	7.2
	29.5	22.4	40	7.2	65.6	10.9	40	7.2
	32.8	22.1	40	7.0				

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
				NAMAKAN LAKE ABOVE KETTLE FALLS, SITE 15				
May 14, 1980	0.5	8.0	---	11.2	27.0	6.0	---	10.6
	3.0	7.4	---	11.1	30.0	6.0	---	10.4
	6.0	7.0	---	11.1	33.0	6.0	---	10.4
	9.0	7.0	62	11.0	36.0	6.0	---	10.4
	12.0	7.0	---	11.0	39.0	6.0	---	10.4
	15.0	6.5	---	10.8	42.0	6.0	---	10.4
	18.0	6.0	---	10.6	45.0	6.0	---	10.3
	21.0	6.0	---	10.6	48.0	6.0	---	10.3
	24.0	6.0	---	10.6				
August 7, 1980	1.0	24.0	46	8.0	33.0	15.3	45	6.9
	3.0	21.6	46	8.1	36.0	14.6	44	7.1
	9.0	21.2	46	7.9	42.0	12.9	44	7.7
	15.0	21.0	46	7.7	48.0	11.3	43	8.4
	21.0	20.6	45	7.6	54.0	9.9	43	8.6
	27.0	18.1	45	6.9	60.0	8.6	42	7.4
	30.0	16.4	45	6.7				
May 6, 1981	0.5	6.0	46	11.5	36.1	5.9	43	11.5
	3.3	6.0	46	11.6	39.4	5.9	42	11.5
	6.6	5.9	45	11.6	42.6	5.9	42	11.5
	9.8	5.9	45	11.6	45.9	5.9	42	11.5
	13.1	5.9	45	11.6	49.2	5.9	42	11.5
	16.4	5.9	45	11.6	52.5	5.9	41	11.5
	19.7	5.9	44	11.6	55.8	5.9	41	11.5
	23.0	5.9	44	11.6	59.1	5.9	41	11.5
	26.2	5.9	44	11.6	62.3	5.9	41	11.5
	29.5	5.9	44	11.6	65.6	5.9	41	11.5
	32.8	5.9	43	11.5				
August 19, 1981	0.5	22.4	44	7.4	33.0	20.1	43	6.3
	3.0	22.3	44	7.4	36.0	19.5	43	5.9
	6.0	22.1	44	7.3	39.0	19.4	43	6.0
	9.0	22.1	44	7.2	42.0	19.1	43	5.9
	12.0	22.0	43	7.0	45.0	18.8	42	5.9
	15.0	21.7	43	7.0	48.0	18.5	42	5.7
	18.0	21.7	43	6.9	51.0	18.4	42	5.4
	21.0	21.7	43	7.0	54.0	18.2	42	5.5
	24.0	21.3	43	6.8	57.0	18.1	42	5.3
	27.0	20.7	43	6.6	60.0	17.8	42	5.4
	30.0	20.3	43	6.3				
May 17, 1982	0.5	7.6	48	13.0	32.8	7.6	42	12.7
	3.3	7.6	48	13.0	36.1	7.5	42	12.7
	6.6	7.6	48	13.0	39.4	7.5	42	12.8
	9.8	7.5	48	13.0	42.6	7.5	42	12.7
	13.1	7.5	48	13.0	45.9	7.5	41	12.4
	16.4	7.6	44	13.0	49.2	7.5	41	12.6
	19.7	7.6	43	12.8	52.5	7.5	41	12.6
	23.0	7.6	43	12.9	55.8	7.5	41	12.6
	26.2	7.6	43	12.6	59.1	7.5	41	12.0
	29.5	7.6	43	12.6				
August 18, 1982	0.5	20.2	41	7.5	36.1	19.7	40	7.2
	3.3	20.1	41	7.4	39.4	19.7	40	7.1
	6.6	20.1	41	7.4	42.6	19.7	39	7.2
	9.8	20.1	41	7.4	45.9	19.7	39	7.1
	13.1	20.1	41	7.4	49.2	19.6	39	7.1
	16.4	20.1	40	7.4	52.5	19.6	38	7.1
	19.7	20.1	40	7.4	55.8	19.6	38	7.1
	23.0	20.1	40	7.3	59.1	19.6	38	7.1
	26.2	19.9	40	7.3	62.3	19.6	38	7.1
	29.5	19.9	40	7.3	65.6	19.6	38	7.1
	32.8	19.8	40	7.2				
May 25, 1983	0.5	9.4	47	11.1	32.8	9.0	44	---
	3.3	9.0	47	10.2	36.1	9.0	44	---
	6.6	9.0	47	7.2	39.4	9.0	44	---
	9.8	9.0	46	6.1	42.6	9.0	43	---
	13.1	9.0	46	---	45.9	9.0	43	---
	16.4	9.0	46	---	49.2	9.0	43	---
	19.7	9.0	46	---	52.5	9.0	43	---
	23.0	9.0	45	---	55.8	9.0	43	---
	26.2	9.0	45	---	59.1	8.9	42	---
	29.5	9.0	45	---				

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
NAMAKAN LAKE ABOVE KETTLE FALLS, SITE 15--Continued								
August 23, 1983	1.0	23.0	43	7.5	36.1	20.8	41	6.9
	3.3	22.8	43	7.5	39.4	19.7	41	6.6
	6.6	22.7	43	7.4	42.6	19.4	41	6.5
	9.8	22.6	43	7.4	45.9	19.1	41	6.4
	13.1	22.7	42	7.4	49.2	19.0	41	6.4
	16.4	22.5	42	7.4	52.5	19.0	40	6.4
	19.7	22.4	42	7.4	55.8	18.8	40	6.2
	23.6	22.1	42	7.2	59.1	18.6	40	6.2
	26.2	21.9	42	7.2	62.3	18.5	40	6.2
	29.5	22.0	41	7.2	65.6	18.4	40	6.1
	32.8	21.3	41	7.1	114.8	17.0	---	---
SAND POINT LAKE, SITE 6								
May 24, 1978	1.0	16.5	---	10.0	27.0	8.0	---	9.7
	3.0	16.0	46	10.0	30.0	8.0	---	9.7
	6.0	15.5	---	10.0	33.0	8.0	---	9.7
	9.0	15.0	---	9.9	36.0	7.0	---	9.7
	12.0	11.0	---	9.9	39.0	7.0	---	9.6
	15.0	10.0	---	9.9	42.0	7.0	---	9.3
	18.0	9.5	---	9.8	45.0	7.0	---	9.4
	21.0	9.0	---	9.8	48.0	6.0	---	9.3
	24.0	8.5	---	9.7	50.0	6.0	---	9.3
August 16, 1978	1.0	21.0	51	7.4	36.0	13.9	54	3.5
	3.0	20.9	51	7.3	39.0	11.0	52	3.0
	6.0	20.8	51	7.2	42.0	10.2	53	2.6
	9.0	20.4	52	6.9	45.0	9.6	54	2.4
	12.0	20.3	52	6.9	48.0	9.4	47	2.2
	15.0	20.0	52	6.7	51.0	9.3	47	0.1
	18.0	19.8	52	6.6	54.0	9.3	47	0.06
	21.0	19.5	53	6.5	57.0	9.3	40	0.05
	24.0	19.3	53	6.3	60.0	9.3	40	0.05
	27.0	18.6	54	6.0	63.0	9.3	47	0.05
	30.0	17.5	55	5.2	66.0	9.3	47	0.05
	33.0	15.9	51	4.3				
November 7, 1978	1.0	7.0	---	9.7	24.0	7.5	---	9.5
	3.0	7.0	---	9.6	27.0	7.5	---	9.5
	6.0	7.0	54	9.6	30.0	7.5	---	9.6
	9.0	7.0	---	9.6	33.0	7.5	---	9.5
	12.0	7.0	---	9.5	36.0	7.5	---	9.5
	15.0	7.0	---	9.5	39.0	7.5	---	9.5
	18.0	7.5	---	9.5	42.0	7.5	---	9.6
	21.0	7.5	---	9.5	45.0	7.5	---	9.6
May 29, 1979	6.6	16.7	52	9.3	54.7	7.1	44	8.8
August 16, 1979	3.0	19.5	56	8.5	36.0	12.0	49	3.6
	9.0	19.5	56	8.3	39.0	11.0	50	3.5
	12.0	19.0	56	8.1	42.0	10.5	49	3.4
	18.0	19.0	56	8.0	45.0	10.0	49	3.4
	24.0	19.0	56	7.6	48.0	9.6	47	3.5
	27.0	19.0	56	7.5	51.0	9.3	47	3.5
	30.0	15.5	52	5.7	54.0	8.9	47	3.3
	33.0	13.0	52	3.8	57.0	8.8	47	3.2
August 7, 1980	1.0	23.5	50	7.8	30.0	14.4	47	5.1
	3.0	22.9	50	7.9	33.0	12.9	47	5.4
	6.0	21.8	50	7.8	36.0	11.7	46	5.3
	12.0	20.8	50	7.7	39.0	10.6	46	5.4
	18.0	20.5	49	7.4	42.0	10.0	46	5.3
	20.0	20.3	49	7.4	45.0	9.2	46	5.3
	22.0	18.2	48	5.7	48.0	9.0	45	5.2
	24.0	16.8	48	5.5	51.0	8.6	44	5.2
	26.0	15.8	48	5.1	54.0	8.3	45	4.9
	28.0	14.8	48	5.1	57.0	8.0	45	4.6

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
				SAND POINT LAKE, SITE 7				
May 24, 1978	1.0	14.0	---	10.2	18.0	9.0	---	10.2
	3.0	13.5	---	10.1	21.0	8.0	---	10.0
	6.0	13.0	44	10.2	24.0	8.0	---	10.0
	9.0	12.0	---	10.7	27.0	7.0	---	10.0
	12.0	11.5	---	10.5	29.0	6.0	---	9.9
	15.0	11.0	---	10.4				
August 16, 1978	1.0	20.8	51	7.6	21.0	20.7	51	7.6
	3.0	20.8	51	7.6	24.0	20.7	51	7.6
	6.0	20.8	51	7.6	27.0	20.7	51	7.6
	9.0	20.7	51	7.6	30.0	20.6	51	7.6
	12.0	20.8	51	7.6	33.0	18.4	48	7.3
	15.0	20.7	51	7.6	36.0	17.4	50	5.5
	18.0	20.7	51	7.6				
November 7, 1978	1.0	7.0	---	8.9	18.0	7.0	---	8.8
	6.0	7.0	52	8.8	24.0	7.0	---	8.7
	12.0	7.0	---	8.8	30.0	7.0	---	8.6
May 29, 1979	6.6	14.8	46	10.4				
August 16, 1979	3.0	19.0	53	8.4	18.0	19.0	52	8.1
	6.0	19.0	53	8.4	21.0	19.0	52	8.1
	12.0	19.0	53	8.3				
May 12, 1980	0.5	9.8	---	9.3	21.0	9.3	---	9.2
	3.0	9.8	---	9.3	24.0	9.1	---	9.2
	6.0	9.8	---	9.4	27.0	9.0	---	9.1
	9.0	9.8	70	9.3	30.0	8.8	---	9.1
	12.0	9.7	---	9.2	33.0	6.9	---	8.9
	15.0	9.7	---	9.3	36.0	6.0	---	8.4
	18.0	9.5	---	9.2				
August 7, 1980	1.0	23.4	50	7.9	18.0	20.6	49	7.6
	3.0	22.3	50	8.0	21.0	20.6	49	7.5
	6.0	21.6	50	8.0	24.0	20.4	49	7.5
	9.0	21.5	50	8.0	27.0	18.7	49	6.6
	12.0	21.1	49	7.9	30.0	14.9	48	5.6
	15.0	21.0	49	7.8				
May 4, 1981	0.5	7.7	44	10.1	21.0	7.3	42	10.6
	3.0	7.7	43	10.4	24.0	7.0	42	10.6
	6.0	7.6	43	10.5	27.0	6.9	42	10.6
	9.0	7.6	43	10.5	30.0	6.6	42	10.5
	12.0	7.6	43	10.5	33.0	5.8	43	10.5
	15.0	7.6	42	10.5	35.0	5.5	43	10.5
	18.0	7.5	42	10.5				
August 17, 1981	0.5	21.9	59	7.2	12.0	21.6	59	6.4
	3.0	21.9	59	7.2	15.0	21.2	56	6.5
	6.0	21.8	59	6.8	18.0	21.0	56	5.9
	9.0	21.7	59	6.8	20.0	20.8	55	5.8
May 18, 1982	0.5	13.5	44	9.8	9.8	13.2	43	9.6
	3.3	13.4	44	9.5	13.1	13.2	43	9.6
	6.6	13.4	43	9.6				
August 17, 1982	0.5	22.0	---	7.8	9.8	22.0	54	7.9
	3.3	22.0	---	7.9	11.2	22.0	---	7.8
	6.6	22.0	---	7.9				
May 26, 1983	0.5	11.7	50	9.6	13.1	11.5	49	7.6
	3.3	11.6	49	10.4	16.4	11.5	48	7.0
	6.6	11.5	49	9.4	19.7	11.5	48	6.4
	9.8	11.5	49	8.7	23.0	11.5	48	6.0
August 25, 1983	1.0	23.0	56	7.4	19.7	22.3	54	7.0
	3.3	23.0	56	7.5	23.0	21.6	54	5.9
	6.6	22.8	56	7.5	26.2	20.3	54	4.5
	9.8	22.7	56	7.4	29.5	17.8	53	3.4
	13.1	22.7	55	7.4	32.8	17.8	53	3.4
	16.4	22.5	55	7.2				

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
			SULLIVAN BAY AT MOUTH OF ASH RIVER, SITE 12					
November 6, 1978	1.0	4.0	---	12.2	9.0	4.0	---	12.4
	3.0	4.0	235	12.3	12.0	4.0	---	12.4
	6.0	4.0	---	12.4	15.0	4.0	---	12.4
May 30, 1979	3.0	16.4	166	7.9	6.0	16.4	166	7.9
August 13, 1979	3.0	20.0	181	8.7	6.0	20.0	187	8.6
May 15, 1980	0.5	11.0	---	9.7	6.0	11.0	---	9.7
	3.0	11.0	205	9.7	7.8	11.0	---	9.5
August 4, 1980	1.0	22.7	157	8.4	9.0	22.3	160	7.6
	3.0	22.7	158	8.3	11.0	22.3	160	7.3
	6.0	22.4	158	7.6				
May 6, 1981	0.5	15.3	156	9.3	9.8	11.8	154	9.3
	3.3	13.8	156	9.5	13.1	11.8	154	9.2
	6.6	12.3	154	9.4				
August 19, 1981	0.5	23.2	191	8.8	6.0	22.2	197	7.0
	3.0	23.1	191	8.8				
May 17, 1982	0.5	15.1	149	13.5	6.0	15.1	151	11.1
	3.3	15.1	151	11.9				
August 16, 1982	1.0	24.5	---	11.9	4.9	24.0	---	11.8
	1.6	24.0	---	12.0	6.6	23.0	---	10.6
	3.3	24.0	158	11.8				
May 25, 1983	0.5	14.1	210	9.0	6.6	13.7	210	9.4
	3.3	13.8	210	9.3	9.8	13.7	210	9.4
August 23, 1983	1.0	25.7	196	13.3	9.8	22.1	193	5.0
	3.3	23.5	193	19.6	11.5	22.0	201	3.7
	6.6	22.4	193	5.9				
			SULLIVAN BAY, SITE 13					
November 6, 1978	1.0	4.5	---	11.9	9.0	4.5	---	12.1
	3.0	4.5	180	11.9	12.0	4.5	---	12.1
	6.0	4.5	---	12.0	15.0	4.5	---	12.2
May 30, 1979	3.0	17.5	145	8.7	15.0	9.3	92	7.7
	6.0	17.5	146	8.7	18.0	8.9	86	8.3
	9.0	17.5	147	8.4	21.0	8.7	86	7.9
	12.0	9.6	142	7.7	24.0	8.7	84	8.5
August 13, 1979	3.0	20.5	151	9.2	15.0	20.5	154	9.3
	6.0	20.5	153	9.2	18.0	20.5	155	9.3
	9.0	20.5	154	9.2	21.0	20.5	156	9.3
	12.0	20.5	154	9.2	23.0	20.5	157	9.3
May 15, 1980	0.5	11.0	---	9.7	6.0	11.0	179	9.5
	3.0	11.0	---	9.7	9.5	11.0	---	9.4
August 4, 1980	1.0	22.9	132	10.6	12.0	22.6	121	9.4
	3.0	22.8	132	10.6	15.0	22.5	126	9.4
	6.0	22.8	134	10.3	18.0	22.4	128	9.4
	9.0	22.7	124	10.0	21.0	22.4	129	9.3
May 6, 1981	0.5	13.0	145	9.4	13.1	11.4	149	8.8
	3.3	12.7	145	9.5	16.4	10.9	148	8.3
	6.6	12.2	145	9.4	19.7	10.5	149	7.8
	9.8	12.2	145	9.5	22.5	10.2	147	7.7
August 19, 1981	0.5	22.8	154	9.2	12.0	21.5	179	3.2
	3.0	22.7	155	9.2	15.0	21.4	181	3.1
	6.0	21.9	143	7.2	18.0	21.4	182	2.5
	9.0	21.6	172	4.3	21.0	21.4	188	2.2

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
SULLIVAN BAY, SITE 13--Continued								
May 17,	0.5	15.3	140	8.6	9.8	15.3	141	9.2
1982	3.3	15.3	140	8.8	13.1	15.3	141	9.3
	6.6	15.2	141	8.7	16.4	15.3	141	9.5
August 18,	0.5	22.0	132	10.4	9.8	21.4	139	8.0
1982	3.3	22.0	132	10.4	13.1	19.8	157	0.5
	6.6	22.0	132	10.4	15.1	19.4	162	0.2
May 25,	0.5	14.9	207	9.2	9.8	14.4	208	9.1
1983	3.3	14.6	207	10.1	13.1	14.3	208	9.3
	6.6	14.4	207	9.0	16.4	14.3	208	7.0
August 23,	1.0	25.1	156	12.3	16.4	22.4	172	4.8
1983	3.3	24.5	156	11.8	19.7	22.3	174	4.4
	6.6	22.8	156	8.8	23.0	22.3	175	3.9
	9.8	22.6	155	7.6	24.6	22.3	175	3.7
	13.1	22.6	160	6.5				
BLACK BAY, SITE 1								
May 22, 1978	3.0	16.0	---	9.9	7.5	15.5	---	---
August 14,	1.0	22.2	80	8.4	6.0	22.1	81	8.3
1978	3.0	22.2	80	8.4	7.5	22.1	81	8.3
November 8,	1.0	4.5	57	11.6	7.0	4.5	---	11.7
1978	6.0	4.5	---	11.6				
May 31, 1979	3.0	15.1	73	7.6	6.0	15.2	74	7.3
August 15, 1979	3.0	18.5	90	---	6.0	18.0	91	---
BLACK BAY, SITE 2								
May 22, 1978	3.0	16.0	68	9.0	7.0	15.5	---	9.0
August 14,	1.0	22.8	89	8.4	6.0	22.7	90	8.1
1978	3.0	22.8	89	8.3	7.5	22.6	90	8.0
November 8,	1.0	6.0	85	11.0	8.0	6.0	---	10.9
1978	6.0	6.0	---	11.0				
May 31, 1979	3.0	14.6	71	7.5	6.0	14.6	71	7.5
August 15, 1979	3.0	19.0	97	---	7.0	17.5	101	---
August 5,	1.0	20.5	---	8.5	6.0	20.5	---	8.3
1980	3.0	20.5	67	8.4				
August 18,	0.5	21.1	104	7.8	6.0	21.1	104	7.0
1981	3.0	21.1	104	7.6				
BLACK BAY, SITE 16								
May 13, 1980	2.5	10.5	100	9.2				
August 5,	1.0	18.0	98	8.2	5.0	18.0	---	---
1980	3.0	18.0	---	---				
May 5,	0.5	10.3	82	9.5	3.0	10.2	82	9.6
1981	2.0	10.3	83	9.6				

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
BLACK BAY, SITE 16--Continued								
August 18, 1981	0.5	20.9	93	6.9	6.0	20.7	92	6.0
	3.0	20.9	92	6.8				
May 19, 1982	0	14.4	78	9.3	6.6	14.0	77	8.9
	3.3	14.3	77	9.1				
August 16, 1982	0.5	22.4	91	13.2	6.2	22.4	90	12.8
	3.3	22.4	90	13.1				
May 23, 1983	0.5	13.9	100	9.2	5.2	12.7	98	8.8
	3.3	13.1	98	8.9				
August 22, 1983	1.0	22.5	91	6.8	4.9	22.3	91	7.4
	1.6	22.5	91	6.8	6.6	22.2	90	7.0
	3.3	22.5	91	6.9				
LOCATOR LAKE, SITE 21								
May 19, 1982	0.5	12.4	26	10.0	23.0	9.4	25	9.4
	3.3	12.4	25	10.0	26.2	7.4	25	9.4
	6.6	12.4	25	10.2	29.5	6.8	25	9.1
	9.8	12.4	25	10.2	32.8	6.5	25	8.9
	13.1	12.3	25	10.2	36.1	6.1	24	8.6
	16.4	12.2	25	10.2	39.4	6.0	24	8.4
	19.7	10.7	25	10.2	42.6	5.9	25	3.5
August 17, 1982	0.5	24.9	26	10.2	26.2	8.2	24	3.4
	3.3	23.2	26	10.0	29.5	7.2	23	3.1
	6.6	22.4	26	9.9	32.8	6.8	22	2.3
	9.8	21.3	26	9.8	36.1	6.3	22	2.0
	13.1	20.3	26	9.3	39.4	6.2	22	1.6
	16.4	18.3	26	6.4	42.6	5.9	21	1.4
	19.7	13.6	25	3.8	45.9	5.8	21	0.8
	23.0	10.2	24	3.7				
SHOEPACK LAKE, SITE 22								
May 19, 1982	0.5	14.4	22	9.4	13.1	14.2	21	8.4
	3.3	14.4	22	8.7	16.4	14.2	21	7.9
	6.6	14.4	21	8.9	19.7	14.1	21	7.0
	9.8	14.3	21	8.7	23.0	8.3	23	7.0
August 17, 1982	0.5	24.3	20	10.2	13.1	18.7	22	5.3
	3.3	22.2	20	9.9	16.4	18.1	22	3.4
	6.6	20.9	21	8.2	19.7	15.6	38	0.6
	9.8	19.5	21	6.8				
CRUISER LAKE, SITE 23								
May 19, 1982	0.5	10.9	19	10.8	32.8	7.5	18	10.7
	3.3	10.8	19	10.8	36.1	7.4	18	10.6
	6.6	10.6	19	11.0	39.4	7.3	17	10.6
	9.8	10.2	19	10.9	42.6	6.6	17	10.4
	13.1	10.0	18	10.8	45.9	6.0	17	10.4
	16.4	9.8	19	10.6	49.2	5.8	17	10.0
	19.7	9.3	18	10.7	52.5	5.7	17	10.0
	23.0	8.9	18	10.9	55.8	5.5	17	9.8
	26.2	8.8	18	10.9	59.1	5.3	17	9.6
	29.5	8.4	18	10.9				

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
				CRUISER LAKE, SITE 23				
August 17, 1982	0.5	22.5	19	9.9	36.1	8.0	15	12.0
	3.3	22.3	19	9.8	39.4	7.0	15	9.5
	6.6	21.9	19	9.8	42.6	6.4	15	8.4
	9.8	21.6	19	9.7	45.9	6.0	14	7.8
	13.1	21.6	18	9.7	49.2	5.7	14	7.6
	16.4	20.8	18	9.6	52.5	5.7	13	7.2
	19.7	20.5	18	9.6	55.8	5.5	13	7.1
	23.0	19.5	18	9.6	59.1	5.4	13	6.4
	26.2	15.2	18	12.1	62.3	5.2	13	6.3
	29.5	11.7	17	12.8	65.6	5.2	13	6.2
	32.8	9.2	16	12.7				
				OSLO LAKE, SITE 24				
May 20, 1982	0.5	14.6	19	9.8	19.7	8.7	20	8.3
	3.3	14.2	19	9.8	23.0	7.2	20	8.0
	6.6	13.8	19	9.6	26.2	6.6	20	7.5
	9.8	13.4	19	9.7	29.5	5.7	20	7.3
	13.1	12.1	20	9.3	32.8	5.0	21	6.0
	16.4	10.8	19	9.1				
August 17, 1982	0.5	23.3	20	9.7	19.7	11.0	20	1.7
	3.3	22.5	19	9.6	23.0	8.2	19	2.1
	6.6	22.4	19	9.5	26.2	6.6	19	1.4
	9.8	20.4	19	8.8	29.5	5.8	16	0.7
	13.1	18.7	19	7.0	32.8	5.2	51	0.5
	16.4	15.4	19	1.3				
				O'LEARY LAKE, SITE 25				
May 20, 1982	0.5	12.8	62	11.0	26.2	7.7	62	9.6
	3.3	12.8	62	11.0	29.5	7.1	62	8.8
	6.6	12.6	62	10.8	32.8	6.7	62	8.6
	9.8	12.6	61	10.5	36.1	6.3	62	8.5
	13.1	12.5	61	10.4	39.4	5.8	62	7.5
	16.4	10.9	61	11.0	42.6	5.4	63	6.9
	19.7	9.3	61	10.7	45.9	5.2	64	5.8
	23.0	8.7	61	10.4	49.2	5.3	64	5.4
August 17, 1982	0.5	22.1	71	11.7	19.7	19.4	68	9.5
	3.3	22.0	71	11.4	23.0	13.8	68	4.1
	6.6	21.9	70	11.3	26.2	11.2	70	2.7
	9.8	21.2	70	11.8	29.5	9.0	67	2.1
	13.1	20.6	70	11.4	32.8	7.2	66	1.1
	16.4	20.0	69	10.7				
May 20, 1982	0.5	11.1	55	10.8	32.8	6.6	52	11.4
	3.3	11.1	55	10.9	36.1	6.5	52	11.0
	6.6	11.0	54	10.8	39.4	6.1	51	11.0
	9.8	10.9	54	10.7	42.6	6.0	51	11.0
	13.1	10.4	54	11.0	45.9	5.9	51	10.7
	16.4	9.9	53	11.1	49.2	5.9	51	10.6
	19.7	9.4	53	11.3	52.5	5.8	50	10.6
	23.0	7.6	53	11.5	55.8	5.8	50	10.8
	26.2	7.1	53	11.6	59.1	5.5	50	10.5
	29.5	6.9	52	11.6				

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
				MUKOODA LAKE, SITE 26--Continued				
August 17, 1982	0.5	21.8	58	10.5	29.5	14.3	56	11.7
	3.3	21.6	58	10.4	32.8	10.7	54	11.1
	6.6	21.5	58	10.3	36.1	9.3	52	10.3
	9.8	21.4	58	10.2	39.4	8.4	51	9.9
	13.1	21.4	57	10.1	42.6	7.7	49	8.4
	16.4	20.3	57	10.2	45.9	7.1	49	7.3
	19.7	19.9	57	10.0	49.2	6.5	48	6.0
	23.0	19.7	57	9.9	52.5	6.0	47	4.3
	26.2	18.4	57	10.0	55.8	5.8	46	3.0
				PEARY LAKE, SITE 30				
May 14, 1983	0.5	13.8	27	8.6	13.0	13.8	27	10.2
	3.0	13.8	27	9.2	16.0	13.8	27	8.6
	7.0	13.8	27	9.3	20.0	11.5	28	5.8
	10.0	13.8	27	10.0				
August 25, 1983	1.0	23.9	31	8.1	10.0	22.2	31	6.0
	3.0	23.7	30	7.9	13.0	21.0	35	1.0
	7.0	23.2	30	7.6	16.0	16.8	101	0.6
				LITTLE TROUT LAKE, SITE 31				
May 24, 1983	0.5	12.4	39	10.4	33.0	7.1	36	9.0
	3.0	12.4	39	9.0	36.0	6.4	36	8.9
	7.0	12.4	39	9.4	39.0	5.7	35	8.5
	10.0	12.3	39	9.8	43.0	5.5	35	8.3
	13.0	12.2	39	10.4	46.0	5.1	35	8.3
	16.0	11.9	39	10.4	49.0	5.0	35	---
	20.0	11.4	38	10.4	52.0	4.9	35	---
	23.0	10.8	38	9.4	56.0	4.9	34	---
	26.0	8.5	37	9.1	59.0	4.8	34	---
	30.0	7.7	36	9.0				
August 25, 1983	1.0	24.6	42	8.1	33.0	10.1	38	12.6
	3.0	24.5	42	8.0	36.0	9.0	37	12.7
	7.0	24.4	42	8.0	39.0	8.2	37	12.2
	10.0	24.3	42	8.0	43.0	7.8	36	12.1
	13.0	23.7	41	8.1	46.0	7.2	36	11.5
	16.0	23.5	41	8.1	49.0	6.7	36	10.4
	20.0	23.4	41	8.1	52.0	6.3	35	9.3
	23.0	19.9	41	11.0	56.0	6.1	35	9.4
	26.0	15.6	40	12.2	59.0	5.7	35	7.9
	30.0	12.6	39	12.5	62.0	5.5	35	7.2
				LUCILLE LAKE, SITE 32				
May 24, 1983	0.5	14.0	20	9.7	13.0	13.9	19	10.2
	3.0	14.0	20	8.8	16.0	13.6	19	8.4
	7.0	14.0	19	10.6	20.0	13.5	19	7.4
	10.0	14.0	19	10.4				
August 25, 1983	1.0	25.2	22	7.7	13.0	23.4	21	7.5
	3.0	24.8	22	7.7	16.0	23.2	21	7.2
	7.0	24.0	21	7.8	20.0	22.4	27	1.0
	10.0	23.6	21	7.7				

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
JORGENS LAKE, SITE 33								
May 24, 1983	0.5	14.2	23	8.5	13.0	13.2	23	8.4
	3.0	14.2	23	8.6	16.0	12.0	23	7.6
	7.0	14.2	23	9.6	20.0	10.9	23	4.8
	10.0	14.2	23	9.8				
August 25, 1983	1.0	24.2	25	7.6	13.0	20.9	27	2.6
	3.0	24.1	25	7.6	16.0	17.1	32	0.5
	7.0	23.2	25	7.5	18.0	15.6	46	0.6
	10.0	22.5	25	6.5				
LITTLE SHOEPACK LAKE, SITE 34								
May 24, 1983	0.5	14.6	23	8.4	13.0	12.2	23	6.4
	3.0	14.5	23	8.7	16.0	10.3	25	3.6
	7.0	14.5	23	9.4	20.0	9.2	34	1.6
	10.0	14.3	23	8.9				
August 25, 1983	1.0	25.7	26	8.1	10.0	21.8	28	3.6
	3.0	23.4	26	7.9	13.0	18.4	39	0.5
	7.0	22.5	26	6.8	15.0	15.4	40	0.5
BEAST LAKE, SITE 35								
May 24, 1983	0.5	13.6	21	10.0	33.0	5.5	19	6.0
	3.0	13.7	21	9.8	36.0	5.4	19	5.5
	7.0	13.7	20	10.4	39.0	5.3	19	5.1
	10.0	13.7	20	10.8	43.0	5.2	19	4.7
	13.0	12.0	20	11.4	46.0	5.1	19	4.2
	16.0	10.8	20	11.2	49.0	5.1	19	---
	20.0	8.8	20	10.0	52.0	5.1	19	---
	23.0	7.6	20	8.4	56.0	5.0	20	---
	26.0	6.3	20	7.5	59.0	5.0	20	---
	30.0	5.9	19	6.5				
August 25, 1983	1.0	24.5	23	8.3	16.0	18.4	22	5.1
	3.0	24.5	23	8.4	20.0	12.0	22	4.1
	7.0	23.1	22	8.5	23.0	9.9	24	2.0
	10.0	22.9	22	8.2	26.0	8.2	24	1.8
	13.0	22.3	22	7.8				
QUILL LAKE, SITE 36								
May 2, 1984	0.5	6.8	29	11.6	20.0	5.8	27	10.1
	3.0	6.7	29	11.0	23.0	5.8	27	10.0
	7.0	6.1	28	10.6	26.0	5.7	27	10.0
	10.0	5.9	28	10.3	30.0	5.7	27	10.0
	13.0	5.8	27	10.3	33.0	5.6	26	10.0
	16.0	5.8	27	10.2	36.0	5.6	26	10.0
August 21, 1984	0.5	23.4	27	10.4	26.0	7.0	25	4.9
	3.0	23.4	26	8.4	30.0	6.4	25	4.3
	7.0	23.3	26	8.3	33.0	6.2	26	3.7
	10.0	23.2	26	7.4	36.0	6.1	27	3.0
	13.0	18.0	26	5.7	39.0	6.0	28	2.4
	16.0	12.6	26	5.3	43.0	5.8	38	2.2
	20.0	9.4	26	5.3	46.0	5.8	48	2.2
	23.0	7.7	25	5.2				

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
				LOITEN LAKE, SITE 37				
May 2, 1984	0.5	6.6	29	10.7	26.0	5.9	27	10.2
	3.0	6.5	29	10.7	30.0	5.8	27	10.2
	7.0	6.0	29	10.5	33.0	5.8	27	9.8
	10.0	5.9	29	10.4	36.0	5.6	27	9.2
	13.0	5.9	29	10.3	39.0	5.4	28	8.8
	16.0	5.9	28	10.3	43.0	5.0	28	7.8
	20.0	5.9	28	10.3	46.0	4.7	29	6.4
	23.0	5.9	28	10.2				
August 21, 1984	0.5	23.4	27	8.3	23.0	9.0	26	4.7
	3.0	23.4	27	7.7	26.0	7.9	26	4.4
	7.0	23.2	27	7.3	30.0	7.3	26	3.9
	10.0	23.2	27	6.9	33.0	6.9	26	3.4
	13.0	21.0	26	5.8	36.0	6.6	28	2.9
	16.0	17.9	27	4.9	39.0	6.4	28	2.5
	20.0	11.1	26	5.1				
				WAR CLUB, SITE 38				
May 2, 1984	0.5	6.8	29	13.0	20.0	6.3	27	10.7
	3.0	6.8	28	11.8	23.0	6.3	27	10.7
	7.0	6.6	28	11.3	26.0	6.3	26	10.7
	10.0	6.4	28	11.0	30.0	6.2	26	10.6
	13.0	6.4	28	10.8	33.0	6.2	26	10.6
	16.0	6.3	27	10.7	36.0	5.9	26	10.4
August 21, 1984	0.5	23.6	27	7.8	20.0	12.7	28	1.3
	3.0	23.6	27	7.8	23.0	10.7	28	1.2
	7.0	23.6	27	6.3	26.0	9.7	27	1.2
	10.0	23.5	26	4.7	30.0	9.1	27	1.2
	13.0	21.4	27	1.7	33.0	8.7	34	1.2
	16.0	16.4	29	1.3	36.0	8.4	39	1.2
				RYAN LAKE, SITE 39				
May 2, 1984	0.5	8.5	33	10.1	10.0	7.2	32	10.3
	3.0	8.2	33	10.2	12.0	7.2	32	10.4
	7.0	7.4	32	10.3				
August 21, 1984	0.5	23.6	29	8.1	10.0	23.0	28	6.1
	3.0	23.2	29	6.8	12.0	22.1	32	3.3
	7.0	23.2	29	6.8				
				BROWN LAKE, SITE 40				
May 2, 1984	0.5	7.2	24	10.5	13.0	6.5	23	10.5
	3.0	7.2	24	10.5	16.0	6.4	23	10.4
	7.0	7.0	24	10.5	20.0	6.3	22	10.4
	10.0	6.8	23	10.5	23.0	6.1	22	10.4
August 21, 1984	0.5	23.3	22	7.3	16.0	12.7	27	1.3
	3.0	23.2	22	7.2	20.0	10.3	36	1.4
	7.0	23.1	22	7.1	23.0	9.3	46	1.4
	10.0	22.2	22	5.9	26.0	8.8	52	1.4
	13.0	16.8	23	1.2				
				TOOTH LAKE, SITE 41				
May 3, 1984	0.5	7.3	33	10.6	20.0	6.2	32	10.3
	3.0	7.2	33	10.6	23.0	6.2	32	10.2
	7.0	6.8	33	10.5	26.0	6.0	31	10.0
	10.0	6.3	33	10.4	30.0	5.8	31	9.7
	13.0	6.3	32	10.3	33.0	5.8	32	9.4
	16.0	6.2	32	10.3	36.0	5.5	32	8.9

Table 20.--*Results of vertical-profile measurements of water temperature, specific conductance, and dissolved oxygen*--Continued

Date	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)	Depth (feet)	Water temperature (°C)	Specific conductance (µS/cm)	Dissolved oxygen (mg/L)
				TOOTH LAKE, SITE 41--Continued				
August 21, 1984	0.5	24.6	31	7.8	23.0	8.4	29	3.4
	3.0	24.0	31	7.5	26.0	7.3	29	3.1
	7.0	23.7	31	7.1	30.0	6.7	29	2.8
	10.0	23.5	30	6.9	33.0	6.4	30	2.3
	13.0	18.1	31	3.5	36.0	6.2	28	1.9
	16.0	13.1	30	3.3	39.0	6.0	30	1.6
	20.0	10.0	29	3.4	43.0	5.9	59	1.5
				EK LAKE, SITE 42				
May 3, 1984	0.5	8.5	31	10.9	10.0	7.2	30	10.6
	3.0	8.0	31	10.9	13.0	7.0	30	10.5
	7.0	7.9	30	10.9	16.0	6.7	30	10.0
August 21, 1984	0.5	23.8	28	6.6	13.0	18.7	38	1.3
	3.0	23.6	27	6.4	16.0	15.5	74	1.1
	7.0	23.5	27	6.3	20.0	14.1	86	1.1
	10.0	23.2	27	5.9	21.0	13.7	87	1.0
				NAMAKAN RIVER AT MOUTH, SITE 20				
May 18, 1982	0.5	11.2	35	11.2	9.8	11.2	34	11.1
	3.3	11.2	35	11.1	13.1	11.2	34	10.6
	6.6	11.2	35	11.0				
August 17, 1982	0.5	22.0	---	8.5	16.4	22.0	---	8.8
	3.3	22.0	---	8.6	19.7	22.0	---	8.8
	6.6	22.0	---	8.7	23.0	22.0	---	8.8
	9.8	22.0	43	8.8	26.2	22.0	---	8.8
	13.1	22.0	---	8.8				
				ASH RIVER AT ASH RIVER FALLS, SITE 27				
August 16, 1982	---	23.5	207	7.9				
				ASH RIVER ABOVE GANNON CREEK, SITE 28				
August 16, 1982	1.0	24.5	---	11.5	7.0	21.0	---	8.6
	2.0	24.0	---	12.6	8.0	20.0	---	7.2
	3.0	23.0	---	12.6	10.0	19.5	---	4.5
	5.0	22.0	209	10.5				
				ASH RIVER BELOW GANNON CREEK, SITE 29				
August 16, 1982	1.0	24.5	---	12.0	8.2	20.0	---	5.9
	3.3	23.5	---	12.2	9.8	20.0	---	5.5
	4.9	22.0	---	11.4	11.5	19.5	---	3.9
	6.6	20.5	201	6.5				
				ASH RIVER AT FRONTIER RESORT (auxillary data), SITE 29A				
August 18, 1982	1.0	25.0	---	11.3	6.6	23.0	---	10.5
	1.6	24.5	---	11.4	8.2	22.5	---	8.7
	3.3	24.5	---	11.6	9.8	21.0	---	6.6
	4.9	23.5	---	11.7	10.8	21.0	---	4.4

*U.S. GOVERNMENT PRINTING OFFICE: 1991--556-199/J4573