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Water Quality of Lakes in Voyageurs National Park, Northern Minnesota, 1999

Water-Resources Investigations Report 00–4281

U.S. Department of the Interior
U.S. Geological Survey

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By Gregory A. Payne

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U.S. Department of the Interior

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Conversion Factors,

Multiply inch-pound unit	By	To obtain metric unit
foot (ft)	0.3048	meter
acre-foot (acre-ft)	0.001	cubic hectometer

Water Quality of Lakes in Voyageurs National Park, Northern Minnesota, 1999

by G.A. Payne

ABSTRACT

Water-quality samples were collected during July 1999 from selected lakes and bays, and the mouths of two rivers that flow into Voyageurs National Park in northern Minnesota. Results of laboratory analyses and field measurements of chemical and physical properties were compared to similar data collected during 1977–83. Water-quality data were evaluated for changes in specific conductance, alkalinity, nutrients, trace metals, bacteria, and trophic state. Specific conductance and alkalinity were similar to the 1977–83 period in much of the Park, but in some lakes and bays these properties may have been influenced by above normal runoff during summer 1999. Fecal-coliform bacteria colony counts were within guidelines for water-contact recreation. Nitrite plus nitrate nitrogen concentrations generally were lower throughout the Park and total phosphorus concentrations were lower in Kabetogama Lake and Black Bay relative to 1977–83. Concentrations of most trace metals were lower compared to 1977–83. Trophic state indices, based on chlorophyll *a* concentrations, indicated lower algal productivity throughout the Park. The largest changes in algal productivity, relative to 1977–83, were in Kabetogama Lake, Black Bay, and Sullivan Bay.

INTRODUCTION

Voyageurs National Park in northern Minnesota (fig. 1) was established in 1975 to preserve, and provide for the public's enjoyment, scenic and natural resources along a historic waterway. Lakes and waterways, which compose a major portion of the Park, provide recreational use, and aquatic systems provide support for much of the Park's fauna. Water quality is an essential element of the Park environment because of its importance to ecosystems and visitor enjoyment.

A water-quality study was undertaken by the U.S. Geological Survey in cooperation with the National Park Service. A study, conducted from 1977 through 1984, collected water-quality data in the newly established Park and provided a basis for evaluating changes in water quality that may occur with time (Payne, 1991). Water quality can change over time; thus, periodic determinations of water quality are needed to assess current conditions and to detect temporal changes. During 1999, a subset of sampling sites used during the 1977–84 study was sampled to re-assess water quality in the Park.

Purpose and Scope

The purpose of this report is to present the results of water-quality sampling and analyses done during 1999 and compare those results to data collected from the 1977–84 study. The 1999 data collection included physical properties, selected trace elements, bacteria, and trophic-state indicators at seven sampling sites located in five selected lakes and bays, and at the mouths of two rivers that flow into the Park.

Approach and Methods

The 1977–84 study characterized water quality on the basis of samples collected at 41 sites located in the Park's lakes, bays, and streams. Sampling in the Park's large lakes and bays was done during 1977–83, whereas sampling during 1984 focussed only on smaller lakes in the Park's interior. A subset of seven sites was selected from the original 41 sites for sampling during the 1999 study (table 1). Five of the selected sites were chosen to represent water quality in each of five selected lakes and bays. Two additional sites were selected at mouths of two rivers that flow into the Park. Locations of the sampling sites are shown in figure 1. One set of samples was collected at each of the seven sampling sites during July 27–28, 1999.

Water-column vertical profiles of temperature, pH, specific conductance, and dissolved-oxygen concentrations were determined using a Hydrolab multi-parameter instrument calibrated at the beginning and end of each day. Secchi-disk transparency was measured at each site using a black and white 20-centimeter Secchi disk. Water samples were collected using a Van Dorn-type sampler. Samples were composited from subsamples collected at the top, center, and bottom of the part of the upper water column equal to twice the Secchi-disk reading. Table 2 lists physical properties determined in the field and chemical constituents that were analyzed in the laboratory. At site 7 and site 14, where temperature profiles indicated presence of a thermocline, samples also were collected from the hypolimnion.

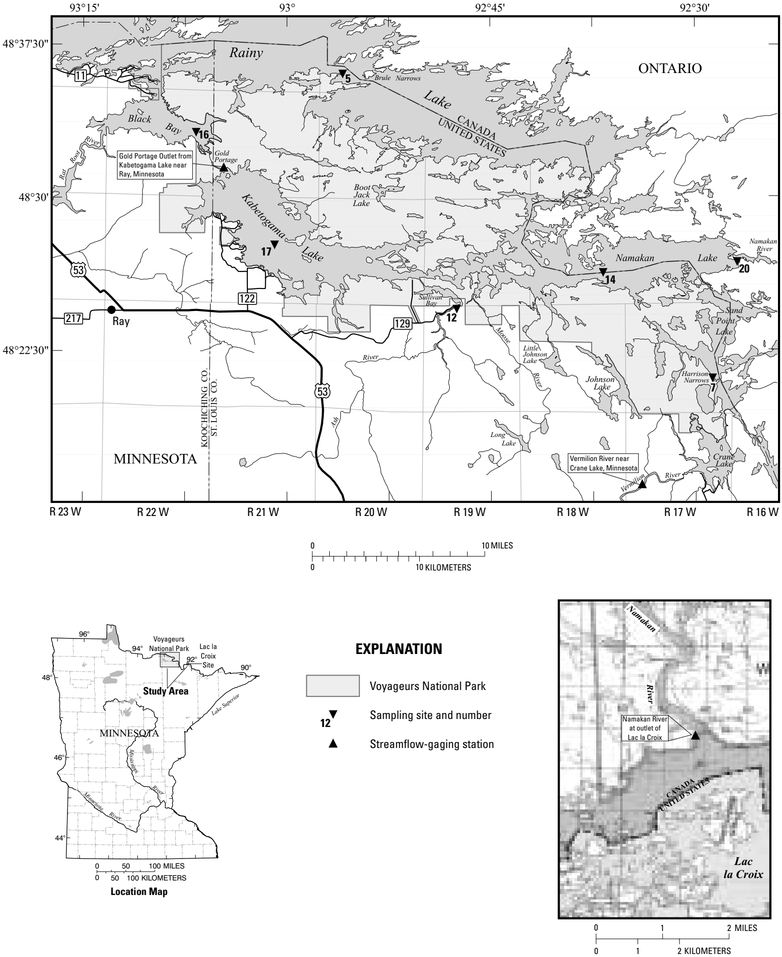

Figure 1. Location of Voyageurs National Park and water-quality sampling sites.

Table 1. Sampling sites in Voyageurs National Park, July 1999

[site numbers correspond to Payne, 1991]

Site name	Site number (shown on fig. 1)	U.S. Geological Survey identification number
Black Bay (Rainy Lake at Black Bay near International Falls, Minnesota)	16	483304093062701
Kabetogama Lake near Ray, Minnesota	17	482721093003901
Namakan Lake near Ray, Minnesota	14	482616092372201
Namakan Lake at mouth of Namakan River, Ontario	20	482709092264601
Rainy Lake at Brule Narrows near International Falls, Minnesota	5	483622092560701
Sand Point Lake below Harrison Narrows near Crane Lake, Minnesota	7	482226092283301
Sullivan Bay (Ash River at entrance to Sullivan Bay near Ray, Minnesota)	12	482451092471001

Table 2. Physical properties and chemical constituents determined for water samples collected in Voyageurs National Park, July 1999

[°C, degrees Celsius; mm Hg, millimeters mercury; µS/cm, microsiemens per centimeter; mg/L, milligrams per liter; µg/L, micrograms per liter; col/100 mL, colonies per 100 milliliters;]

Constituent or physical property	Reporting unit	Method reporting limit
Air pressure	mm Hg	1 mm
Water temperature	°C	0.1 unit
Transparency, Secchi disk	feet	0.1 foot
Specific conductance, field	uS/cm @ 25 °C	1 uS/cm
Specific conductance, laboratory	uS/cm @ 25 °C	1 uS/cm
Field pH	standard units	0.1 unit
Laboratory pH	standard units	0.1 unit
Dissolved oxygen	mg/L	0.1 mg/L
Fecal coliform bacteria, membrane filter	col/100 mL	1 col/100 mL
Total alkalinity, as $CaCO_3$	mg/L	1 mg/L
Dissolved nitrite nitrogen	mg/L	0.001 mg/L
Dissolved nitrite plus nitrate nitrogen	mg/L	0.005 mg/L
Dissolved ammonia nitrogen	mg/L	0.002 mg/L
Dissolved ammonia plus organic nitrogen	mg/L	0.1 mg/L
Total ammonia plus organic nitrogen	mg/L	0.1 mg/L
Total phosphorus	mg/L	0.004 mg/L
Dissolved phosphorus	mg/L	0.004 mg/L
Dissolved orthophosphorus	mg/L	0.001 mg/L
Total arsenic	µg/L	1 µg/L
Total barium	ug/l	0.9 µg/L
Total cadmium	µg/L	1 µg/L
Total chromium	µg/L	1 µg/L
Total copper	µg/L	1 µg/L
Total lead	µg/L	1 µg/L
Total nickel	µg/L	1 µg/L
Total selenium	µg/L	1 µg/L
Total silver	µg/L	1 µg/L
Total zinc	µg/L	40 µg/L
Chlorophyll *a*	µg/L	0.1 µg/L
Chlorophyll *b*	µg/L	0.1 µg/L

Samples sent to the laboratory to determine concentrations of chemical constituents were collected, processed, preserved, and analyzed using procedures and methods described by Britton and Greeson (1989) and Fishman and Friedman (1989). Samples were analyzed at the National Water-Quality Laboratory in Denver, Colorado. Results of analyses were published in U.S. Geological Survey Water-Resources Data, Minnesota Water Year 1999 Annual Report (Mitton and others, 2000).

Quality-Assurance Results

Laboratory supplied blank water was processed through collection bottles and filtering devices to quality assure equipment and procedures used in the field. Results of analyses performed on these blanks showed little evidence of sample contamination. All trace-metal concentrations were less than the method reporting limit (MRL) for each constituent. Nutrient concentrations were greater than or equal to the MRL for dissolved ammonia nitrogen (0.004 mg/L), dissolved nitrite nitrogen (0.001 mg/L), dissolved ammonia plus organic nitrogen (0.06 mg/L), and dissolved orthophosphorus (0.001 mg/L).

A replicate sample was collected at site 16 in Black Bay to assure the quality of sampling precision. Results of analyses of the replicate sample are shown in table 3. Results from the replicate sample were in close agreement for all constituents except for dissolved ammonia plus organic nitrogen, which differed by 29 percent, and for chlorophyll *a* which differed by 33 percent.

WATER QUALITY

Water Chemistry

Water-chemistry data collected during 1999 was compared with data that were collected during 1977–83 (Payne, 1991). Most of the samples during the previous study were collected during May and August, but some were collected during March 1977 and November 1978. Rainy Lake at Brule Narrows near International Falls, Minnesota (site 5) (hereinafter referred to as Rainy Lake), Sand Point Lake below Harrison Narrows near Crane Lake (site 7) (hereinafter referred to as Sand Point Lake), and Kabetogama Lake near Ray, Minnesota (site 17) (hereinafter referred to as Kabetogama Lake), were sampled 15 times (March 1977-August 1983). Namakan Lake near Ray, Minnesota (site 14) (hereinafter referred to as Namakan Lake) and Sullivan Bay (site 12) were sampled 11 times (November 1978-August 1983), and Black Bay (site 16) was sampled 8 times (May 1980-August 1983). Namakan Lake at the mouth of the Namakan River, Ontario (site 20) (hereinafter referred to as Namakan Lake at the mouth of the Namakan River) was sampled only twice during the previous study (May and August 1982), so there are few data for comparison, but that site was sampled

Table 3. Results of analyses for quality-assurance replicate samples collected in Rainy Lake at Black Bay near International Falls, Minnesota, site 16, in Voyageurs National Park, July 1999

[mg/L, milligrams per liter; µg/L, micrograms/L; µS/cm, microsiemens per centimeter;]

	Dissolved nitrite nitrogen (mg/L)	Dissolved nitrite plus nitrate nitrogen (mg/L)	Dissolved ammonia nitrogen (mg/L)	Dissolved ammonia plus organic nitrogen (mg/L)	Total ammonia plus organic nitrogen (mg/L)	Total phosphorus (mg/L)	Dissolved phosphorus (mg/L)
Sample 1	0.001	<0.005	0.003	0.308	0.465	0.025	0.008
Sample 2	0.001	<0.005	0.005	0.398	0.494	0.026	0.008

	Dissolved orthophosphorus (mg/L)	Total arsenic (µg/L)	Total barium (µg/L)	Total cadmium (µg/L)	Total chromium (µg/L)	Total copper (µg/L)	Total lead (µg/L)
Sample 1	0.003	<1	11.898	<1	<1	1.852	<1
Sample 2	0.003	<1	12.111	<1	<1	2.005	<1

	Total nickel (mg/L)	Total selenium (mg/L)	Total silver (mg/L)	Total zinc (mg/L)	Chlorophyll *a* (mg/L)	Chlorophyll *b* (mg/L)	Specific conductance, laboratory (uS/cm at 25 degrees Celsius)
Sample 1	<1	<1	<1	<40	1.8	<0.1	94.9
Sample 2	<1	<1	<1	<40	2.4	<0.1	95.9

because the Namakan River is the largest inflow to the Park (2,780,000 acre-feet average annual runoff at the outlet of Lac la Croix, fig. 1) (Mitton and others, 2000). The water quality in Namakan Lake was very similar to water quality in the Namakan Lake at the mouth of the Namakan River during the previous study (Payne, 1991), suggesting that inflow from the Namakan River strongly influences water quality in Namakan Lake. Analytical results from samples collected during July 1999 at Namakan Lake at the mouth of the Namakan River during July 1999 also were nearly identical to results from samples collected in Namakan Lake for all constituents except nitrite plus nitrate nitrogen.

Specific conductance

Specific conductance values measured during July 1999 (fig. 2) are very similar to median values measured during 1977–83 except for Sand Point Lake and Kabetogama Lake. The narrow interquartile ranges for these water bodies, except for Sullivan Bay, indicate that major-ion chemistry has been relatively stable.

In Sand Point Lake, specific conductance during July 1999 was somewhat elevated, and exceeded the interquartile range of values measured during 1977–83. The vertical profile determined in Sand Point Lake (fig. 3) shows a layer of warmer, higher-conductance water (64 µS/cm), extending to a depth of 21 feet, overlying cooler lower-conductance water (55 µS/cm). Specific conductance in the underlying layer was very near the median value (52 µS/cm) for this site. Sand Point Lake receives inflow from the Vermilion River through Crane Lake. Streamflow at the USGS gaging station, Vermilion River near Crane Lake, was about 75 percent above normal during July 1999, delivering

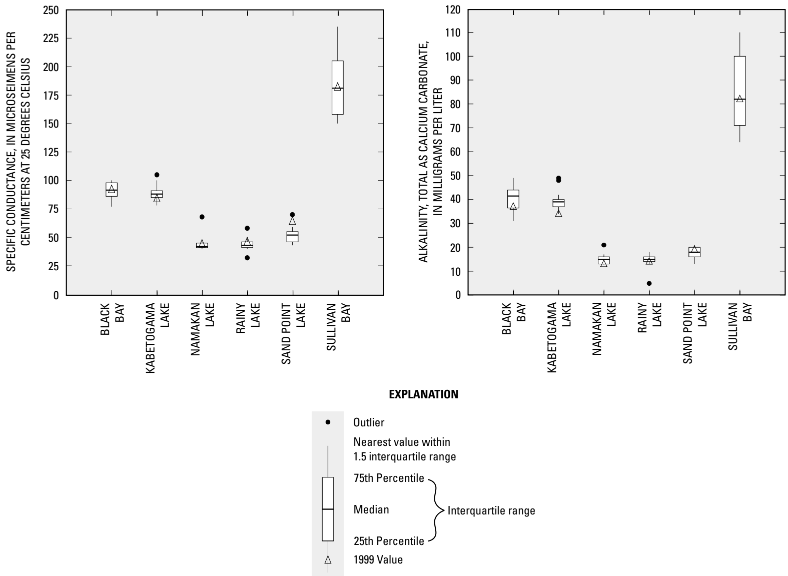

Figure 2. Specific conductance and alkalinity for selected sites in Voyageurs National Park, 1977-83, and July 1999.

87,010 acre-feet of water that month (Mitton and others, 2000). The elevated specific conductance measured in Sand Point Lake during 1999 may reflect the large July inflows from the Vermilion River. Specific conductance data for the Vermilion River are sparse, but values measured by the Minnesota Pollution Control Agency (L. Hotka, written commun.) on July 12, 1967 (65 µS/cm) and September 19, 1968 (63 µS/cm) closely match the values measured in the epilimnion of Sand Point Lake during July 1999.

In Kabetogama Lake, specific conductance during July 1999 (84 µS/cm) was slightly lower than the interquartile range of values (85–90 µS/cm) measured during 1977–83. The vertical profile determined at this site indicated that specific conductance was uniform throughout the water column. Water from Namakan Lake, which has lower specific conductance, can enter Kabetogama Lake through a narrows where the lakes are joined. Analyses of samples collected in Kabetogama Lake near the narrows during 1977–83 indicated a mixture of water from the two lakes (Payne, 1991). The slightly decreased specific conductance in Kabetogama Lake during July 1999 may, similarly, reflect influence of water from Namakan Lake.

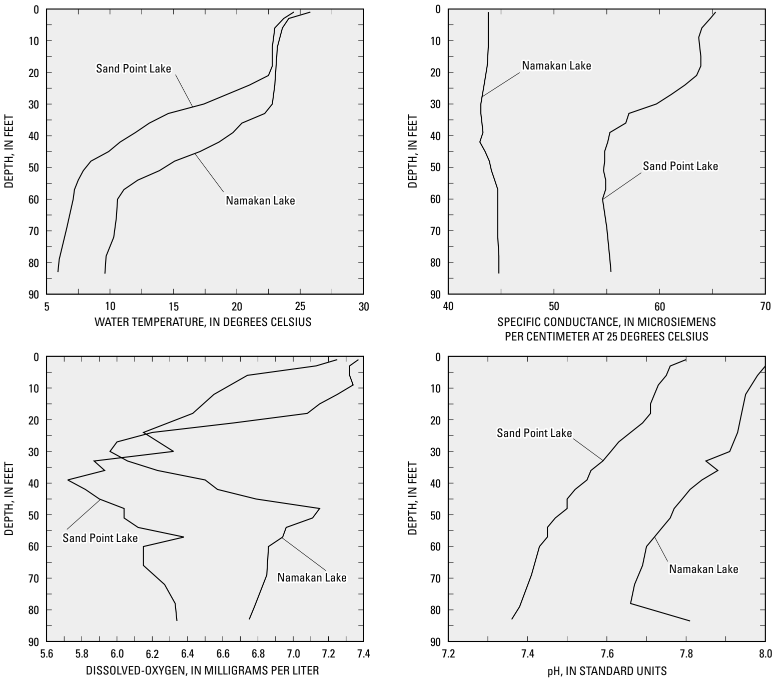

Figure 3. Vertical profiles for Namakan Lake (Site 14) and Sand Point Lake (Site 7), July 1999.

Alkalinity

Water from Kabetogama Lake flows into Black Bay through the Gold Portage. Decreased alkalinity in Black Bay in July 1999, relative to 1977–83 (fig. 2) may reflect the influence of inflow from Kabetogama Lake. Streamflow at the USGS gaging station at Gold Portage was above normal during June and July 1999, based on flows recorded from 1983–99. Total flow from April 17 to July 27, 1999 was about 64,000 acre feet. Similarly, alkalinity in Kabetogama Lake during 1999 may reflect the influence of inflowing water from Namakan Lake.

Nutrients

Dissolved nitrite plus nitrate nitrogen concentrations during July 1999 were less than the method reporting limit (0.005 mg/L) in samples from Black Bay, Kabetogama Lake, Sand Point Lake, and Sullivan Bay (fig. 4). Nitrite plus nitrate concentrations also were low in samples from Rainy Lake (0.017 mg/L) and Namakan Lake (0.012 mg/L). Nitrite plus nitrate nitrogen concentrations were less than the 25th percentile for 1977–83 data for all sites except Sullivan Bay (fig. 4). In hypolimnetic waters (Namakan Lake and Sand Point Lake, nitrite plus nitrate nitrogen concentrations were greater relative to epilimnetic waters. The nitrite plus nitrate nitrogen concentration (0.021mg/L) in the July 1999 sample from Namakan Lake at mouth of Namakan River was greater than concentrations at the other sites, but was less than concentrations measured at the same site during May 1982 (0.05 mg/L) and August 1982 (0.13 mg/L). The low nitrite plus nitrate concentrations in epilimnetic water relative to hypolimnetic water and inflowing water from the Namakan River probably reflect phytoplankton utilization of nitrate. Nitrite concentrations in all samples were low, ranging from 0.001 to 0.003 mg/L.

Ammonia was sampled infrequently during the 1977–83 sampling; therefore, there are few ammonia data for comparison with the 1999 results. All sites, however, were sampled during August 1980 and those results ranged from 0.02 mg/L in Namakan Lake and in Rainy Lake to 0.39 mg/L in Sullivan Bay. During July 1999, ammonia concentrations generally were lower, ranging from 0.003 to 0.022 mg/L. Data from the two studies should be compared with caution because the 1980 analyses were performed on whole-water samples whereas filtered-water samples were analyzed during 1999.

Total ammonia plus organic nitrogen concentrations in July 1999 samples were within the interquartile range of 1977–83 concentrations at all sites except Black Bay where the July 1999 concentration was less than the 25th percentile (fig. 4).Total nitrogen concentrations are summations of the concentrations of dissolved nitrite plus nitrate nitrogen and total ammonia plus organic nitrogen. These calculated total nitrogen concentrations for both the 1977–83 and 1999 data sets are shown in figure 4. Total nitrogen concentrations in 1999 were less than median values for 1977–83 in all the major water bodies except Sullivan Bay. The most substantial difference between the 1977–83 values and 1999 values occurred in Black Bay.

Total-phosphorus concentrations in Kabetogama Lake, Sullivan Bay, and Black Bay during 1977–83 were greater in May than in August (Payne,1991). Because of this seasonal variability, it was deemed appropriate to compare the July 1999 results with results from August 1977–83 (fig. 4). The largest differences are seen in Black Bay and Kabetogama Lake where 1999 concentrations are substantially lower than median values for 1977–83.

Trace metals

Cadmium, chromium, lead, selenium, and silver concentrations in all July 1999 samples were less than the MRL of 1 µg/L. Zinc concentrations in all July 1999 samples were less than the MRL of 40 µg/L. These constituents were sampled and analyzed infrequently during the 1977–83 study, but were detected at concentrations greater than the MRL at some sites. During 1977–83, lead was detected in samples from Namakan Lake and Namakan Lake at the mouth of the Namakan River, Rainy Lake, Kabetogama Lake, Sullivan Bay, and Black Bay in concentrations that ranged from 1 to 3 µg/L. Similarly, chromium, selenium, and zinc were detected in some samples during the 1977–83 study. Non-detections of these constituents in the July 1999 samples may reflect a decrease in their presence in the Park's waters or result from implementation of improved quality-assurance protocols during sample collection and processing.

Arsenic concentrations were 2 µg/L in Sullivan Bay, 1 µg/L in Kabetogama Lake, and 1 µg/L in Rainy Lake. Barium was detected in samples from all sites at concentrations that ranged from 8 to 20 µg/L. Copper was detected in samples from all sites at concentrations that ranged from 1 to 3 µg/L. Copper concentrations were greater in samples from hypolimnetic water in Namakan and Sand Point Lakes (2–3 µg/L) than samples collected in the epilimnion (1 µg/L). Nickel was detected in one sample from Sullivan Bay at a concentration of 1 µg/L.

Bacteria

Fecal coliform bacteria are used as indicator bacteria by the State of Minnesota. The standard for contact recreation is a geometric mean (based on at least 5 samples per month) of 200 col/100 mL (colonies per 100

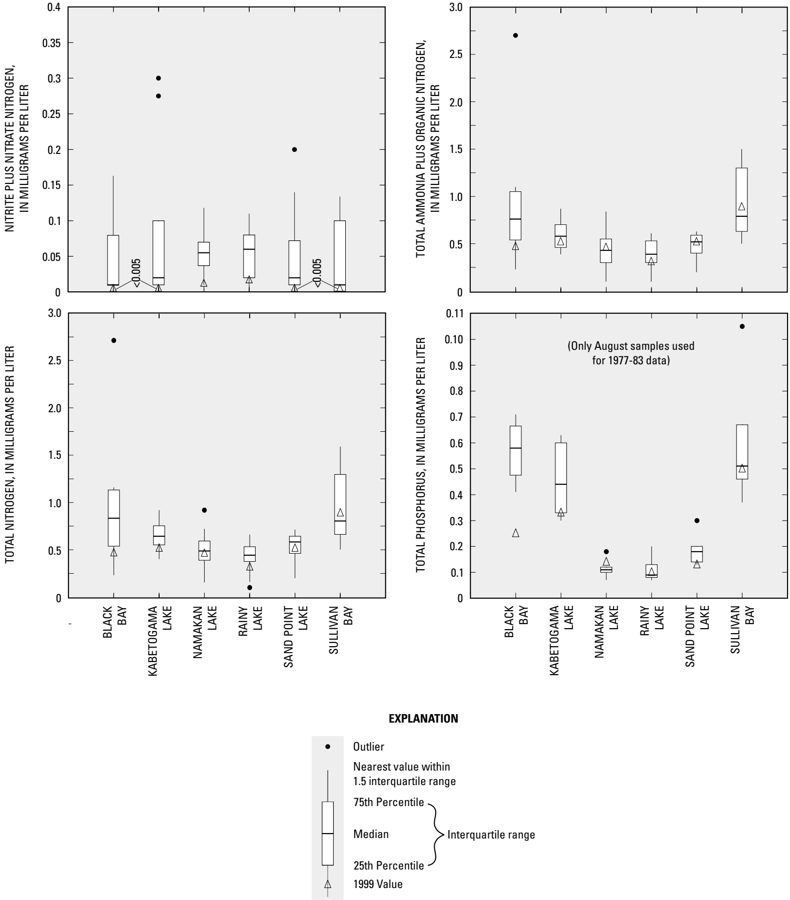

Figure 4. Nutrient concentrations for selected sites in Voyageurs National Park, 1977-83, and July 1999.

milliliters) and the concentration shall not exceed 400 col/100 mL in more than 10 percent of the samples collected in any month (Minnesota Rules, 1999). Although five samples per month, as required by the standard, were not collected during this study, results from the single sample collected at each site were within the standard. Counts were 1 col/100 mL in samples from Sand Point Lake, Namakan Lake, Kabetogama Lake, and Rainy Lake; 3 col/100 mL in samples from the Namakan Lake at the mouth of the Namakan River and Black Bay; and 8 col/100 mL in Sullivan Bay. In comparison, samples collected during 1980 yielded counts of 1 col/100 mL in Sand Point Lake, Namakan Lake, Kabetogama Lake, and Sullivan Bay, 2 col/100 mL in Rainy Lake, and 30 col/100 mL in Black Bay (U.S. Geological Survey, 1981).

Thermal and Chemical Stratification

Well developed thermal stratification, as evidenced by a thermocline, was present in Namakan Lake and Sand Point Lake. The temperature profiles for these sites (fig. 3) show distinct thermal zones. While both sites have similar thermal stratification, only Sand Point Lake shows warmer, higher-conductance water overlying cooler, lower-conductance water (fig. 3). The dissolved-oxygen profiles (fig. 3) for these sites show a distinct pattern, common to both sites, whereby dissolved-oxygen concentrations decrease to a minimum near the upper boundary of the thermocline and then increase with depth near the lower boundary of the thermocline. The vertical distribution of pH values, in contrast, shows a gradual decline with depth that steepens slightly at the top of the thermocline (fig. 3).

Thermal profiles determined during July 1999 in Namakan Lake and Sand Point Lake were similar to profiles determined at those sites during 1977–83. The variation in specific conductance with depth at Sand Point Lake was not, however, observed during 1977–83.

Trophic Status

Trophic State Indices (TSI) were computed using equations developed by Carlson (1977). The indices are computed from measurements of Secchi-disk transparency or results of analyses for chlorophyll *a* or total phosphorus. Carlson's index is a numeric scale that represents the amount of algal biomass in surface waters. Each 10-unit increment in the scale represents a doubling of algal biomass. An evaluation of TSI calculated from data collected during the 1977–83 study (Payne, 1991) found that TSI computed from chlorophyll *a* concentrations may be preferable to TSI values computed from total phosphorus concentrations (TSI TP) because data from lakes in Voyageurs National Park at times exhibit a poor fit to Carlson's regression that relates chlorophyll *a* to total phosphorus. Indices computed from Secchi-disk transparency (TSI SD), while responsive to algal biomass, also are affected by soluble organic substances that color some of the Park's water bodies.

TSI were computed from chlorophyll *a* data collected during July 1999 and compared to indices computed from summer (August) data collected during 1977–83. Results are shown in figure 5. Examining TSI values based on chlorophyll *a* (TSI CHL), the greatest differences between 1977–83 and 1999 are in Sullivan Bay, Kabetogama Lake, and Black Bay. The 1999 TSI CHL values for these water bodies, which are more than 20 scale units less than median values for 1977–83, indicate a decreased biomass. Chlorophyll *a* concentrations in these water bodies during 1999 were 10–13 percent of median values for the 1977–83 sampling period, and similar to median concentrations in the less productive Namaka, Sand Point, and Rainy Lakes (fig. 5). Although the chlorophyll *a* concentrations and corresponding TSI CHL values for all water bodies sampled in 1999 were less than median values for the 1977–83 study, the differences were much greater for Black Bay, Sullivan Bay, and Kabetogama Lake.

The decrease in algal biomass was reflected in increased Secchi-disk transparency (fig. 5) and decreased TSI SD values (fig. 5) in Black Bay, Sullivan Bay, and Kabetogama Lake, but decreased TSI SD values did not occur in Namakan Lake, Sand Point Lake, or Rainy Lake. The decrease in TSI SD was 2–4 scale units (in relation to median values for 1977–83) in Black Bay, Sullivan Bay and Kabetogama Lake, underscoring the limitations of using Secchi-disk readings for evaluating algal biomass in these water bodies.

A decrease in algal biomass is a response to decreased nutrient levels, particularly phosphorus, in lakes where phosphorus is a limiting nutrient. In Black Bay and Kabetogama Lake, total phosphorus concentrations during July 1999 were less than median values for 1977–83 (fig. 4), but the corresponding TSI TP values underestimate the reduction in algal biomass (fig. 5). In Rainy and Namakan Lakes, the TSI TP values predict increases in algal biomass relative to median values from the earlier study, but productivity, as measured by chlorophyll *a* concentrations, decreased. In Sullivan Bay, TSI TP values predict very little change in productivity but algal biomass, as measured by chlorophyll *a* concentration, was substantially lower than median values for 1977–83. These data suggest that total phosphorus concentrations, and corresponding TSI TP values, are imprecise indicators of algal biomass in these water bodies. The preceding

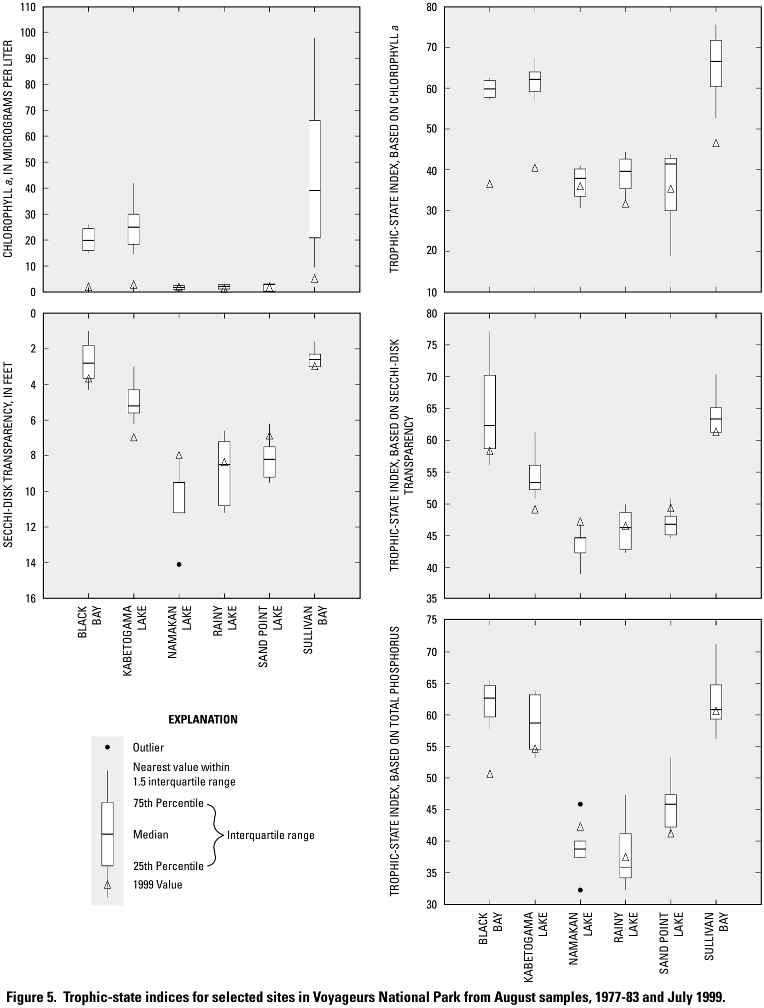

Figure 5. Trophic-state indices for selected sites in Voyageurs National Park from August samples, 1977-83 and July 1999.

discussion, however, is based on a single set of chlorophyll *a* analyses that are assumed to represent average summer algal productivity. Algal productivity can fluctuate from week to week; therefore, this assessment of trophic status is subject to uncertainty inherent to temporal variation of chlorophyll *a* concentrations.

The low level of algal productivity during July 1999 coincides with low concentrations of soluble inorganic nitrogen and phosphorus in the euphotic zone, especially in Black Bay, Kabetogama Lake, Sullivan Bay, and Sand Point Lake, where nitrite plus nitrate concentrations were less than 0.005 mg/L. Dissolved orthophosphorus concentrations ranged from 1–6 µg/L in all water bodies except Sullivan Bay where the concentration was 15 µg/L, suggesting that the phytoplankton communities were at, or approaching, limiting conditions with respect to available nitrogen and phosphorus.

SUMMARY

Water-quality samples were collected during July 1999 from selected lakes and bays, and the mouths of two rivers that flow into Voyageurs National Park. Results of laboratory analyses and field measurements of chemical and physical properties were compared to similar data collected during a study conducted during 1977–83. Water-quality data were evaluated for changes in specific conductance, alkalinity, nutrients, trace metals, bacteria, and trophic state.

Specific conductance and alkalinity showed little change from the 1977–83 study. The most change in specific conductance, an increase, was seen in the epilimnetic waters in Sand Point Lake, which may have been influenced by above normal inflow from the Vermilion River during the summer of 1999. The most change in alkalinity, a decrease, was seen in Black Bay and Kabetogama Lake. Lower alkalinity in Black Bay may reflect above normal inflow from Kabetogama Lake. Alkalinity in Kabetogama Lake may reflect inflow of relatively low alkalinity water from Namakan Lake.

Nutrient concentrations showed a decrease in nitrite plus nitrate nitrogen concentrations at all sampling sites and a decrease in total phosphorus concentrations in Black Bay and Kabetogama Lake relative to the 1977–83 period.

Trace metals were detected less frequently in samples collected during 1999 compared to the 1977–83 period. Chromium, lead, selenium, and zinc, which were detected in some samples during 1977–83, were all reported at less than the method reporting limit in samples collected during 1999. Arsenic was detected at three sites. Barium and copper were detected in all samples collected during 1999. Copper was more concentrated in samples of hypolimnetic water than in samples of epilimnetic water. Nickel was detected at one site.

Fecal-coliform bacteria colony counts ranged from 1 to 8 col/100 mL. These counts are within the State of Minnesota standard of 200 col/100 mL for contact recreation.

Vertical profiles of temperature, specific conductance, dissolved oxygen, and pH showed patterns generally similar to profiles measured 1977–83. Strong thermal stratification, as indicated by the presence of a thermocline, was present in Namakan Lake and Sand Point Lake. While the position and thickness of the thermocline in these two lakes were similar to conditions observed during 1977–83, the presence of higher-conductivity water in the epilimnion of Sand Point Lake, relative to conductivity in the hypolimnion, was not observed during the 1977–83 period.

Trophic status during 1999, as determined from chlorophyll *a* measurements of algal productivity, was below median 1977–83 trophic levels at all sampling sites. The largest change in algal productivity was in Black Bay, Kabetogama Lake, and Sullivan Bay where chlorophyll *a* concentrations were 10–13 percent of median values determined during 1977–83. Trophic state indices based on total phosphorus concentrations and Secchi-Disk transparencies indicated a change in trophic state for Black Bay and Kabetogama Lake, but the change in those indices was less than the change in the index based on chlorophyll *a*. Low concentrations of soluble inorganic nitrogen and orthophosphorus in the euphotic zone, combined with low levels of algal productivity, suggest that nutrient availability was limiting trophic levels during July 1999.

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