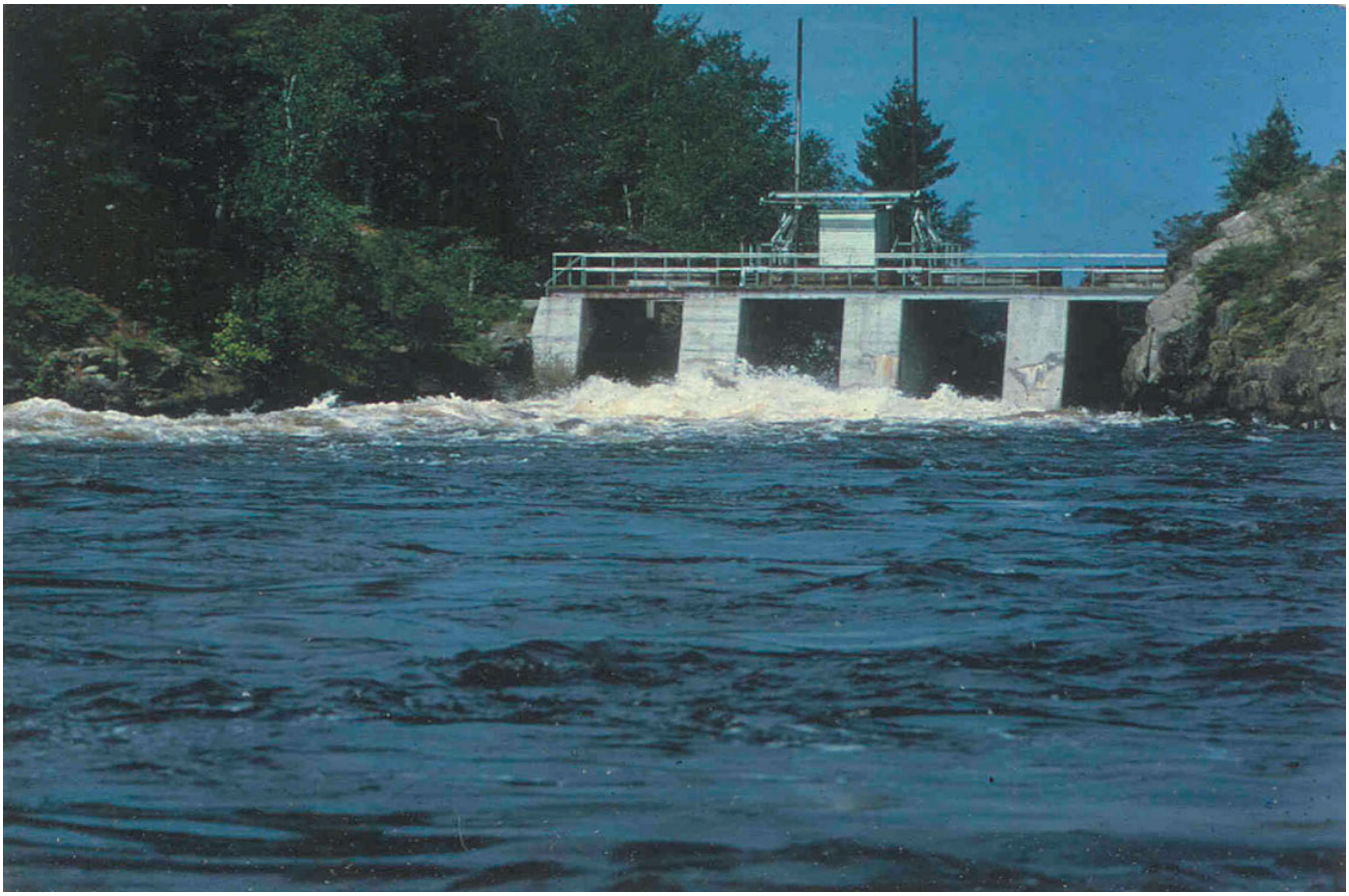
Prepared in cooperation with the National Park Service

Effects of Changes in Reservoir Operations on Water Quality and Trophic-State Indicators in Voyageurs National Park, Northern Minnesota, 2001-03



Scientific Investigation Report 2004-5044

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

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By Victoria C. Christensen, Gregory A. Payne, and Larry W. Kallemeyn

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Conversion Factors

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Vertical coordinate information is referenced to the *insert datum name (and abbreviation) here, for instance, "North American Vertical Datum of 1988 (NAVD 88)"*

Horizontal coordinate information is referenced to the *insert datum name (and abbreviation) here, for instance, "North American Datum of 1983 (NAD 83)"*

Altitude, as used in this report, refers to distance above the vertical datum.

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

NOTE TO USGS USERS: Use of hectare (ha) as an alternative name for square hectometer (hm^2) is restricted to the measurement of small land or water areas. Use of liter (L) as a special name for cubic decimeter (dm^3) is restricted to the measurement of liquids and gases. No prefix other than milli should be used with liter. Metric ton (t) as a name for megagram (Mg) should be restricted to commercial usage, and no prefixes should be used with it.

Effects of Changes in Reservoir Operations on Water Quality and Trophic-State Indicators in Voyageurs National Park, Northern Minnesota, 2001-03

By Victoria G. Christensen, Gregory A. Payne, and Larry W. Kallemeyn

Abstract

Implementation of an order by the International Joint Commission in January 2000 has changed operating procedures for dams that regulate two large reservoirs in Voyageurs National Park in northern Minnesota. These new procedures were expected to restore a more natural water regime and affect water levels, water quality, and trophic status. Results of laboratory analyses and field measurements of chemical and physical properties from May 2001 through September 2003 were compared to similar data collected prior to the change in operating procedures. Rank sum tests showed significant decreases in chlorophyll-*a* concentrations and trophic state indices for Kabetogama Lake (p=0.021) and Black Bay (p=0.007). There were no significant decreases in total phosphorus concentration, however, perhaps due to internal cycling of phosphorus. No sites had significant trends in seasonal total phosphorus concentrations, with the exception of May samples from Sand Point Lake, which had a significant decreasing trend (tau=-0.056, probability=0.03). May chlorophyll-*a* concentrations for Kabetogama Lake showed a significant decreasing trend (tau=-0.42, probability=0.05). Based on mean chlorophyll trophic-state indices (2001-03), Sand Point, Namakan, and Rainy Lakes would be classified oligotrophic to mesotrophic, and Kabetogama Lake and Rainy Lake at Black Bay would be classified as mesotrophic. The classification of Sand Point, Namakan, and Rainy Lakes remain the same for data collected prior to the change in operating procedures. In contrast, the trophic classification of Kabetogama Lake and Rainy Lake at Black Bay has changed from eutrophic to mesotrophic.

Introduction

Voyageurs National Park (hereinafter referred to as the Park) contains four large lakes: Sand Point, Namakan, Rainy, and Kabetogama (fig. 1). These lakes comprise about 40 percent of the Park. All these lakes existed as natural water bodies before dams were built and have been regulated since the early 1900's. Rainy Lake is a reservoir unto itself. Namakan Reservoir consists of five connected lakes. Three of the lakes, Sand Point, Namakan, and Kabetogama, are in Voyageurs National Park. Regulation of both Rainy Lake and Namakan Reservoir has altered the magnitude and timing of water-level fluctuations and has removed much of the hydrologic variability the Park's lakes.

Rule curves show bands of permitted maximum and minimum water levels that are allowed throughout the year. Rule curves give guidance for the operation of a reservoir, and daily flow at a dam is set based on the rule curve. The rule curves established in 1970 for Rainy and Namakan Reservoirs allowed larger-than-natural fluctuations in lake levels on Namakan Reservoir to maintain less-than-natural fluctuations on Rainy Lake.

On January 6, 2000, the International Joint Commission (IJC), the international body that sets the rules for the operation of dams on waters shared by the United States and Canada, issued new rules to restore a more natural water regime to the Park's lakes (Kallemeyn, 2000). The IJC encouraged water management agencies to research and monitor the effects of the changes on the ecosystem. Operation of the Park's reservoirs under the new rules will most likely change magnitude and direction of water flow between lakes in Namakan Reservoir and between Namakan Reservoir and Rainy Lake.

Water flows from Namakan Reservoir into Rainy Lake at three locations—through the dams at Squirrel and Kettle Falls at the northwest end of Namakan Lake, at Bear Portage on the north-central side of Namakan Lake, and at Gold Portage at the west end of Kabetogama Lake. The operation of Namakan Reservoir under the new rules likely will result in an increase in the number of days that water flows through Gold Portage, a natural spillway. When the Namakan Reservoir level reaches an elevation of 339.39 m (1113.5 ft) above the North

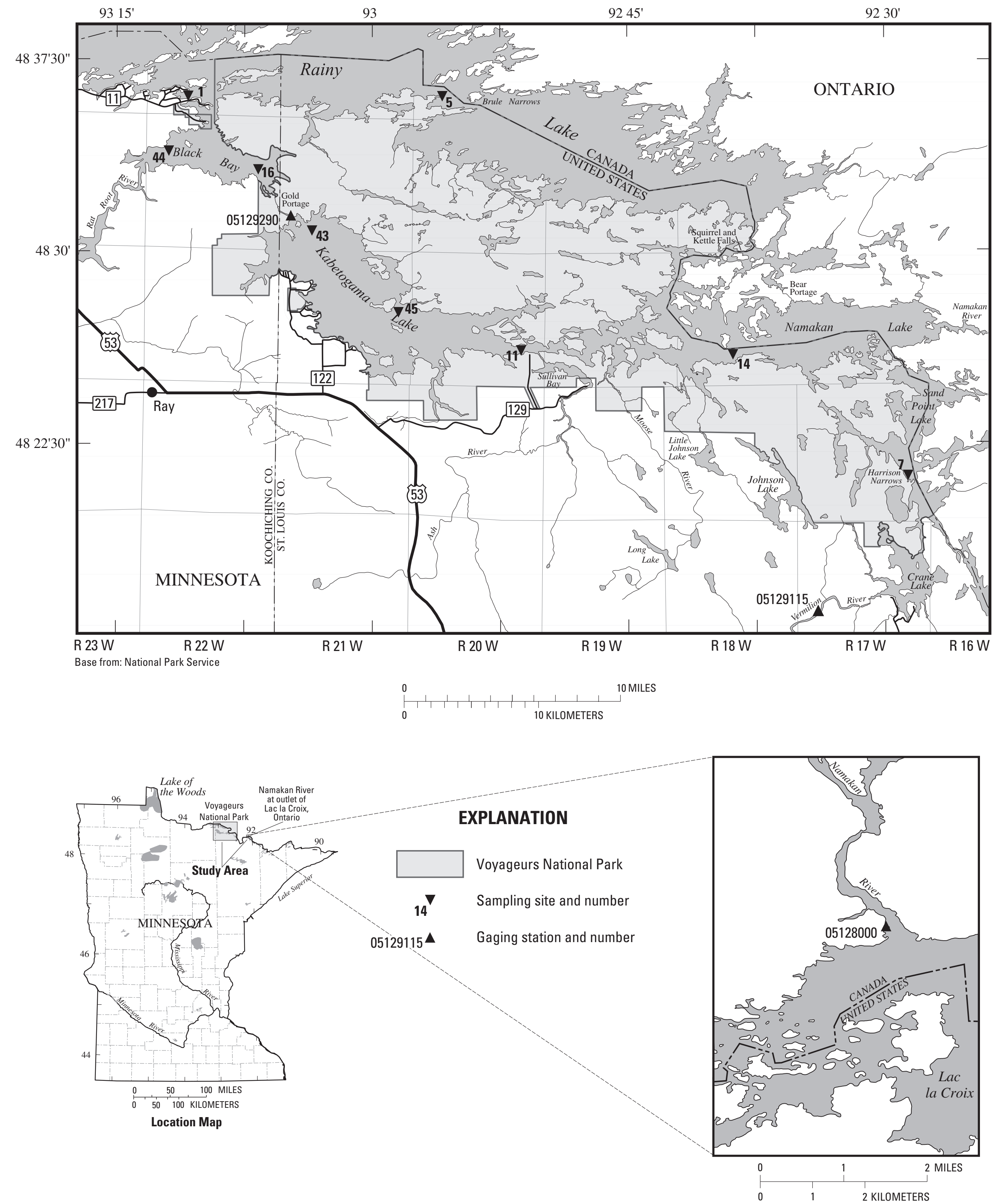

Figure 1. Location of Voyageurs National Park, water-quality sampling sites and gaging stations.

American Vertical Datum of 1988 (NAVD88), water begins to spill over into Rainy Lake (International Rainy Lake Board of Control and International Lake of the Woods Control Board, 1984). Streamflow records from the U.S. Geological Survey (USGS) gaging station at Gold Portage (1984-98) indicate there has been flow through Gold Portage, on average, 253 days per year. Operating Namakan Reservoir at the midpoint (water level) of the new rule curve, as directed by the IJC order, would result in flow through Gold Portage about 325 days per year. If Namakan Reservoir were operated at the maximum levels allowed in the order, flow would be expected through Gold Portage 365 days per year (Kallemeyn and others, 2003). Increased flow through Gold Portage will result in more water from Kabetogama Lake entering Black Bay, a shallow, eutrophic bay of Rainy Lake. Increased outflow at the west end of Kabetogama Lake also may result in more inflow of water from Namakan Lake at the east end of Kabetogama Lake where the two lakes are connected. Evidence of Namakan Lake water entering Kabetogama Lake was seen in data collected during 1977-84 (Payne, 1991). The effects of the rule changes on the Bear Portage outlet of the Namakan Reservoir will not be as dramatic as the effects on Gold Portage. The outlet sill (elevation) at Bear Portage (approximately 340.39 m or 1,116.8 ft above NAVD88) is 1 m higher than the outlet level at Gold Portage. Timing of hydrologic events in Namakan Reservoir is expected to change, with peak lake-surface elevations, and peak outflow occurring in late May to early June, rather than late June to early July.

The new rules also were proposed to lower phosphorus loading into Namakan Reservoir. Changes in water flow and phosphorus concentration could dramatically change the chemistry and biology of the Park's lakes, perhaps restoring them to conditions similar to those before the dams were built. The chemistry of Namakan and Kabetogama Lakes is quite different. Biological production in shallow (less than 24 m), nutrient-rich Kabetogama Lake is typically 2-3 times that in deep, nutrient-poor Namakan Lake. Thus, the change in reservoir operation could change the location and quality of Namakan Reservoir water delivered to Rainy Lake.

Without a monitoring program in place, it would be impossible to determine if the new rule changes are having any effect on water quality. The USGS entered into a cooperative agreement with the National Park Service (NPS) at Voyageurs National Park to study the effects of water-level changes on water quality and trophic state. The monitoring program established by the agencies will help document these effects and evaluate the effectiveness of the IJC's efforts to alleviate water-quality problems. The specific objectives of this study were to gather sufficient water-quality data to document changes in primary productivity, nutrient enrichment, and major-ion chemistry in the Rainy-Namakan Reservoir system due to changes in reservoir operation. Emphasis was placed on monitoring nutrients and indicators of biological activity in Kabetogama Lake and Black Bay because these water bodies were expected to be most affected by the rule-curve changes (partially due to the more frequent flow incidence anticipated through Gold Portage).

Study Area

Morphologically, Rainy Lake and Namakan Reservoir are typical of lakes located on rocks of the Precambrian shield. They have irregular shorelines with numerous rock outcrops and islands. Littoral areas with fine-grained sediments are primarily restricted to creek or river deltas, or protected embayments. In total, Rainy Lake covers 92,000 hectares and Namakan Reservoir about 26,000 hectares. The total volume of Rainy Lake is about 3 times that of Namakan Reservoir. While both Rainy Lake and Namakan Reservoir have maximum depths of about 50 m, there is considerable variation in maximum and mean depth between individual lake basins. The maximum depth of Kabetogama Lake is about 24 m and the mean depth is about 9 m. While thermoclines are typically present throughout summer in the deeper basins, thermal stratification occurs infrequently in Kabetogama Lake. When Kabetogama Lake is thermally stratified, dissolved oxygen concentrations below the thermocline are usually less than the accepted standards for aquatic life. The lakes are typically ice covered for about 5 or 6 months per year, with ice-up occurring in mid- to late November and ice-out occurring about May 1.

Background

Sand Point, Namakan, and Rainy Lakes, which receive most of their inflow from drainage areas with large areas of exposed bedrock and thin noncalcareous glacial sediments, have been characterized as oligotrophic to mesotrophic, and have low dissolved solids and alkalinity. In contrast, Kabetogama Lake, which receives much of its inflow from an area overlain by calcareous glacial sediment, has been characterized as eutrophic, and has greater dissolved solids and alkalinity. A baseline water-quality study during 1977-84 (Payne, 1991) reported samples collected in a stream near the west end of the Park had dissolved-solid concentrations about five times and total alkalinity concentrations about eight times concentrations measured in the Namakan River (fig. 1). The baseline study was conducted to determine major water types and characteristics of the large lakes and bays in Voyageurs National Park. A subsequent study during 1999 (Payne, 2000) was conducted and results were compared to the data collected during 1977-84. The results showed that specific conductance and alkalinity values from 1999 were similar to those from the 1977-84 study. Nitrite plus nitrate nitrogen concentrations generally were lower throughout the Park and total phosphorus concentrations were lower in Kabetogama Lake and Rainy Lake at Black Bay (hereinafter referred to as Black Bay) relative to the baseline study. Trophic state indices (TSI), based on chlorophyll-*a* concentrations (Carlson, 1977), indicated lower algal biomass throughout the Park. The largest decreases in algal biomass in 1999, relative to the baseline study, were in Kabetogama Lake, Black Bay, and Sullivan Bay.

Hargis (1981) measured chlorophyll-*a* concentrations in the summer of 1979. These chlorophyll-*a* values were used to calculate trophic state indices for stations in each of the four large lakes in the Park. Kepner and Stottlemyer (1988) converted the Hargis data to lakewide means and compared it to their own data collected in 1985 and 1986. There were no obvious trends in TSI between 1979 and 1986. TSI values reported by Kepner and Stottlemyer ranged from 40-54 in Sand Point, 34-46 in Namakan, 36-50 in Rainy, and 44-65 in Kabetogama.

Kepner and Stottlemyer (1988) reported values for specific conductance, chlorophyll-*a* concentrations, and carbon assimilation rates from Kabetogama Lake that typically were 2 to 3 times greater than those from the three less productive lakes. Analysis with a total-phosphorus mass-balance model indicated the peak total-phosphorus concentrations in Kabetogama Lake, which occur during spring, would be reduced from about 0.034 to 0.030 mg/L if the previous rule curves (International Joint Commission Order Prescribing Method of Regulating the Levels of Boundary Waters, Supplementary Order dated July 29, 1970) were replaced by one approximating natural conditions. The authors attributed this to (1) a reduction in bottom areas exposed by drawdown and accompanying sediment-water interactions, (2) reduced nutrient inputs resulting from die-off of littoral vegetation, and (3) reduced nutrient concentrations due to changing (rather than constant) volume. The authors, stressing that the model was uncalibrated, concluded a return to natural fluctuations could reduce phytoplankton biomass and the accompanying primary production. These changes, in turn, could have ramifications throughout the food web.

Purpose and Scope

The purpose of this report is to describe effects of changes in reservoir operations on water quality and trophic state in Voyageurs National Park. Data collected in 2001-03 are described and compared to data collected in 1977-83, 1985, and 1986. This report will attempt to answer the following questions: (1) Are changes in primary productivity and nutrient enrichment, relative to baseline data, taking place in Kabetogama Lake and Black Bay, post January 2000 rule-curve change? (2) Are changes in primary productivity and nutrient enrichment in Kabetogama Lake and Black Bay greater than changes at reference sites in Sand Point Lake, Namakan Lake, and Rainy Lake?

Answers to these questions are intended to establish a baseline for comparison with future studies of reservoir operation. Results also may contribute toward improved understanding of how water levels may affect water quality.

Methods

Nine sampling sites were selected for the 2001-03 study described in this report. Six sampling sites correspond to those used for collection of baseline water-quality data as described and numbered in Payne (1991). These are Site 7 in Sand Point Lake, Site 14 in Namakan Lake, Site 5 in Rainy Lake, Site 11 in Kabetogama Lake, and Sites 1 and 16 in Black Bay. Rainy Lake at Black Bay near International Falls (Site 16) was not sampled after June 9, 2003 due to low water, which made boat access difficult. Two additional sites were established in Kabetogama Lake (43 and 45) and one additional site was established in Black Bay (44) (fig. 1). A list of the sites sampled during the current study and their corresponding USGS station and site numbers are listed in table 1.

Water-quality monitoring was most intensive in Kabetogama Lake and Black Bay. Water samples were collected at 2-week intervals from May through October at three sites in Kabetogama Lake and at three sites in Black Bay (Sites 11, 43, and 45; and 1, 16, and 44; respectively, fig. 1). Samples were analyzed to determine concentrations of chlorophyll-*a* and total phosphorus. Secchi-disk transparency and vertical profiles of specific conductance, pH, temperature, and dissolved oxygen were measured at each site during each sampling. Barometric pressure was measured for use in the calibration of dissolved oxygen meters.

Table 1. Sites sampled for baseline water quality, Voyageurs National Park, Minnesota, 2001-03.

USGS station number		Site number (figure1)
482226092283301	Sand Point Lake below Harrison Narrows near Crane Lake	7
482616092372201	Namakan Lake near Ray	14
483622092560701	Rainy Lake at Brule Narrows near International Falls	5
482607092511701	Kabetogama Lake at Mouth of Meadwood Bay near Ray	11
483012093035001	Kabetogama Lake at Cemetary Island near Ray	43
482731092574701	Kabetogama Lake near Grave Island near Ray	45
483511093092801	Rainy Lake at Black Bay Narrows near International Falls	1
483304093062701	Rainy Lake at Black Bay near International Falls	16
483341093111501	Rainy Lake at Black Bay (West) near International Falls	44

During May and August, the Kabetogama and Black Bay sites were sampled for determination of additional constituents, including alkalinity, dissolved solids, and dissolved magnesium, calcium, sodium, potassium, manganese, chloride, sulfate, nitrite nitrogen, and nitrite plus nitrate-nitrogen, dissolved ammonia, dissolved and total ammonia plus organic nitrogen, dissolved phosphorus, dissolved ortho-phosphorus, and chlorophyll-*b*. Dissolved nitrate nitrogen was calculated for these samples by subtracting dissolved nitrite from dissolved nitrite plus nitrate results. Three additional sites were sampled during May and August at locations in Sand Point, Namakan, and Rainy Lake (Sites 7, 14, and 5, respectively, fig. 1). These additional sites were used for comparative purposes. Sampling for major ions was intended to provide information on the extent of water exchange between Namakan Lake, Kabetogama Lake, and Black Bay. Sampling for major ions was discontinued after 2001 and therefore, the analysis of water exchange is limited.

A list of physical properties measured, water-quality constituents analyzed, reporting units and method reporting limits are listed in table 2. Reporting limits indicated by less than (<) values in analytical results, can be different from the method reporting limits because of sample matrix effects and other sources of variability. Physical properties measured at the field site included air pressure, specific conductance, pH, water temperature, transparency, and dissolved oxygen. Specific conductance, water temperature, pH, and dissolved-oxygen concentration were measured using portable field instruments. Although observations of field values were recorded throughout the water column, only those obtained at the Secchi depth are reported herein.

Depth of water transparency was measured using a standard black and white Secchi disk, a metal disk painted with alternate quadrants of black and white. The disk is lowered from the water surface to determine light penetration through the water. Because of its historical use at the Park, the Secchi-disk transparency is an important reading to show temporal change in water clarity. Although more accurate methods of measuring water clarity are available, Secchi-disk measurements are popular because they are simple and inexpensive. Secchi-disk readings do, however, have their limitations. They depend on the eyesight of the viewer, the time of day, the color of the water, and the condition of the disk. These limitations should be kept in mind when comparing readings either through time or from site to site.

Samples of water were collected from top, center, and bottom positions in the water column. The top subsample was collected at a depth of less than 1 m, the center subsample was collected at the depth of the Secchi disk reading, and the bottom subsample was collected at twice the depth of the Secchi disk reading. Samples were collected using a Van-Dorn type sampler. Subsamples were composited (equal-volume) into bottles and placed in coolers with ice immediately after collection.

Water samples were processed in a field laboratory on site or in a laboratory vehicle where they were filtered and preserved as required. Alkalinity was determined by incremental titration at the field laboratory. Measured volumes of composite whole water for determination of chlorophyll-*a* and *b* were filtered in the field laboratory and the filter containing the algal material was packaged and frozen immediately. Samples were shipped from the field laboratory to the USGS National Water-Quality Laboratory (NWQL) in Denver, Colorado using commercial next-day delivery. The NWQL reports estimated (E) values for several reasons, including when constituents were detected below the method reporting level, the concentrations were outside the calibration range, or there was a deviation in the standard operating procedure. In tables of NWQL data within this report, estimated values were used in the computation of means and medians. Mean and median values were not computed for data sets with more than one censored value (less than). For those data sets with only one censored value, one-half that value was used in the calculation of mean and median concentrations.

The Natural Resources Research Institute (NRRI), in Duluth, Minnesota, analyzed additional biweekly water samples (for phosphorus and chlorophyll, using EPA 365.3 and Standard Method 10200, respectively (John Ameel, Natural Resources Research Institute, written commun., February 16, 2004)). Analytical results from the NWQL and NRRI are reported in separate tables (tables 10-12, appendix). Statistical tests were performed on NWQL data only, so as not to misinterpret differences among the lakes and bays from differences which may result from analytical variability between the NWQL and NRRI.

Separate data sets were analyzed by NRRI and Braun Intertec Corporation, Minneapolis, Minnesota to assess spatial variability. These data are discussed in the Quality Assurance and Quality Control section of this report. Braun Intertec Corporation analyzed phosphorus using USEPA method 365.4 and chlorophyll-*a* using Standard Method 10200 (Steven Albrecht, Braun Intertec, written commun., August 7, 2003).

Streamflow and lake-elevation data were gathered from gaging stations currently in operation at Gold Portage Outlet at Kabetogama Lake (USGS station number 05129290), Namakan River at Outlet of Lac La Croix (USGS station number 05128000), Rainy Lake near Fort Francis (USGS station number 05129400), and Vermillion River near Crane Lake (USGS station number 05129115). Additional streamflow data was gathered from Squirrel and Kettle Falls and Bear Portage.

Quality Assurance and Quality Control

A primary data quality objective was to ensure that samples were representative of the water bodies under investigation. Quality assurance was assessed with specific procedures, such as instrument calibration, to ensure data reliability. To understand the error associated with the sample data, 11 of the 44 full-suite samples collected and analyzed by the NWQL were quality control samples (field blanks or replicates).

Table 2. Reporting limits of physical properties measured and water-quality constituents sampled in Voyageurs National Park, Minnesota, 2001-03

[°C, degrees Celsius; m, meters; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; µg/L, micrograms per liter; --, not analyzed]

Physical property or constituent	Field instrument	Reporting limit: National Water-Quality Laboratory	Reporting limit: Braun Intertec Corporation	Reporting limit: Natural Resources Research Institute
Air pressure	1 mm	--	--	--
Specific conductance, field	1 µs/cm	--	--	--
Specific conductance, laboratory	--	1 µs/cm	--	--
Field pH	0.1 unit	--	--	--
Laboratory pH	-	0.1 unit	--	--
Water temperature	0.1 °C	--	--	--
Transparency, Secchi disk	0.1 m	--	--	--
Dissolved oxygen	0.1 mg/L	--	--	--
Dissolved calcium	--	0.025 mg/L	--	--
Dissolved magnesium	--	0.008 mg/L	--	--
Dissolved sodium	--	0.06 mg/L	--	--
Dissolved potassium	--	0.09 mg/L	--	--
Bicarbonate alkalinity as HCO_3	--	1 mg/L	--	--
Carbonate alkalinity, as CO_3	--	1 mg/L	--	--
Total alkalinity as $CaCo_3$	--	1 mg/L	--	--
Dissolved sulfate	--	0.11 mg/L	--	--
Dissolved chloride	--	0.08 mg/L	--	--
Dissolved nitrite nitrogen	--	0.001 mg/L	--	--
Dissolved nitrite plus nitrate nitrogen	--	0.005 mg/L	--	--
Dissolved ammonia nitrogen	--	0.002 mg/L	--	--
Dissolved ammonia plus organic nitrogen	--	0.1 mg/L	--	--
Total ammonia plus organic nitrogen	--	0.1 mg/L	--	--
Total phosphorus	--	0.004 mg/L	0.01 mg/L	0.007 mg/L
Dissolved phosphorus	--	0.004 mg/L	--	--
Dissolved orthophosphorus	--	0.001 mg/L	--	--
Dissolved manganese	--	3.0 µg/L	--	--
Chlorophyll-*a*	--	0.1 µg/L	0.5 µg/L	0.01 µg/L
Chlorophyll-*b*	--	0.1 µg/L	--	--

Spatial variability also was assessed through the collection of samples from randomly selected sites in Kabetogama Lake.

Instrument calibration for portable field instruments was undertaken at the start of each day and was verified at the end of each day. More frequent calibration was initiated if end-of-day verifications indicated that instruments were not holding calibration. Observations of physical properties in the water column (specific conductance, temperature, pH, and dissolved oxygen) were recorded at 1 m intervals normally, but submeter intervals were used when specific conductance changed more than 5 percent per meter, temperature changed more than 1 degree Celsius per meter, or pH changed more than 0.5 unit per meter. Submeter recording intervals also were used to more precisely delineate any part of the water column where dissolved-oxygen concentrations were less than 5 mg/L.

Effectiveness of equipment cleaning and sample processing was assessed by laboratory analysis of field blanks. To quality assure equipment and procedures used in the field, laboratory blank water was processed through collection bottles and filtering devices using the same methods as for native water samples. Results of analysis performed on these blanks showed little evidence of sample contamination. Concentrations for all blank samples collected in 2001 and 2002 were less than the method reporting limit (MRL) for each constituent (table 2). A blank water sample processed on May 28, 2003 had concentrations less than the MRL for all constituents with the exception of ammonia, which was detected at a concentration of 0.027 mg/L (MRL 0.002 mg/L).

For this study, within-site variability associated with sample collection and analysis was determined through the collection of replicate samples from Rainy Lake at Black Bay Narrows near International Falls (Site 1), Rainy Lake at Brule Narrows near International Falls (Site 5), and Kabetogama Lake near Grave Island near Ray (Site 45). Samples were collected following procedures used during the baseline study (Payne, 1991) for comparability with historical data. Results of analysis of the replicate samples are shown in table 3. A typical quality-control objective for precision of replicate samples is a maximum relative percentage difference of 20 percent (Taylor, 1987). The median relative percentage difference was less than 20 for all constituents; however, one paired sample collected on May 15, 2001 at Rainy Lake at Brule Narrows showed a relative percentage difference of 40 percent for ammonia, 22 percent for chlorophyll-*a*, and 29 percent for chlorophyll-*b*. The ammonia and chlorophyll-*b* concentrations were close to their method detection limit, which may account for the increased variability. These percentage differences need to be taken into account when evaluating the variability between samples from the same site.

To assess intrabasin spatial variability of limnological characteristics in Kabetogama Lake, an additional nine sites were sampled along with Sites 11, 43, and 45 (fig. 1) on June 20-21, 2003, and July 18, 2003. The nine sites were randomly selected using a geographic information system from the portion of the lake where water depths equaled or exceeded 5 m. Voyageurs National Park staff and volunteers from the North Star Chapter of the Academy of Hazardous Materials Managers conducted sampling at these sites. Samples were collected using the same field procedures as previously described for Sites 11, 43, and 45 (Payne, 1991). Total phosphorus and chlorophyll-*a* analyses for the June samples were completed at the NRRI in Duluth, Minnesota, and for the July samples at Braun Intertec Corporation, Minneapolis, Minnesota. No comparisons were made between the June and July samples because different laboratories were used and no replicates between laboratories were analyzed. The data tables for the

Table 3. Median relative percentage differences for major ions, nutrients, and chlorophyll concentrations in replicate samples collected at Rainy and Kabetogama Lakes, Voyageurs National Park, Minnesota, 2001-02

.[mg/L, milligrams per liter; µg/L, micrograms per liter]

Constituent	Median relative percentage difference	Pairs of replicate samples
Dissolved solids (mg/L)	0.0	1
Dissolved calcium (mg/L)	3.1	1
Dissolved magnesium (mg/L)	2.3	1
Dissolved potassium (mg/L)	4.3	1
Dissolved sodium (mg/L)	7.1	1
Dissolved chloride (mg/L)	10.6	1
Dissolved sulfate (mg/L)	5.7	1
Dissolved manganese (µg/L)	1.3	1
Dissolved nitrite nitrogen (mg/L)	0.0	2
Dissolved nitrite plus nitrate nitrogen (mg/L)	9.1	2
Dissolved ammonia nitrogen (mg/L)	20.0	2
Dissolved ammonia plus organic nitrogen (mg/L)	6.3	2
Total ammonia plus organic nitrogen (mg/L)	7.4	2
Total phosphorus (mg/L)	8.7	3
Dissolved phosphorus (mg/L)	4.4	2
Dissolved orthophosphorus (mg/L)	9.1	2
Chlorophyll-*a* (µg/L)	15.7	2
Chlorophyll-*b* (µg/L)	14.3	2

spatial analysis are not contained in this report, and are on file at the Voyageurs National Park Office, International Falls, Minnesota. A summary of the spatial analysis follows.

Values for total phosphorus and chlorophyll-*a* from the Sites 11, 43, and 45 were generally within the range of values from the additional nine sites. In June, total phosphorus concentrations at Sites 11, 43, and 45 (0.014, 0.012, 0.010 mg/L) were within the range of values from the nine additional sites (0.06 – 0.016 mg/L, mean 0.011). The chlorophyll-*a* concentration at Site 43 in June was 2.84 µg/L, which was 0.34 µg/L greater than the maximum concentration observed at any of the nine sites. Chlorophyll-*a* concentrations at Sites 45 (1.84 µg/L) and 11 (1.67 µg/L) were within the range of 0.67 to 2.50 µg/L measured at the other nine sites.

Except for total phosphorus at Site 11 (0.014 mg/L), concentrations in July at Sites 11, 43, and 45 were within the range of values from the nine additional sites. Total phosphorus concentrations at Sites 43 and 45 were 0.018 and 0.017 mg/L, respectively, while the range for the nine sites was 0.016–0.026 mg/L. The range for chlorophyll-*a* was 5.4–21.0 mg/L (mean 9.8 mg/L), and the concentrations at Sites 11, 43, and 45 were 5.7, 6.9, and 9.1 mg/L, respectively.

Streamflow

Water generally flows through Voyageurs National Park from the southeast to the northwest along the United States/Canada border. On average 109 m^3/sec flow from the Namakan River into the Park annually (Kallemeyn and others, 2003). Combined with an average of 9 m^3/sec from the Vermillion River, this accounts for 80 percent of the inflow to the Namakan Reservoir.

Water flows from Namakan Reservoir into Rainy Lake at four locations—Squirrel and Kettle Falls, Gold Portage, and Bear Portage (fig. 1). Most of this flow discharges through the adjacent regulated dams at Squirrel and Kettle Falls. The quantity of water that moved from Namakan Reservoir to Rainy Lake from 2001 to October 2003 is represented by the hydrographs for Squirrel and Kettle Falls, Gold Portage, and Bear Portage (fig. 2).

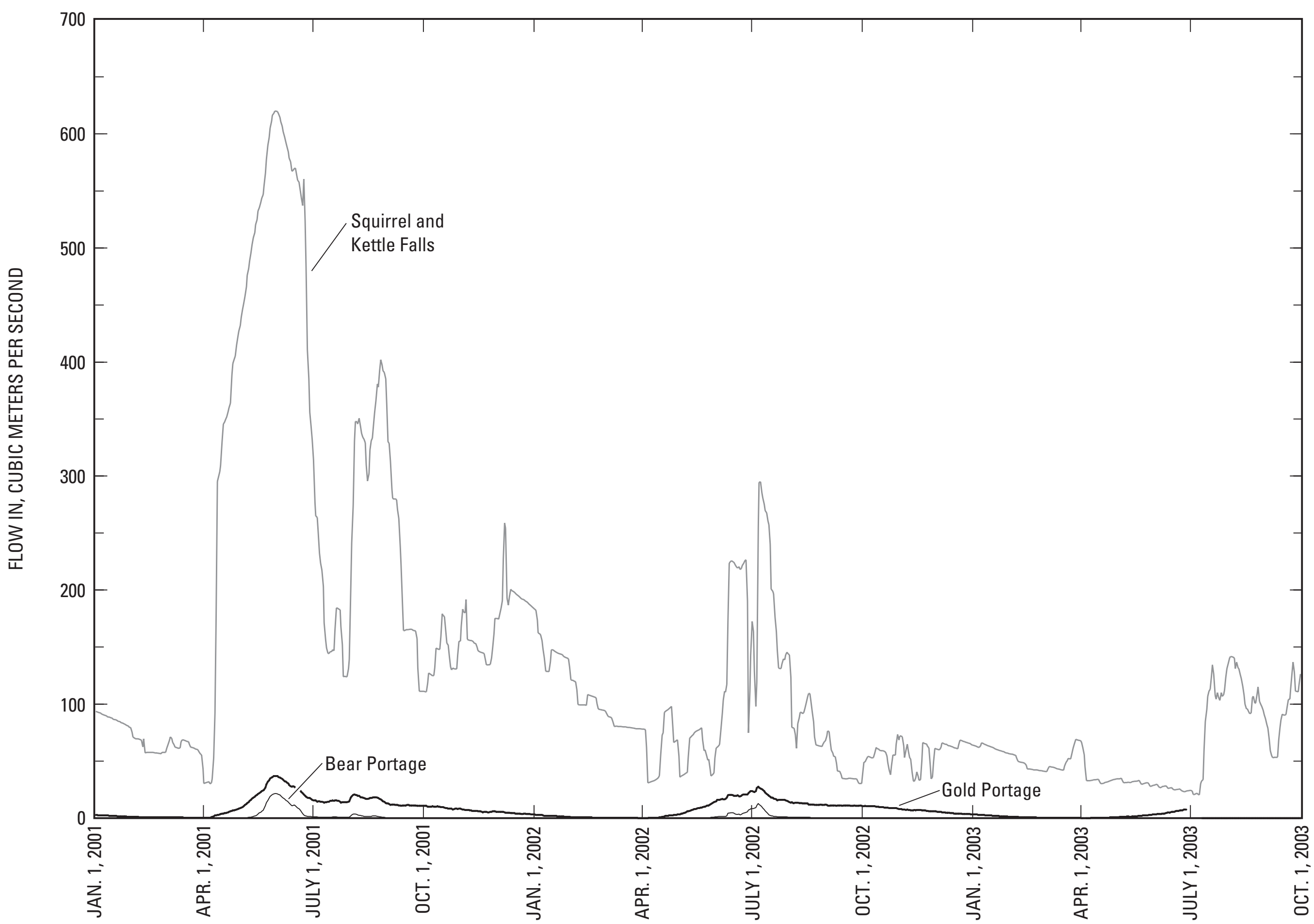

Figure 2. Hydrographs for the three locations where Namakan Reservoir (including Namakan Lake and Kabetogama Lake) flows into Rainy Lake (data from Lake of the Woods Control Board, 2004).

Reservoir Operations

The new rule curves were implemented on January 6, 2000 for regulating water levels on Rainy Lake and Namakan Reservoir. The requisite maximum and minimum water levels as defined by the IJC for Namakan Reservoir are shown in figure 3a. The actual water levels also are shown. The rule curve levels and actual levels for Rainy Lake are shown in figure 3b.

During 2001 and 2002, the maximum rule curve water levels were exceeded during late spring and early summer. According to the IJC, at the end of March 2001, there was near-normal water content in the snowpack, normal to greater than normal soil moisture and well below normal baseflow in the basin's rivers and streams (International Rainy Lake Board of Control and International Rainy River Water Pollution Board, 2002). Two substantial periods of rainfall in the spring (mid-April to mid-June) and summer (late July) caused the high water levels and flows in spring and summer 2001. High water level conditions existed not only in the Rainy-Namakan Basin, but extended downstream to the Lake of the Woods. On Rainy and Namakan Lakes the 2001 levels were the highest since 1968 (International Rainy Lake Board of Control and International Rainy River Water Pollution Board, 2002).

Rainy Lake also experienced very high water levels in 2002 due to heavy rainfall on June 9 and 10 and June 22-23. On Rainy Lake, the 2002 peak level was the highest since 1950 (International Rainy Lake Board of Control and International Rainy River Water Pollution Board, 2002). A decrease in Namakan Reservoir outflow along with localized heavy rainfall on July 4-5, 2002 over the Namakan Lake and its tributaries contributed to high levels on Namakan Reservoir.

Very dry conditions from November 1, 2002 through March 31, 2003 resulted in low water conditions on Rainy Lake and Namakan Reservoir. Measured precipitation during this period was the least since 1901 (International Rainy Lake Board of Control, news release May 30, 2003). Dry conditions continued through the summer of 2003, with Namakan Reservoir levels remaining near the lower rule curve and Rainy Lake levels about 1 m below the lower rule curve (fig. 3).

Changes in timing of peak lake-surface elevations in Namakan Reservoir did not occur as expected. Although the peak elevation occurred earlier as expected in 2001, the 2002 peak elevation occurred around July 1 as it had before the rule curve change. The peak elevations may have been affected by extreme rainfall experienced throughout Northwest Minnesota (Wiche and others, 2002). In 2003, a year of drought conditions, peak lake-surface elevation occurred much later (fig. 3).

On the basis of streamflow records from the USGS gaging station at Gold Portage (1984-2000), flow occurred on average for 253 days per year under the IJC 1970 order. Under the IJC's 2000 order flow occurred an average for 312 days per year (365 in 2001, 344 in 2002, and 227 in 2003). Namakan Reservoir was operated near the maximum of the IJC 2000 order during most of 2001 and exceeded the maximum during high flows in the spring and summer. During 2002, the reservoir operated closer to the midpoint of the IJC rule curve, but still exceeded the maximum during summer high flows. However, after two years of high flows (2001 and 2002), the area had drought conditions in 2003 and the reservoir operated substantially below the minimum rule curve during the second half of 2003. A beaver dam constructed in Gold Portage in early summer further restricted outflow. As a result of drought conditions and the beaver dam the incidence of flow through Gold Portage was less than predicted.

Water-Quality Results

Results of analyses of physical properties, alkalinity, dissolved solids, major ions, nutrients and chlorophyll were evaluated to determine the major characteristics, water types, and algal productivity of the lakes and bays (tables 8-12, appendix). The baseline study (Payne, 1991) divided the waters of the Park into three groups on the basis of the characteristics of specific conductance, transparency, alkalin-

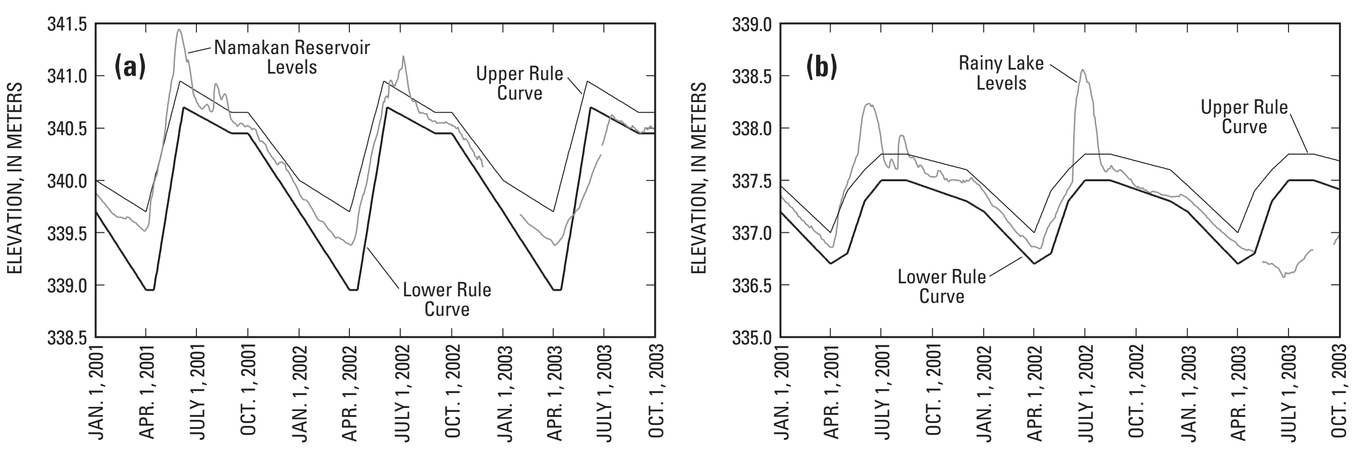

Figure 3. International Joint Commission 2000 Rule Curves and 2001-03 lake levels for (a) Namakan Reservoir and (b) Rainy Lake.

ity, nutrient concentrations, and algal productivity. The groups were (1) Sand Point (Site 7), Namakan (Site 14), and Rainy Lakes (Site 5); (2) Kabetogama Lake (Sites 11, 43, and 45) and Black Bay (Sites 1, 16, and 44); and (3) Sullivan Bay. In each of these characteristics, the water bodies in groups 1 and 3 were at opposite extremes, whereas characteristics of Kabetogama Lake and Black Bay were approximately midway between the extremes. Sullivan Bay was not sampled during the current study (2001-03); however, the samples collected during 2001 through 2003 indicate that Sand Point, Namakan, and Rainy Lakes continue to show similar characteristics, whereas Kabetogama Lake and Black Bay have substantially different water-quality characteristics than the other lakes.

During the 2001-03 study, samples also were used to determine water quality in the Park with respect to established water-quality criteria. Sand Point, Namakan, Rainy, and Kabetogama Lakes are classified by the State of Minnesota for domestic consumption, aquatic life and recreation, and industrial consumption (Minnesota Rules, Chapter 7050.0470). The quality of these waters must meet the primary (maximum contaminant levels) and secondary drinking water standards issued by the U.S. Environmental Protection Agency (USEPA). Results were compared to criteria established by the USEPA for drinking water, recreation, and protection of aquatic life (USEPA, 1986). Most of the constituents and properties listed in table 2 that have USEPA criteria were within recommended limits. An exception was dissolved oxygen, which occurred below the USEPA standard of 5 mg/L in Kabetogama Lake and Black Bay at least once at four sampling sites during the study. In addition, pH values at times exceeded the USEPA guideline of 8.5 in Kabetogama Lake and Black Bay. Dissolved oxygen concentrations below 5 mg/ L can seriously impair the aquatic ecosystem. Levels of pH typically rise above 8.5 under intense photosynthesis and indicate high alkalinity, which may affect the taste of the water.

For all constituent concentrations presented in this section, the percentage differences (table 3) in the quality control samples need to be considered. This is particularly important for dissolved chloride, dissolved ammonia nitrogen, and chlorophyll-*a* and –*b*, all of which had median relative percentage differences for replicate samples greater than 10.

Physical properties, alkalinity, dissolved solids, and major ions

A summary of selected physical properties and alkalinity results for the nine sites are shown in table 4. Analyses for dissolved solids and major ions were discontinued at the end of the first sampling season, and are of limited value for showing trends or providing information on the extent of water exchange between the lakes. Data presented in figure 4 for Black Bay and Kabetogama Lake represent the means for samples collected at the three sites in Black Bay (Sites 1, 16, and 44) and the three sites in Kabetogema Lake (Sites 11, 43, and 45).

Secchi-disk transparency varied seasonally as well as annually at some sites during 2001 through 2003 (fig. 4). Secchi-disk transparencies for Black Bay generally were shallower than transparencies for the other lakes and peaked (deepest transparencies) in late June. During 2003, the Sand Point, Namakan, and Rainy Lakes not only had deeper transparencies, but also showed a different pattern with at least one peak occurring in August. Kabetogama Lake had deeper transparencies than Black Bay for all 3 years. Secchi-disk transparencies that are shallower during the summer season may be due to increased amount of algae (possibly caused by decreased zooplankton that graze on the algae), recirculation of bottom sediment due to motorboat activity or wind action, increased runoff, or plant decomposition. Blue green algae blooms contribute to shallower Secchi-disk transparencies from late July through August in Kabetogama Lake (Kallemeyn and others, 2003).

Specific conductance and alkalinity values generally were greater in Black Bay and Kabetogama Lake when compared to the other three lakes. Dissolved solids also were greater in Black Bay and Kabetogama Lake, as was dissolved calcium and magnesium (table 9, appendix). Dissolved concentrations of sodium, potassium, sulfate, and chloride did not follow this pattern. Potassium was smallest in Namakan Lake and Rainey Lake (Site 5). The greatest concentrations of sodium, sulfate, and chloride were measured in samples from Sand Point Lake. The relative proportions of the major cations (calcium, magnesium, sodium, and potassium) for each lake are similar to the proportions reported in the baseline study (Payne, 1991).

Nutrients

Nitrogen and phosphorus are essential for the growth and reproduction of plants. Rooted aquatic plants and algae require dissolved forms of nitrogen and phosphorus as nutrients. Compounds of nitrogen, such as nitrate, nitrite, and ammonia, are the basic building blocks for protein synthesis, whereas phosphorus serves as an energy source in cellular chemical reactions. Large inputs of nitrogen compounds and phosphorus into the aquatic environment can cause excessive algal growth. This may reduce the aesthetic and recreational value of water, and stress aquatic organisms, resulting from depleted dissolved oxygen concentrations when algal blooms die. Therefore, it is desirable to prevent or mitigate the introduction of excessive nutrient concentrations into surface water where sensitive aquatic organisms may be present.

Total phosphorus concentrations are shown in figure 4b. Kabetogama Lake and Black Bay generally had greater concentrations of total phosphorus from 2002-03 than Sand Point, Namakan, and Rainy Lakes. Greater mean total phosphorus concentrations in summer indicate that there is an input of phosphorus during the summer season from either external (inflow or precipitation) or internal (lake sediments) sources

Table 4. Summary of selected physical properties and alkalinity results, Voyageurs National Park, Minnesota, 2001-03.

[Measurements shown here are those recorded at the Secchi depth; °C, degrees Celsius; m, meters; µS/cm; microsiemens per centimeter; mg/L, milligrams per liter]

	Water Temperature (°C)	Secchi disk transparency (m)	Specific conductance, field (µS/cm)	Field pH	Dissolved oxygen (mg/L)	Total alkalinity as $CaCO_3$ (mg/L)	Bicarbonate alkalinity as HCO_3 (mg/L)
Sand Point Lake below Harrison Narrows near Crane Lake, Site 7							
minimum	2.2	1.3	55	7.0	6.9	16	20
maximum	25.2	3.3	82	7.7	11.8	21	25
mean	15.5	2.4	69	7.4	9.5	19	23
median	17.0	2.3	69	7.4	9.7	20	24
Namakan Lake near Ray, Site 14							
minimum	5.2	2.1	37	6.7	7.4	14	17
maximum	25.3	4.1	55	7.9	12.7	16	20
mean	16.7	3.0	48	7.3	9.7	15	19
median	18.2	3.0	48	7.2	9.2	16	20
Rainy Lake at Brule Narrows near International Falls, Site 5							
minimum	6.2	2.0	42	6.5	7.2	14	17
maximum	23.7	3.0	64	8.2	13.1	16	20
mean	16.3	2.5	49	7.2	9.6	15	19
median	17.7	2.3	48	7.3	9.0	15	19
Kabetogama Lake at Mouth of Meadwood Bay near Ray, Site 11							
minimum	8.0	1.2	57	7.0	4.7	22	27
maximum	26.8	3.7	118	9.2	12.2	56	68
mean	18.4	2.1	90	7.9	9.0	39	48
median	19.5	2.1	96	7.7	8.7	39	48
Kabetogama Lake at Cemetary Island near Ray, Site 43							
minimum	7.6	1.2	64	6.6	5.1	34	41
maximum	25.2	4.0	106	9.1	13.3	58	71
mean	18.0	2.2	94	7.8	8.9	42	51
median	19.6	2.2	96	7.7	8.9	40	49
Kabetogama Lake near Grave Island near Ray, Site 45							
minimum	6.8	1.1	65	7.3	4.9	31	38
maximum	25.6	3.3	109	9.2	12.8	56	68
mean	18.1	2.2	94	7.9	9.0	42	51
median	19.5	2.2	96	7.8	9.0	41	50
Rainy Lake at Black Bay Narrows near International Falls, Site 1							
minimum	5.5	0.3	55	7.1	6.0	20	24
maximum	29.5	1.5	108	8.5	13.3	54	66
mean	17.9	0.9	86	7.7	8.9	35	43
median	18.0	0.9	92	7.7	8.5	36	44
Rainy Lake at Black Bay near International Falls, Site 16							
minimum	6.1	0.3	42	7.3	3.9	35	43
maximum	26.9	1.8	104	8.8	13.5	42	51
mean	17.5	0.9	90	7.8	8.7	38	47
median	18.0	0.9	93	7.7	8.8	38	47
Rainy Lake at Black Bay (West) near International Falls, Site 44							
minimum	5.5	0.1	61	6.4	4.7	33	40
maximum	27.3	2.2	157	9.1	13.2	59	72
mean	18.2	0.6	102	7.6	8.3	43	52
median	19.3	0.7	103	7.5	8.3	43	52

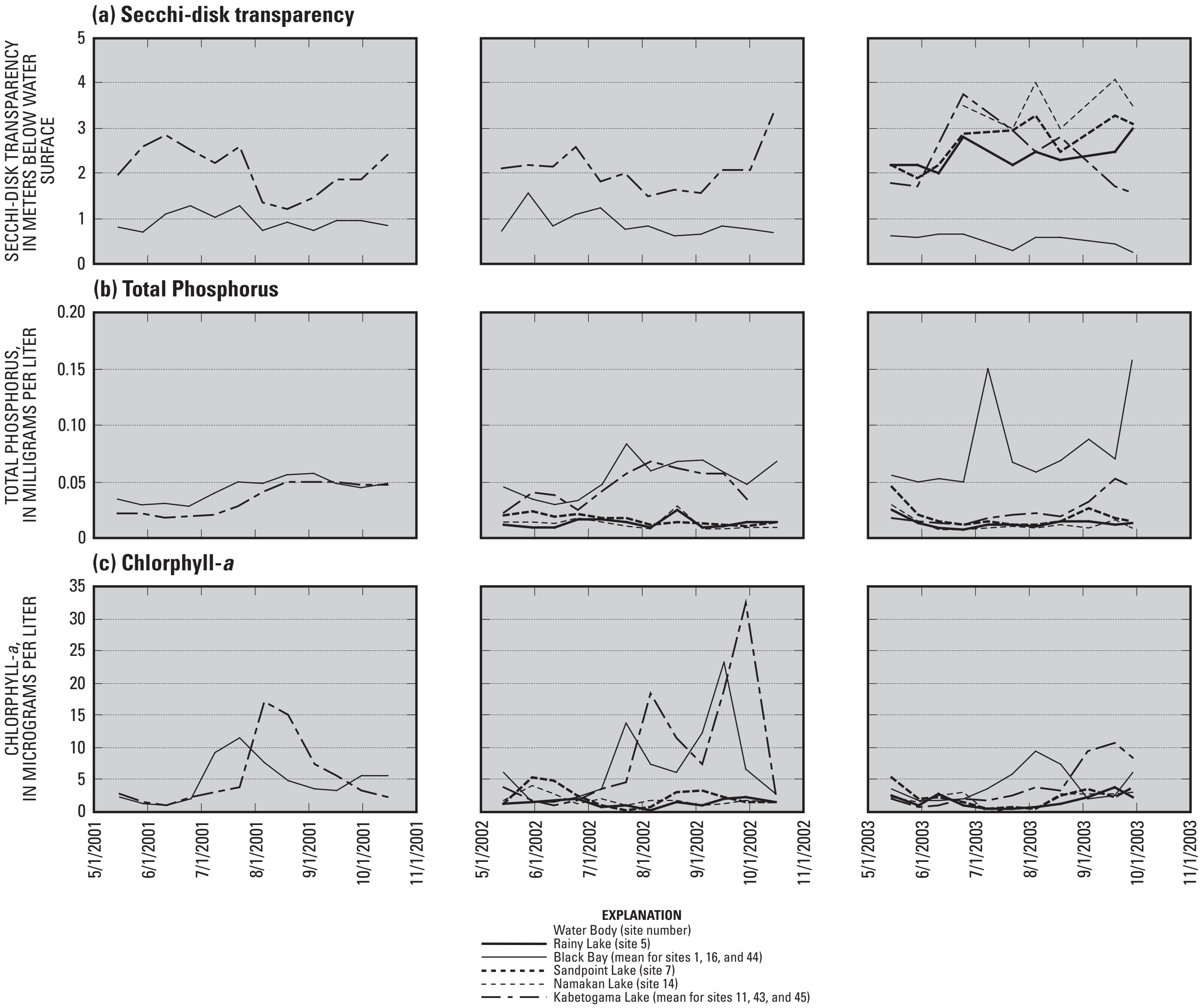

Figure 4. Monthly data for (a) Secchi-disk transparency, (b) total phosphorus, and (c) chlorophyll-*a*

(Payne, 1991). The concentrations of phosphorus in Black Bay were generally greater in 2003 than in 2001 and 2002. Total phosphorus concentrations at Rainy Lake at Black Bay (west) near International Falls (Site 44) on July 7, 2003 and September 28, 2003 contribute to this pattern (table 10, appendix). Because Black Bay is shallow, bottom sediments are frequently stirred up from wind action and motorboat activity. With the low water levels in 2003, this bottom sediment stirring probably was accentuated and account for increased phosphorus concentrations. Total phosphorus concentrations at Kabetogama Lake in 2003, however, generally were lower than in 2001 and 2002. By combining the 3 sites in Kabetogama Lake, the mean spring (May samples only) total phosphorus concentration was 0.020 mg/L.

Similar to total phosphorus, mean total ammonia plus organic nitrogen concentrations were greater in Black Bay and Kabetogama Lake than in Sand Point, Namakan, and Rainy Lakes (table 5). In general, all sites showed greater total ammonia plus organic nitrogen concentrations in August than in May. Nitrite plus nitrate nitrogen concentrations greatly varied in all the lakes and were greatest in lakes having low total phosphorus concentrations (Sand Point, Namakan, and Rainy). Lower mean nitrite plus nitrate nitrogen concentrations in Black Bay and Kabetogama Lake corresponded to greater mean total phosphorus concentrations. This may be the result of greater utilization of nitrate in the highly productive lakes. Nitrite plus nitrate nitrogen concentrations were below detection limits in several samples from Kabetogama Lake and Black Bay, indicating that utilization was great (Payne, 1991).

Algal Productivity

Chlorophyll is a colored pigment in plants that absorbs light energy (Coleman and Dewar, 1997). During photosynthesis, carbohydrates are formed from water and carbon dioxide under the influence of sunlight and chlorophyll. These

Table 5. Summary of selected nutrient analytical results, Voyageurs National Park, Minnesota, 2001-03

[all units in milligrams per liter; <, less than; --not determined]

	Dissolved nitrite plus nitrate nitrogen	Dissolved ammonia plus organic nitrogen	Total ammonia plus organic nitrogen	Total phosphorus	Dissolved phosphorus
Sand Point Lake below Harrison Narrows near Crane Lake, Site 7					
minimum	<0.022	0.41	0.49	0.012	0.006
maximum	0.143	0.63	0.63	0.021	0.012
mean	0.056	0.48	0.56	0.018	0.010
median	0.046	0.44	0.58	0.020	0.011
Namakan Lake near Ray, Site 14					
minimum	0.038	0.32	0.38	0.008	0.003
maximum	0.092	0.35	0.53	0.028	0.005
mean	0.057	0.33	0.44	0.016	0.004
median	0.055	0.33	0.44	0.014	0.005
Rainy Lake at Brule Narrows near International Falls, Site 5					
minimum	0.040	0.30	0.37	0.011	0.003
maximum	0.094	0.34	0.37	0.038	0.006
mean	0.066	0.31	0.37	0.018	0.005
median	0.056	0.31	0.37	0.013	0.005
Kabetogama Lake at Mouth of Meadwood Bay near Ray, Site 11					
minimum	<0.005	0.37	0.48	0.013	0.007
maximum	0.035	0.52	0.78	0.063	0.018
mean	--	0.43	0.65	0.030	0.011
median	--	0.42	0.66	0.026	0.010
Kabetogama Lake at Cemetary Island near Ray, Site 43					
minimum	<0.005	0.37	0.51	0.014	0.004
maximum	<0.013	0.46	0.93	0.087	0.024
mean	--	0.41	0.64	0.040	0.010
median	--	0.39	0.54	0.035	0.007
Kabetogama Lake near Grave Island near Ray, Site 45					
minimum	<0.005	0.39	0.49	0.012	0.004
maximum	0.037	0.46	1.10	0.082	0.020
mean	--	0.42	0.69	0.035	0.010
median	--	0.43	0.57	0.028	0.008
Rainy Lake at Black Bay Narrows near International Falls, Site 1					
minimum	<0.005	0.35	0.49	0.026	0.006
maximum	0.060	0.73	0.90	0.079	0.032
mean	--	0.53	0.73	0.044	0.016
median	--	0.49	0.69	0.043	0.011
Rainy Lake at Black Bay near International Falls, Site 16					
minimum	<0.005	0.36	0.46	0.023	0.006
maximum	0.057	0.54	1.10	0.104	0.021
mean	--	0.44	0.74	0.054	0.012
median	--	0.44	0.72	0.049	0.011
Rainy Lake at Black Bay (West) near International Falls, Site 44					
minimum	<0.013	0.47	0.65	0.029	0.011
maximum	0.064	0.77	1.10	0.230	0.027
mean	0.019	0.62	0.83	0.062	0.018
median	0.008	0.64	0.83	0.057	0.015

carbohydrates undergo a series of complex reactions to form the compounds of which plant biomass is made. Chlorophyll-*a* concentrations can be a simple indicator of algal biomass in surface water.

Chlorophyll-*a* varies seasonally (fig. 4c) with peak concentrations normally occurring in late summer. Sites in Sand Point, Namakan, and Rainy Lakes maintained low chlorophyll-*a* concentrations from 2001 through 2003. Chlorophyll-*a* concentrations at these sites never exceeded 6 mg/L. Kabetogama Lake and Black Bay had greater chlorophyll-*a* concentrations and more pronounced seasonal variation than the Sand Point, Namakan, and Rainy sites. The range in chlorophyll-*a* concentrations in Kabetogama Lake was less than 0.1 to an estimated 67.3 mg/L, and the range in Black Bay was an estimated 0.7 to 47.8 mg/L (table 6).

Peaks in chlorophyll concentrations generally occurred in late summer. In Black Bay and Kabetogama Lake, concentrations were greater in 2002 than 2001 and a second peak concentration occurred in mid to late September 2002. It is important to note that samples were not collected on the same day each year and much of the uncertainty in annual changes of chlorophyll concentrations may be associated with sampling date (Hanna and Peters, 1991).

During 2003, chlorophyll-*a* concentrations generally were lower at all sites and were substantially lower at Black Bay and Kabetogama Lake. Also during 2003, Black Bay experienced its peak concentration at the beginning of August, with much lower concentrations in September. At Kabetogama Lake, however, the peak concentration occurred in mid-September. Low chlorophyll-*a* concentrations in September in Black Bay may have resulted from less nutrient rich water from Kabetogama Lake that was flowing through Gold Portage and into Black Bay during late summer, as it had in the previous 2 years (fig. 3). This can be explained by the low water levels in 2003 and the beaver dam at Gold Portage, described previously.

Trophic State Indicators

Federal requirements for "fishable" and "swimmable" waters have resulted in numerous efforts to classify a lake's trophic state (Carlson and Simpson, 1996). Nutrient and chlorophyll-*a* concentration data along with transparency measurements normally are used in these classification systems. 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 and the range of the index is approximately 0-100 (but, theoretically, the index has no limit). Each 10-unit increment in the scale represents a doubling of algal biomass in surface waters.

The significance of the TSI is that it is a simple numeric index that can be related to the traditional typological scheme

Table 6. Summary of chlorophyll-*a* analytical results, Voyageurs National Park, Minnesota, 2001-03

[all units in micrograms per liter]

Sand Point Lake below Harrison Narrows near Crane Lake, Site 7	
minimum	0.2
maximum	3.0
mean	1.7
median	2.1
Namakan Lake near Ray, Site 14	
minimum	0.5
maximum	2.1
mean	1.6
median	1.9
Rainy Lake at Brule Narrows near International Falls, Site 5	
minimum	1.0
maximum	3.6
mean	1.6
median	1.1
Kabetogama Lake at Mouth of Meadwood Bay near Ray, Site 11	
minimum	0.8
maximum	31.2
mean	5.8
median	3.0
Kabetogama Lake at Cemetary Island near Ray, Site 43	
minimum	0.4
maximum	23.7
mean	5.7
median	3.5
Kabetogama Lake near Grave Island near Ray, Site 45	
minimum	<0.1
maximum	67.3
mean	7.7
median	3.5
Rainy Lake at Black Bay Narrows near International Falls, Site 1	
minimum	1.0
maximum	14.9
mean	5.0
median	3.6
Rainy Lake at Black Bay near International Falls, Site 16	
minimum	0.9
maximum	27.2
mean	6.5
median	3.5
Rainy Lake at Black Bay (West) near International Falls, Site 44	
minimum	0.7
maximum	47.8
mean	6.0
median	3.2

of Nauman (1919). Unlike the typological index, Carlson's index represents a continuum of trophic state, and not simply the four traditional lake types (oligotrophic, mesotrophic, eutrophic, and hypereutrophic). The continuum may be more useful for assessing the change of lake trophic state through time and comparing between lakes that are very similar.

An evaluation of TSI calculated from data collected during the baseline study (Payne, 1991) found that TSI computed from chlorophyll-*a* concentrations (TSI CHY) might be preferable to TSI values computed from total phosphorus concentrations (TSI TP) because data from lakes in Voyageurs National Park at times does not match Carlson's regression that relates chlorophyll-*a* to phosphorus. Soluble organic substances that color some of the Park's water bodies affect the indices computed from Secchi-disk transparency (TSI SD).

The sampling schedule for this study resulted in about 12 sets of samples for each site in Black Bay and Kabetogama Lake during each May-October sampling season. TSI CHY values ranged from 9 to 71 during the 2001-03 study, with the exception of one sample collected at Kabetogama Lake during 2001, in which the chlorophyll-*a* value was less than 1. For that sample a value of one-half the minimum reporting limit (MRL) was used to compute the TSI CHY means. Values for Black Bay ranged from 27 to 68, whereas Kabetogama Lake had the maximum TSI CHY value of 71 on September 30, 2002. Biweekly samples collected at Sand Point, Namakan, and Rainy Lakes were analyzed by NRRI (table 12, appendix). Because of potential variability among different laboratories, caution should be exercised when comparing TSI values at these reference sites with Kabetogama and Black Bay (for which biweekly chlorophyll-*a* samples were analyzed by the NWQL). In general, the TSI values for Sand Point, Namakan, and Rainy Lakes were lower, ranging from 9 to 47.

Sand Point, Namakan, and Rainy Lakes all had mean TSI CHY values (2001-03) of 33-34. The mean value for Black Bay was 44 and the mean value for Kabetogama Lake was 43. Based on these values, these lakes would be considered oligotrophic to mesotrophic. Using mean lake values, Kabetogama Lake and Black Bay would be considered mesotrophic; however individual TSI CHY values would classify these water bodies as eutrophic during the late summer.

Effects on Water Quality and Trophic State

Historical climate and hydrologic conditions

Total ammonia plus organic nitrogen, total phosphorus, dissolved phosphorus, chlorophyll-*a*, and trophic state indices were compared between the 2001-03 study period and the baseline study (1977-84). Changes between the two may be due not only to changes in lake outflows (and ultimately the new rule curves), but possibly due to historical hydrologic and climate conditions.

Monthly mean air temperatures at the International Falls weather station for May through September from 2001 to 2003 exceeded the mean temperatures for May through September 1948 to 2003 in 11 of the 15 months (National Oceanic and Atmospheric Administration, 2003). The warmer air temperatures for 2001 to 2003 extended the warming trend that started in 1980 (Kallemeyn and others, 2003). Climate conditions during the baseline study were more variable than 2001–03 with 1977, 1980, 1981, and 1983 being above average temperature years and 1978, 1979, and 1982 being below average years. Accumulated degree days less than 10 degrees Celsius (^{o}C) in the water column for the surface to 10 m depth zone (epilimnion) for the summer and early fall of 2001 to 2003, which are positively correlated with air degree days, generally exceeded long-term mean values (Kallemeyn and others, 2003). Accumulated degree days in Kabetogama and Rainy Lakes were greater than the long-term mean in all 3 years. In Namakan Lake, the accumulated degree days from 2001 and 2002 exceeded the long-term mean, whereas the 2003 value was slightly less than the long-term mean. The 2001 accumulated degree days for Sand Point Lake also exceeded the long-term mean, but in 2002 and 2003 the accumulated degree-days were about 35 units below the long-term mean. The accumulated degree-days in the water column in 2001 were the greatest that has been recorded in the last 23 years in all the lake basins except Kabetogama Lake, where it was the fourth greatest.

During the period from 1948 to 2002 there has been a downward trend in precipitation of about –0.79 cm (–0.31 inches) per decade (Kallemeyn and others, 2003). During the baseline study, 4 years had below average precipitation, and 4 years had above average precipitation. Total annual precipitation was above average in 2001, slightly below average in 2002 (Kallemeyn and others, 2003), and below average in 2003. Although 2002 had below average precipitation, Rainy Lake and Rainy River (west of the study area in fig. 1) experienced very high water levels and flows during the late spring and summer of 2002 (International Rainy Lake Board of Control and International Rainy River Water Pollution Board, 2002). The 2002 peak level on Rainy Lake was the highest since 1950 (International Rainy Lake Board of Control and International Rainy River Water Pollution Board, 2002), due to extreme rainfall events that occurred in June. Average inflow from the Namakan River (which supplies most of the water to Namakan Reservoir) during 1977-84 was 114 m^3/s (about 4,024 ft^3/s). During the current study average flow was 94 m3/s.

Comparison with pre-rule curve changes

Numerous studies have been conducted to serve as a baseline to compare to the post-2000 rule curve samples collected from the lakes in Voyageurs National Park. Hargis (1981) measured chlorophyll-*a* concentrations in the summer of 1979. Keppner and Stottlemeyer (1988) converted the Hargis data to lakewide means and compared it to their own data collected in 1985 and 1986. Payne (1991) reported on samples collected in 1977-84 and again in July 1999 (Payne, 2000). The baseline data mostly were collected during May and August, therefore May and August data from the current study were compared to seasonal means to document change that may have occurred in the first years following the January 2000 implementation of the new rules for reservoir operation.

May and August data from the current study and the baseline study (Payne, 1991) are compared in figure 5. For each site a minimum of five data points per study were used for comparison. Because not all sites were sampled during the baseline study, Kabetogama Lake is evaluated with data from Site 11, and Black Bay is evaluated with data from Site 16.

The results were mixed for median total ammonia plus organic nitrogen concentrations. For some lakes there was a slight increase from baseline to 2001-03 (Sand Point and Kabetogama Lakes), a slight decrease (Namakan Lake and Black Bay), or almost no change (Rainy Lake). Rank sum tests (Helsel and Hirsch, 1992) performed on the nitrogen data showed no significant differences in mean ammonia plus organic nitrogen concentrations between the baseline and 2001-03 data sets.

All sites had greater median total phosphorus concentrations during 2001-03 than during the baseline study (fig. 5). Rank sum tests performed on the total phosphorus data showed no significant differences between mean concentrations between the baseline study and the 2001-03 study. Median dissolved phosphorus results were mixed. For Sand Point Lake there was an increase in the median concentration, Namakan Lake and Black Bay had a decrease in median concentration, and Rainy and Kabetogama Lakes had little change (fig. 5).

All median chlorophyll-*a* concentrations (and median TSI CHY values) were lower in 2001-03 than during the baseline study. Decreases between the baseline and 2001-03 chlorophyll-*a* and TSI CHY mean values in Kabetogama Lake and Black Bay were significant ($p=0.021$ and $p=0.007$, respectively).

Because the inflows to the reservoirs (Namakan and Vermillion Rivers) were not sampled during the current study, it is impossible to say whether phosphorus loading has increased or decreased. It is possible that a substantial amount of total phosphorus in the lakes is being recycled from internal sources (lake sediments) rather than external sources (inflows from Namakan and Vermillion Rivers).

Decreased TSI CHY values indicate a decreased algal biomass. This decrease in algal biomass also was reflected in slightly deeper Secchi-disk transparency. For example, the mean Secchi-disk transparency in Black Bay (Site 16) during the baseline study was 0.82 m (Payne, 1991, p. 28), whereas during the current study the mean was 0.94 m. A decrease in algal biomass normally is a response to decreased nutrient concentrations, particularly phosphorus, in lakes where phosphorus is a limiting nutrient; however, median total phosphorus concentrations did not decrease between the two study periods. Not only were the median values for chlorophyll-*a* and TSI CHY lower, but also the range in the data was smaller for most of the sites. This is particularly noticeable in Kabetogama Lake and Black Bay (fig. 5).

The results of the current study (2001-03) generally are similar to results of the interim USGS study (Payne, 2000), which compared the water quality of samples collected in July 1999 to samples collected during the baseline study. Between the baseline study and 1999 significant differences were observed in total phosphorus, chlorophyll-*a*, and Secchi disk transparency (Payne, 2000). Total phosphorus and total ammonia plus organic nitrogen concentrations in 1999 were lower than the baseline study in Black Bay and Kabetogama Lake. Median chlorophyll-*a* concentrations at Kabetogama Lake and Black Bay were about 10 percent less than the baseline study median values. This decrease in algal biomass was evident from the increase in 1999 Secchi-disk transparency values at Black Bay and Kabetogama Lake. These changes were consistent with the monitoring data presented by Kallemeyn and others (2003).

Results of the current study (2001-03) were compared to the results of the previous USGS studies to minimize variability of results due to differences in site location, laboratory, and field methods. Results also were compared to Hargis (1981) and Kepner and Stottlemyer (1988) because the USGS studies were not continuous. The compilation of these shorter term data sets produced a more continuous set of data, reducing the likelihood of only evaluating data sampled during extreme or unusual hydrologic events. For this same reason, continued monitoring of the trophic status may be necessary to document changes resulting from the 2000 rule curve change. The samples from other studies were collected at different sites on these lakes and chlorophyll-*a* concentrations can be quite variable throughout a large water body, therefore some of the differences in results may be due to spatial variability. In addition, the TSI values presented in Kepner and Stottlemyer (1988) made no distinction between Rainy Lake and Black Bay. To limit the variability due to timing of sample collection, only August values are compared in table 7.

All major lakes in the Park experienced lower TSI CHY values during 2001-03 than during any of the previous studies. TSI CHY values at Sand Point Lake in 2001-03 were 34 percent lower than the combined mean of the previous studies. TSI CHY values at Namakan Lake were 24 percent lower, and TSI CHY values at Kabetogama were 13 percent lower than the previous studies. Although Rainy Lake was not distinguished from Black Bay in the Hargis (1981) study or in the Kepner and Stottlemyer (1988) study, combined 2001-03 Rainy Lake and Black Bay values were 21 percent lower than the mean reported values from 1979 to 1986. Rainy Lake and Black Bay TSI CHY values were 31 percent and 20 percent lower, respectively, in 2001-03 than during the USGS baseline study.

Because line graphs and boxplots are ways of visualizing data and are not statistical tests, a Kendall's tau trend test

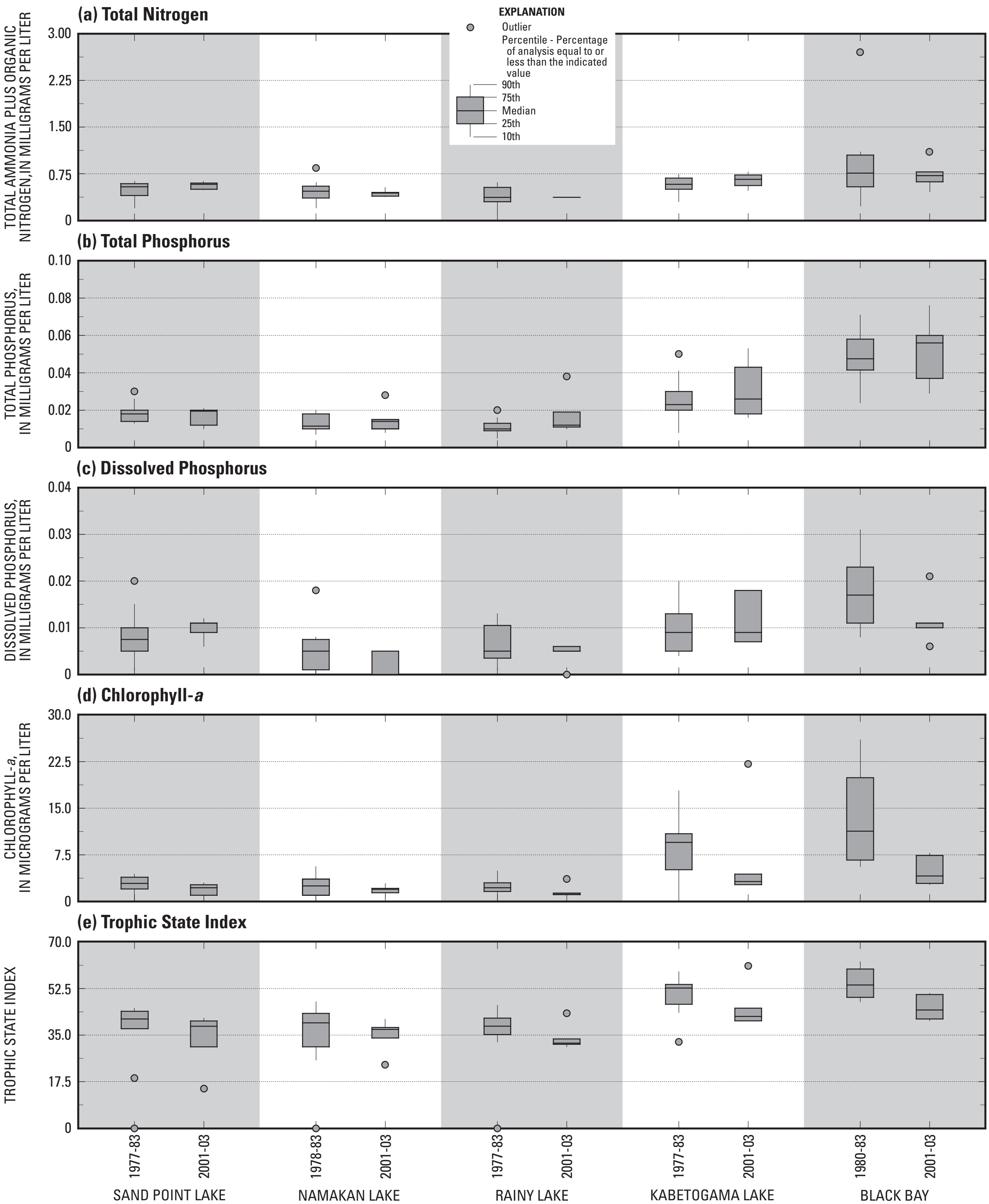

Figure 5. Boxplots comparing historical baseline concentrations to 2001-03 for (a) total ammonia plus organic nitrogen, (b) total phosphorus, (c) dissolved phosphorus, (d) chlorophyll-*a*, and (e) trophic state index.

Table 7. Comparison of mean August trophic state values based on chlorophyll-*a* analysis for major lakes and bays in Voyageurs National Park, Minnesota

[--, not determined]

Lake	1979 (as reported by Hargis, 1981)	1985 (as reported by Kepner and Stottlemeyer, 1988)	1986 (as reported by Kepner and Stottlemeyer, 1988)	1979-83 (as reported by Payne, 1991)	2001-03 Current study
Sand Point Lake	46	54	45	36	30
Namakan Lake	44	41	46	35	32
Rainy Lake	53	43	46	39	27
Kabetogama Lake	65	58	64	58	53
Black Bay	--	--	--	60	48

(Kendall, 1975) was performed on the data. Tau is a measure of the strength of the monotonic association between two variables, whereas the probability (p-value) is the likelihood of obtaining the test statistic (tau). Kendall's tau was chosen for a variety of reasons. Kendall's tau is a nonparametric trend test that is rank based and, therefore, resistant to the effects of extreme values and to deviations from a linear relation (Hirsch and others, 1993). All monthly sample sets had between 7 and 13 values and Kendall's tau may be more appropriate than other trend tests for sample sizes less than 20 (Helsel and Hirsch, 1992).

To eliminate interlaboratory variability, only data from the NWQL were used, and to eliminate seasonal variability, the trend test was performed separately on May and August data. Algal productivity is highly seasonal, thus comparing a May value to an August value does not contribute any information about the existence of a trend (Smith and others, 1982). Samples collected in June, July, and September were not included because samples were not collected during these months in the baseline study. Including these data could lead to false trends for 2001-03.

Separating May and August values also revealed patterns in the data. While, there were positive trends (increasing concentrations) in total phosphorus for all the sites during May, none were significant (having a probability value of less than 0.05). For the August samples, the only site showing a trend was Sand Point Lake, which had a significant negative trend (decreasing concentrations) in total phosphorus (tau=-0.56, probability=0.03).

Results of trend tests for TSI CHY were the same as those for chlorophyll-*a*, because the TSI is based on the chlorophyll-*a* value. Any differences between the tau are due to rounding. There were negative trends in TSI CHY (and chlorophyll-*a*) at all sites during May. However, the only significant trend was at Kabetogama Lake (tau=-0.42, probability=0.05). None of the sites had significant trends in August.

Comparison of Kabetogama Lake and Black Bay with other lakes

Lower nutrient concentrations, lower chlorophyll-*a* concentrations, and lower trophic state indices were measured in Sand Point, Namakan, and Rainy Lakes, near the eastern and northern boundaries of the Park than in Kabetogama Lake and Black Bay (fig. 5). Kabetogama Lake and Black Bay, located at the southern and western boundaries of the Park, not only had greater (mean and median, tables 5 and 6) nutrient and chlorophyll concentrations, and trophic indices, but also generally had greater alkalinities, greater dissolved solids concentrations, and lower Secchi-disk transparencies (table 4). The differences between Kabetogama Lake and Black Bay and the other lakes during the current study were similar to those found during the baseline USGS study (Payne, 1991) and during the interim USGS study (Payne, 2000).

Although water-quality samples were not collected from Namakan River as part of the current study, Payne (1991) reports that the water quality of the three lakes along the eastern and northern boundary were similar to those of the Namakan River—the major source of inflow that drains an extensive area of exposed bedrock and thin noncalcareous glacial sediments east of the Park. The soil in this area is relatively shallow, has a thin layer of forest litter, and is strongly acidic (Kepner and Stottlemyer, 1988). If the soil material is derived from granite, it also is typically low in nutrients (Kallemeyn and others, 2003). Kabetogama Lake and Black Bay receive inflow from two streams that drain an area that is overlain by calcareous drift south and west of the Park. These soils have clay loam sub-layers and are poorly drained (Kepner and Stottlemyer, 1988). Kabetogama Lake has greater concentrations of nutrients in inflows than the Park's other large lakes (Payne, 1991) presumably because the sediments flowing into Kabetogama Lake are unusually rich in nutrients.

Not only is the source of the inflows important to water quality, but also the depth and circulation of the lakes are important. Sand Point, Namakan, and Rainy Lakes are deeper and have dimictic circulation (the lake water mixes twice per year during spring and fall turnover), whereas Kabetogama Lake and Black Bay are shallower and have polymictic circulation (mixing many times per year). The shallow water bodies experienced seasonal increases in nutrient concentrations that did not occur in the deeper lakes. This indicates a possible link between the frequent recirculation of these lakes and the internal recycling of phosphorus (Payne, 1991).

Comparison of the extent of the changes in water quality shows that changes in Kabetogama Lake and Black Bay were greater than the other lakes. In particular, differences in median chlorophyll-a concentration and trophic state index were greater in Kabetogama and Black Bay than in Sand Point, Namakan, and Rainy Lake. This also was evident from the significant decreases in mean chlorophyll-a and TSI CHY values for Kabetogama Lake and Black Bay.

Continued monitoring of the trophic status of the lakes and bays may be necessary to determine if changes in water quality are due to changes in water-level fluctuation. The data collected while the IJC's 2000 rule curves are in effect will serve as a baseline for any future changes in lake level management. Some alternatives for future monitoring include monthly sampling for total phosphorus and chlorophyll-*a*, monthly monitoring of physical properties, and monitoring inflows and outflows throughout the summer. Monitoring inflows and outflows may include the use of water-quality monitors to measure physical properties, and total phosphorus. Continued sampling during May and August would be one alternative for ensuring a continuum in the data set, given the historic emphasis on the collection of May and August total phosphorus and chlorophyll-*a* samples. Continued sampling may be important because the hydrologic events during the 2001-03 study were extreme and monitoring for water-quality changes over long periods of time could reduce the possibility of sampling only during extraordinary hydrologic conditions. Long-term sampling also is useful in making decisions concerning lake management.

Summary

Implementation of an order by the International Joint Commission in January 2000 has changed operating procedures for dams that regulate Rainy Lake and Namakan Reservoir, two large reservoirs in Voyageurs National Park in northern Minnesota. These new procedures were expected to restore a more natural water regime and affect water levels, water quality, and trophic state. Water-quality samples were collected from May 2001 through September 2003 from sites in Rainy Lake, including Black Bay, and Namakan Reservoir, which consists of five inter-connected lakes, including Sand Point, Namakan, and Kabetogama. Results of laboratory analysis and field measurements of chemical and physical properties were compared to baseline data collected prior to the change in operating procedures.

Due to the unusually excessive precipitation events in 2001 and 2002, and the drought conditions in 2003, Rainy and Namakan Reservoir levels exceeded the bounds of the 2000 rule curve during all 3 years of the study. Given that the IJC's rule curves were not adhered to, attempts to determine whether water quality and trophic state have been affected by the rule change has been difficult. Changes in the timing of peak lake-surface elevations in Namakan Reservoir were not as substantial as expected. Peak lake-surface elevation occurred earlier in 2001, but occurred later than predicted (late June to early July) in 2002, and much later than predicted in 2003. Operation of Namakan Reservoir under the new rule curve and local hydrologic conditions resulted in an increase in the number of days that water flowed through Gold Portage in 2001 and 2002; however, incidence of flow was 227 days in 2003, well below the value expected if operating within the limits of the new rule curve.

The changes in water management rules also were expected to lower phosphorus loading in Namakan Reservoir, and especially in Kabetogama Lake. The median total phosphorus concentration, however, increased slightly in Kabetogama Lake (as well as all the other major lakes and bays) between 1977-84 (the U.S. Geological Survey baseline study) and 2001-03. Because the inflows to the reservoirs (Namakan and Vermillion Rivers) were not sampled during the current study, it is not possible to conclude whether phosphorus loading has increased or decreased. It is possible that a substantial amount of total phosphorus in the lakes is being recycled from internal sources (lake sediments) rather than external sources (inflows from Namakan and Vermillion Rivers). Kendall's tau trend tests were calculated for all sites. To eliminate seasonal variability, the trend test was performed separately on May and August data. No sites had significant increasing May or August trends. August total phosphorus values showed a significant decreasing trend (tau=-0.56, probability=0.03) for Sand Point Lake.

Changes in productivity and nutrient enrichment, relative to baseline data, also were examined. Sand Point, Namakan, and Rainy Lakes all had mean trophic state index (TSI CHY) values (May through October 2001-03) of 33-34. The mean value for Black Bay was 44 and the mean value for Kabetogama Lake was 43. Given the TSIs calculated for the Voyageurs Lakes from 2001-03, Sand Point, Namakan, and Rainy Lakes would be considered oligotrophic to mesotrophic, and Kabetogama and Black Bay would be considered mesotrophic. TSI CHY values at Kabetogama were 13 percent lower than the previous studies. Two previous studies made no distinction between Rainy Lake and Black Bay. Therefore 2001-03 data from Rainy Lake and Black Bay was combined for comparison. Combined 2001-03 Rainy Lake and Black Bay TSI CHY values were 21 percent lower than the mean reported values from 1979–1986. Comparison of Rainy and Black Bay individually, showed that 2001-03 TSI CHY values were 31 percent and 20 percent lower, respectively than during the baseline study. Mean and median chlorophyll-*a* concentration decreased in all lakes and bays between the baseline study and the current study. Rank sum tests showed that the decreases in mean concentration between the baseline and 2001-03 study were significant for Kabetogama Lake (p=0.021) and Black

Bay (p=0.007). However, Kendall's tau trend tests for May and August data, showed no significant positive or negative trends in chlorophyll-a or TSI CHY, with the exception of the May chlorophyll-*a* and TSI CHY values which had a significant negative trend (tau=-0.42, probability=0.05) for Kabetogama Lake.

One of the objectives of the report was to examine whether the changes in Kabetogama Lake and Black Bay were greater than the changes in Sand Point, Namakan, and Rainy Lakes. Changes in median concentration for some constituents were greater in Black Bay and Kabetogama Lake compared to the other three lakes (chlorophyll-*a* and TSI CHY), whereas changes in median concentrations for other constituents (for example, total ammonia plus organic nitrogen and total phosphorus) were similar to the other three lakes. The range in the data (minimum to maximum chlorophyll-*a* concentrations and trophic state indices) was noticeably smaller in 2001-03 compared to baseline in Black Bay and Kabetogama Lake, whereas the ranges in other lakes decrease. In addition, the oligotrophic to mesotrophic classification of Sand Point, Namakan, and Rainy Lakes did not change between the baseline and current studies. In contrast, Kabetogama Lake and Black Bay were classified as eutrophic during the baseline study; based on 2001-03 data, they would be considered mesotrophic.

Changes in water quality of the lakes in Voyageurs National Park may be due to changes in water level fluctuation. However, given the extreme hydrologic conditions during 2001-03 study, continued monitoring of the trophic status of the lakes and bays may be necessary. The water-quality monitoring collected while the IJC's 2000 rule curves are in effect will serve as a baseline for any future changes in lake level management. In addition to continued monitoring, some alternatives include monthly sampling for total phosphorus and chlorophyll-*a*, monthly monitoring of physical properties, and monitoring inflows and outflows throughout the summer. Due to the historic emphasis on the collection of May and August total phosphorus and chlorophyll-*a* samples, continued sampling during May and August would be one alternative for ensuring a continuum in the data set. Monitoring for water-quality changes over long periods of time could reduce the possibility of sampling only during extraordinary hydrologic extremes and are useful in making informed lake management decisions.

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Appendix

Table 8. Physical properties and alkalinity results by site, Voyageurs National Park, Minnesota, 2001-03.

[Water quality measurements shown here are those recorded for samples from the Secchi depth; mm Hg, millimeters of mercury; °C, degrees Celsius; m, meters; µS/cm; microsiemens per centimeter; mg/L, milligrams per liter; --, not determined]

Date	Air Pressure (mm Hg)	Water Temperature (°C)	Secchi disk transparency (m)	Specific conductance, field (µS/cm)	Specific conductance, laboratory (µS/cm)	Field pH	Laboratory pH	Dissolved oxygen (mg/L)	Total alkalinity as $CaCO_3$ (mg/L)	Bicarbonate alkalinity as HCO_3 (mg/L)	Carbonate alkalinity as CO_3 (mg/L)
Sand Point Lake below Harrison Narrows near Crane Lake, Site 7											
5/16/01	--	10.7	1.7	63	60	7.0	7.3	10.9	16	20	0
8/21/01	730	21.4	1.3	64	62	7.3	7.2	6.9	20	24	0
5/14/02	--	4.9	1.6	82	--	7.4	--	11.8	--	--	--
8/21/02	730	19.1	2.3	55	--	7.7	--	9.9	--	--	--
5/14/03	--	7.6	2.2	76	--	7.2	--	11.7	--	--	--
5/29/03	--	14.8	1.9	66	--	7.3	--	11.5	21	25	0
6/10/03	--	2.2	2.2	66	--	7.1	--	10.2	--	--	--
6/24/03	--	20.6	2.9	67	--	7.6	--	8.8	--	--	--
7/23/03	--	22.0	2.9	71	--	7.5	--	8.0	--	--	--
8/5/03	--	23.6	3.3	72	--	7.5	--	7.7	--	--	--
8/19/03	--	25.2	2.5	73	--	7.7	--	7.7	--	--	--
9/19/03	--	--	3.3	--	--	--	--	--	--	--	--
9/29/03	--	13.3	3.1	72	--	7.1	--	9.4	--	--	--
Namakan Lake near Ray, Site 14											
5/16/01	--	9.9	2.1	50	46	7.2	7.6	10.7	14	17	0
8/21/01	731	22.1	2.3	48	49	7.3	7.9	7.8	16	20	0
5/14/02	--	5.2	2.1	55	--	7.2	--	12.7	--	--	--
8/21/02	731	18.9	2.7	37	--	7.4	--	10.1	--	--	--
5/14/03	--	5.9	3.0	55	--	7.1	--	12.0	--	--	--
5/29/03	--	16.0	--	46	--	7.0	--	12.4	16	20	0
6/10/03	--	16.7	--	46	--	7.4	--	10.4	--	--	--
6/24/03	--	20.1	3.5	46	--	7.6	--	9.2	--	--	--
7/22/03	--	21.9	3.0	48	--	7.9	--	8.2	--	--	--
8/5/03	--	23.3	4.0	47	--	7.2	--	7.4	--	--	--
8/19/03	--	25.3	3.0	48	--	7.3	--	7.7	--	--	--
9/19/03	--	18.2	4.1	48	--	6.7	--	8.0	--	--	--
9/29/03	--	13.6	3.5	49	--	7.1	--	9.0	--	--	--
Rainy Lake at Brule Narrows near International Falls, Site 5											
5/15/01	--	8.2	2.3	56	49	7.4	7.3	13.1	15	19	0
8/20/01	735	21.5	2.3	47	48	7.5	7.9	8.0	16	19	0
5/13/02	--	6.2	2.3	64	--	7.6	--	12.9	--	--	--
8/20/02	--	17.0	2.7	42	--	8.2	--	8.8	--	--	--
5/13/03	--	10.5	2.2	52	--	6.6	--	12.1	--	--	--
5/28/03	--	13.4	2.2	47	--	7.1	--	12.1	16	20	0
6/9/03	--	15.9	2.0	44	--	--	--	9.8	--	--	--
6/23/03	--	19.0	2.8	46	--	7.5	--	9.3	--	--	--
7/21/03	--	21.0	2.2	48	--	7.7	--	8.3	--	--	--
8/4/03	--	22.1	2.5	47	--	7.3	--	7.8	--	--	--
8/18/03	--	23.7	2.3	48	--	6.8	--	7.7	--	--	--
9/2/03	--	19.2	2.5	48	--	6.5	--	7.8	--	--	--
9/15/03	--	18.3	3.0	48	--	7.1	--	7.2	14	17	0
9/28/03	--	12.1	3.0	48	--	6.9	--	9.2	15	19	0
Kabetogama Lake at Mouth of Meadwood Bay near Ray, Site 11											
5/16/01	--	8.0	2.1	102	--	7.4	--	9.3	35	42	0

Table 8. Physical properties and alkalinity results by site,Voyageurs National Park, Minnesota, 2001—Continued.

Date	Air Pressure (mm Hg)	Water Tempera-ture (°C)	Secchi disk transpar-ency (m)	Specific conductance, field (µS/cm)	Specific con-ductance, laboratory (µS/cm)	Field pH	Labora-tory pH	Dissolved oxygen (mg/L)	Total alkalinity as $CaCO_3$ (mg/L)	Bicarbon-ate alkalin-ity as HCO_3 (mg/L)	Carbonate alkalinity as CO_3 (mg/L)
Kabetogama Lake at Mouth of Meadwood Bay near Ray, Site 11—Continued											
5/30/01	--	14.8	--	95	--	7.4	--	7.0	--	--	--
6/12/01	--	18.2	2.5	94	--	7.0	--	--	36	43	0
6/25/01	--	--	2.2	99	--	7.7	--	8.7	37	45	0
7/10/01	--	22.5	2.1	98	--	8.0	--	8.6	51	62	0
7/24/01	--	24.2	2.6	96	--	7.4	--	10.9	31	38	0
8/7/01	--	26.8	1.3	97	--	9.0	--	9.9	35	43	--
8/21/01	731	22.9	1.2	100	99	8.6	7.8	9.5	42	52	--
9/5/01	--	21.5	1.5	104	--	7.7	--	8.5	44	54	0
9/18/01	--	19.0	2.5	98	--	8.0	--	7.1	56	68	0
10/2/01	--	16.3	1.8	77	--	7.6	--	8.5	39	48	0
10/17/01	--	11.3	2.0	80	--	7.6	--	8.6	41	50	0
5/14/02	--	8.3	1.9	99	--	7.3	--	12.2	--	--	--
5/30/02	--	13.9	2.1	62	--	7.8	--	4.7	22	27	0
6/12/02	--	15.4	1.5	--	--	7.2	--	--	--	--	--
6/26/02	--	19.8	2.5	75	--	8.1	--	8.7	--	--	--
7/9/02	--	23.6	1.5	118	--	8.1	--	9.2	--	--	--
7/23/02	--	24.4	2.5	99	--	8.2	--	9.6	--	--	--
8/6/02	--	22.3	1.8	90	--	7.8	--	8.3	--	--	--
8/21/02	731	20.4	1.4	80	--	8.5	--	11.7	--	--	--
9/5/02	--	20.0	1.5	79	--	7.9	--	8.3	--	--	--
9/17/02	--	20.5	1.5	78	--	8.3	--	9.8	--	--	--
9/30/02	--	15.5	2.0	59	--	7.6	--	8.9	--	--	--
10/16/02	--	9.9	2.8	57	--	7.7	--	10.1	--	--	--
5/14/03	--	9.9	2.0	105	--	7.4	--	12.2	35	43	0
5/29/03	--	15.7	1.8	90	--	8.0	--	11.9	40	49	0
6/10/03	--	17.2	2.6	85	--	--	--	9.7	--	--	--
6/24/03	--	19.1	3.7	86	--	7.7	--	8.1	--	--	--
7/8/03	--	20.6	3.2	86	--	7.7	--	8.4	--	--	--
7/22/03	--	22.1	2.6	95	--	8.3	--	8.2	--	--	--
8/5/03	--	23.3	2.7	98	--	8.8	--	8.5	--	--	--
8/19/03	--	25.3	1.8	99	--	9.2	--	8.8	--	--	--
9/3/03	--	20.6	1.4	97	--	7.7	--	7.2	--	--	--
9/17/03	--	19.2	2.2	98	--	7.7	--	8.2	40	49	0
9/29/03	--	14.0	2.1	97	--	7.6	--	8.9	39	48	0
Kabetogama Lake at Cemetary Island near Ray, Site 43											
5/17/01	--	7.6	1.8	87	94	7.5	7.8	9.1	37	45	0
5/31/01	--	13.6	2.7	94	--	6.6	--	7.1	--	--	--
6/12/01	--	18.5	3.3	--	--	7.5	--	--	--	--	--
6/26/01	--	22.8	2.5	92	--	7.4	--	9.0	34	41	--
7/10/01	--	19.8	2.5	94	--	7.7	--	9.5	34	41	0
7/24/01	--	22.3	2.3	96	--	7.9	--	11.0	40	49	0
8/7/01	--	25.2	1.6	93	--	9.0	--	8.8	55	67	--
8/22/01	731	22.2	1.2	97	93	9.0	8.8	10.0	38	46	3
9/5/01	--	20.7	1.5	96	--	7.9	--	8.1	50	61	0
9/18/01	--	17.9	1.5	98	--	7.4	--	9.1	40	49	0
10/2/01	--	15.3	1.7	101	--	7.6	--	8.9	58	71	0
10/17/01	--	10.0	2.3	99	--	7.6	--	8.7	40	48	0

Table 8. Physical properties and alkalinity results by site,Voyageurs National Park, Minnesota, 2001—Continued.

Date	Air Pressure (mm Hg)	Water Temperature (°C)	Secchi disk transparency (m)	Specific conductance, field (µS/cm)	Specific conductance, laboratory (µS/cm)	Field pH	Laboratory pH	Dissolved oxygen (mg/L)	Total alkalinity as $CaCO_3$ (mg/L)	Bicarbonate alkalinity as HCO_3 (mg/L)	Carbonate alkalinity as CO_3 (mg/L)
Kabetogama Lake at Cemetary Island near Ray, Site 43—Continued											
5/14/02	--	8.0	1.8	102	--	8.0	--	13.3	--	--	--
5/30/02	--	14.6	2.2	99	--	7.5	--	5.1	--	--	--
6/12/02	--	15.8	2.5	100	--	7.4	--	--	--	--	--
6/26/02	--	19.9	2.8	76	--	7.5	--	9.0	--	--	--
7/9/02	--	22.8	2.0	94	--	8.5	--	10.0	--	--	--
7/23/02	--	22.1	1.5	94	--	7.7	--	7.4	--	--	--
8/6/02	--	21.3	1.3	93	--	8.9	--	11.0	--	--	--
8/21/02	731	19.4	1.8	86	--	8.4	--	11.1	--	--	--
9/5/02	--	20.3	1.8	88	--	8.0	--	7.7	--	--	--
9/17/02	--	19.6	2.5	87	--	7.5	--	7.4	--	--	--
9/30/02	--	14.0	2.2	75	--	7.4	--	8.9	--	--	--
10/16/02	--	8.0	4.0	64	--	7.6	--	10.0	--	--	--
5/14/03	--	12.7	1.7	106	--	8.0	--	10.6	34	42	0
5/29/03	--	15.6	1.7	92	--	7.4	--	10.2	42	51	0
6/10/03	--	17.6	2.6	93	--	7.4	--	8.9	--	--	--
6/24/03	--	21.1	3.8	95	--	7.9	--	8.6	--	--	--
7/8/03	--	19.8	3.0	100	--	7.8	--	8.3	--	--	--
7/22/03	--	21.4	2.3	101	--	8.1	--	8.7	--	--	--
8/5/03	--	22.9	2.8	101	--	8.8	--	8.7	--	--	--
8/19/03	--	25.0	1.5	103	--	9.1	--	8.2	--	--	--
9/3/03	--	19.6	1.5	101	--	8.0	--	8.3	--	--	--
9/17/03	--	19.0	2.4	102	--	6.8	--	5.9	41	50	0
9/29/03	--	12.6	3.1	99	--	7.1	--	8.0	38	47	0
Kabetogama Lake near Grave Island near Ray, Site 45											
5/17/01	--	11.2	2.0	97	101	7.8	7.6	11.4	41	50	0
5/31/01	--	14.1	2.5	98	--	7.4	--	6.8	--	--	--
6/12/01	--	16.9	2.8	94	--	7.3	--	--	37	45	0
6/26/01	--	21.0	2.9	96	--	7.8	--	9.0	50	60	0
7/10/01	--	20.8	2.1	95	--	7.8	--	9.0	36	44	0
7/24/01	--	21.9	2.9	95	--	7.4	--	10.3	38	47	0
8/7/01	--	25.2	1.1	94	--	9.1	--	9.6	50	60	--
8/22/01	731	22.3	1.3	100	98	8.9	8.6	10.0	44	53	4
9/5/01	--	21.0	1.4	98	--	7.6	--	5.8	31	38	0
9/18/01	--	18.4	1.6	98	--	7.8	--	8.2	41	50	0
10/2/01	--	16.0	2.1	101	--	7.7	--	8.0	56	68	0
10/16/01	--	11.3	3.0	101	--	7.6	--	8.5	40	49	0
5/14/02	--	6.8	2.7	109	--	7.5	--	12.8	--	--	--
5/30/02	--	15.3	2.3	91	--	8.0	--	4.9	48	58	0
6/12/02	--	14.7	2.5	96	--	7.4	--	--	--	--	--
6/26/02	--	18.3	2.5	72	--	7.7	--	8.3	--	--	--
7/9/02	--	23.4	2.0	94	--	8.5	--	9.9	--	--	--
7/23/02	--	22.6	2.0	95	--	7.9	--	8.7	--	--	--
8/6/02	--	21.5	1.5	92	--	8.2	--	9.4	--	--	--
8/21/02	730	19.5	1.7	86	--	8.1	--	10.0	--	--	--
9/5/02	--	20.1	1.5	88	--	7.8	--	7.9	--	--	--
9/17/02	--	19.7	2.3	87	--	7.6	--	8.4	--	--	--

Table 8. Physical properties and alkalinity results by site,Voyageurs National Park, Minnesota, 2001—Continued.

Date	Air Pressure (mm Hg)	Water Tempera-ture (°C)	Secchi disk transpar-ency (m)	Specific conductance, field (µS/cm)	Specific con-ductance, laboratory (µS/cm)	Field pH	Labora-tory pH	Dissolved oxygen (mg/L)	Total alkalinity as $CaCO_3$ (mg/L)	Bicarbon-ate alkalin-ity as HCO_3 (mg/L)	Carbonate alkalinity as CO_3 (mg/L)
Kabetogama Lake near Grave Island near Ray, Site 45 —Continued											
9/30/02	--	15.1	2.0	76	--	7.6	--	9.1	--	--	--
10/16/02	--	9.6	3.3	65	--	7.6	--	10.2	--	--	--
5/14/03	--	11.8	1.7	108	--	7.8	--	11.6	35	43	0
5/29/03	--	13.9	1.7	92	--	7.5	--	11.6	41	50	0
6/10/03	--	17.0	2.8	92	--	--	--	9.6	--	--	--
6/24/03	--	21.5	--	93	--	8.2	--	9.0	--	--	--
7/8/03	--	19.5	2.7	97	--	7.6	--	8.0	--	--	--
7/22/03	--	21.6	2.6	98	--	8.4	--	8.5	--	--	--
8/5/03	--	23.4	2.9	98	--	9.0	--	9.2	--	--	--
8/19/03	--	25.6	1.8	101	--	9.2	--	8.8	--	--	--
9/3/03	--	20.0	1.8	100	--	7.7	--	7.1	--	--	--
9/17/03	--	19.2	2.9	100	--	7.4	--	7.1	40	49	0
9/29/03	--	13.5	3.0	99	--	7.5	--	8.8	39	48	0
Rainy Lake at Black Bay Narrows near International Falls, Site 1											
5/15/01	--	10.4	0.9	--	88	7.3	7.6	11.3	35	43	0
5/29/01	--	14.6	0.9	99	--	7.7	--	9.9	--	--	--
6/11/01	--	20.4	1.3	96	--	7.5	--	8.5	40	49	0
6/25/01	--	22.0	1.1	98	--	7.5	--	6.0	35	43	0
7/9/01	--	24.0	1.0	98	--	8.2	--	--	39	47	0
7/23/01	--	26.4	1.3	99	--	7.7	--	12.4	36	44	0
8/6/01	--	29.5	0.8	99	--	8.0	--	7.3	43	52	0
8/20/01	735	21.4	0.9	103	105	7.8	7.5	7.9	47	57	0
9/4/01	--	19.5	0.8	101	--	7.6	--	9.2	43	52	0
9/17/01	--	16.8	1.0	76	--	7.5	--	8.2	29	36	0
10/1/01	--	14.1	0.8	97	--	7.5	--	8.6	54	66	0
10/16/01	--	8.0	1.0	91	--	7.8	--	13.3	38	47	0
5/13/02	--	11.3	0.9	103	--	7.8	--	11.9	--	--	--
5/28/02	--	14.5	1.2	108	--	7.7	--	6.6	--	--	--
6/11/02	--	13.9	1.0	66	--	7.5	--	--	--	--	--
6/24/02	--	20.5	1.0	81	--	8.2	--	8.3	--	--	--
7/8/02	--	22.5	1.5	107	--	7.5	--	6.9	--	--	--
7/22/02	--	24.3	1.0	103	--	7.5	--	10.3	--	--	--
8/5/02	--	20.7	0.8	93	--	8.2	--	8.9	--	--	--
8/20/02	--	17.6	0.7	96	--	8.1	--	8.6	--	--	--
9/4/02	--	19.6	0.5	79	--	7.9	--	8.4	--	--	--
9/16/02	--	17.5	1.0	62	--	7.9	--	8.9	--	--	--
10/2/02	--	11.4	0.8	66	--	7.3	--	6.1	--	--	--
10/15/02	--	5.5	0.8	58	--	7.6	--	12.0	--	--	--
5/13/03	--	13.8	0.7	86	--	7.8	--	10.7	26	32	0
5/28/03	--	14.5	0.9	55	--	7.3	--	10.3	22	27	0
6/9/03	--	18.0	0.9	79	--	--	--	7.3	--	--	--
6/23/03	--	19.5	0.9	61	--	7.6	--	9.2	--	--	--
7/7/03	--	21.3	0.5	103	--	7.9	--	8.4	--	--	--
7/21/03	--	22.7	0.9	79	--	7.8	--	7.7	--	--	--
8/4/03	--	22.6	0.9	78	--	8.3	--	7.7	--	--	--
8/18/03	--	24.3	0.7	73	--	8.5	--	8.5	--	--	--

Table 8. Physical properties and alkalinity results by site,Voyageurs National Park, Minnesota, 2001—Continued.

Date	Air Pressure (mm Hg)	Water Tempera-ture (°C)	Secchi disk transpar-ency (m)	Specific conductance, field (µS/cm)	Specific con-ductance, laboratory (µS/cm)	Field pH	Labora-tory pH	Dissolved oxygen (mg/L)	Total alkalinity as $CaCO_3$ (mg/L)	Bicarbon-ate alkalin-ity as HCO_3 (mg/L)	Carbonate alkalinity as CO_3 (mg/L)
Rainy Lake at Black Bay Narrows near International Falls, Site 1—Continued											
9/2/03	--	18.0	0.3	97	--	7.1	--	7.3	--	--	--
9/15/03	--	17.5	0.8	61	--	7.1	--	7.4	20	24	0
9/28/03	--	8.8	0.3	70	--	7.4	--	9.9	24	29	0
Rainy Lake at Black Bay near International Falls, Site 16											
5/15/01	--	12.7	0.7	93	91	7.7	7.5	11.0	37	45	0
5/29/01	--	13.0	0.5	89	--	8.0	--	10.2	--	--	--
6/11/01	--	19.1	1.0	93	--	7.4	--	9.1	--	--	--
6/25/01	--	22.0	1.5	95	--	7.5	--	6.8	--	--	--
7/9/01	--	22.9	1.3	94	--	7.9	--	8.6	--	--	--
7/23/01	--	25.9	1.3	100	--	7.3	--	11.1	--	--	--
8/6/01	--	26.9	0.7	89	--	8.8	--	8.8	--	--	--
8/20/01	736	20.8	1.2	98	95	7.7	7.7	7.2	42	51	0
9/4/01	--	20.0	0.9	96	--	7.5	--	7.3	--	--	--
9/17/01	--	17.0	1.3	100	--	7.4	--	6.5	--	--	--
10/1/01	--	15.0	1.2	100	--	7.4	--	7.3	--	--	--
10/16/01	--	7.7	0.8	92	--	8.5	--	13.5	--	--	--
5/13/02	--	10.3	0.6	104	--	7.5	--	11.6	--	--	--
5/28/02	--	13.8	1.3	101	--	7.7	--	6.2	--	--	--
6/11/02	--	15.4	1.0	98	--	7.5	--	--	--	--	--
6/24/02	--	19.7	1.5	42	--	8.2	--	7.7	--	--	--
7/8/02	--	21.8	1.8	92	--	7.9	--	8.9	--	--	--
7/22/02	--	24.0	0.5	100	--	7.7	--	11.2	--	--	--
8/5/02	--	20.9	1.0	93	--	8.2	--	9.2	--	--	--
8/20/02	731	18.7	0.6	95	--	8.2	--	8.9	--	--	--
9/4/02	--	19.4	0.8	89	--	7.9	--	7.8	--	--	--
9/16/02	--	17.2	1.0	84	--	7.9	--	8.0	--	--	--
10/2/02	--	11.9	0.8	72	--	7.3	--	3.9	--	--	--
10/15/02	--	6.1	0.5	61	--	7.5	--	11.0	--	--	--
5/13/03	--	13.9	0.6	100	--	7.7	--	10.1	35	43	0
5/28/03	--	18.0	0.3	85	--	7.4	--	8.7	39	48	0
6/9/03	--	17.4	0.7	86	--	--	--	4.5	--	--	--
Rainy Lake at Black Bay (West) near International Falls, Site 44											
5/15/01	--	15.4	0.8	99	103	7.4	7.5	8.5	43	52	0
5/29/01	--	14.8	0.7	115	--	7.7	--	8.8	--	--	--
6/11/01	--	19.7	1.0	103	--	6.9	--	6.7	40	49	0
6/25/01	--	22.2	1.2	104	--	7.5	--	7.0	38	47	0
7/9/01	--	22.7	0.8	102	--	7.7	--	6.4	44	54	0
7/23/01	--	25.2	1.2	105	--	7.6	--	10.3	49	60	0
8/6/01	--	25.9	0.7	96	--	7.3	--	4.7	39	48	0
8/20/01	735	22.2	0.6	106	107	7.9	8.1	8.3	49	59	0
9/4/01	--	19.5	0.5	113	--	7.6	--	8.3	47	57	0
9/17/01	--	15.9	0.6	104	--	7.5	--	7.4	45	54	0
10/1/01	--	14.0	0.8	103	--	7.5	--	8.3	44	53	0
10/16/01	--	7.7	0.8	97	--	7.9	--	13.2	59	72	0
5/13/02	--	11.7	0.7	129	--	7.3	--	10.7	--	--	--
5/28/02	--	15.6	2.2	113	--	7.6	--	5.5	--	--	--
6/11/02	--	15.8	0.5	107	--	7.9	--	--	--	--	--

Table 8. Physical properties and alkalinity results by site,Voyageurs National Park, Minnesota, 2001—Continued.

Date	Air Pressure (mm Hg)	Water Tempera-ture (°C)	Secchi disk transpar-ency (m)	Specific conductance, field (µS/cm)	Specific con-ductance, laboratory (µS/cm)	Field pH	Labora-tory pH	Dissolved oxygen (mg/L)	Total alkalinity as $CaCO_3$ (mg/L)	Bicarbon-ate alkalin-ity as HCO_3 (mg/L)	Carbonate alkalinity as CO_3 (mg/L)
Rainy Lake at Black Bay (West) near International Falls, Site 44—Continued											
6/24/02	--	20.1	0.8	109	--	7.8	--	10.5	--	--	--
7/8/02	--	21.6	0.5	96	--	7.4	--	6.5	--	--	--
7/22/02	--	23.6	0.8	102	--	7.2	--	9.3	--	--	--
8/5/02	--	20.7	0.8	93	--	8.4	--	9.5	--	--	--
8/20/02	734	17.9	0.6	96	--	8.2	--	8.7	--	--	--
9/4/02	--	19.3	0.8	88	--	7.8	--	8.1	--	--	--
9/16/02	--	17.4	0.5	84	--	8.1	--	9.2	--	--	--
10/2/02	--	10.9	0.8	72	--	7.3	--	4.8	--	--	--
10/15/02	--	5.5	0.8	61	--	7.0	--	11.6	--	--	--
5/13/03	--	13.0	0.6	98	--	7.7	--	10.3	33	40	0
5/28/03	732	18.1	--	85	--	7.2	--	8.4	38	46	0
6/9/03	--	19.6	0.4	91	--	--	--	7.5	--	--	--
6/23/03	--	22.6	0.5	98	--	7.3	--	7.3	--	--	--
7/7/03	--	20.6	0.1	157	--	7.5	--	7.9	--	--	--
7/21/03	--	22.0	0.3	114	--	7.2	--	6.9	--	--	--
8/4/03	--	23.8	0.3	108	--	8.8	--	9.2	--	--	--
8/18/03	--	27.3	0.2	115	--	9.1	--	9.3	--	--	--
9/2/03	--	18.9	0.2	109	--	6.4	--	6.6	--	--	--
9/15/03	--	17.1	0.2	103	--	6.5	--	7.0	38	46	0
9/28/03	--	8.0	0.1	94	--	6.7	--	9.6	35	43	0

Table 9. Dissolved solids and major ion analytical results by site, Voyageurs National Park, Minnesota, 2001

(all units in milligrams per liter)

Date	Dissolved solids	Dissolved calcium	Dissolved magnesium	Dissolved potassium	Dissolved sodium	Dissolved chloride	Dissolved sulfate	Dissolved manganese
Sand Point Lake below Harrison Narrows near Crane Lake, Site 7								
5/16/01	54	5.8	2.3	1.0	1.9	2.1	4.1	6.2
8/21/01	61	6.3	2.5	1.2	1.8	2.5	3.4	5.2
Namakan Lake near Ray, Site 14								
5/16/01	44	4.9	1.8	0.6	1.3	1.1	2.8	E1.9
8/21/01	44	4.9	1.8	0.6	1.4	1.7	3.1	<3.0
Rainy Lake at Brule Narrows near International Falls, Site 5								
5/15/01	49	5.2	1.8	0.6	1.3	1.0	2.8	<3.0
8/20/01	42	5.0	1.9	0.7	1.3	1.1	3.4	<3.0
Kabetogama Lake at Mouth of Meadwood Bay near Ray, Site 11								
8/21/01	76	11.7	4.5	1.0	1.4	1.1	2.1	<3.0
Kabetogama Lake at Cemetary Island near Ray, Site 43								
5/17/01	59	10.6	4.1	0.8	1.5	1.2	2.5	<3.0
8/22/01	63	11.3	4.4	0.9	1.5	1.3	2.3	<3.0
Kabetogama Lake near Grave Island near Ray, Site 45								
5/17/01	65	12.0	4.6	1.0	1.5	1.3	2.5	<3.0
8/22/01	68	11.7	4.5	1.0	1.5	1.3	2.2	<3.0
Rainy Lake at Black Bay Narrows near International Falls, Site 1								
5/15/01	75	10.6	4.4	1.0	1.3	1.2	2.2	E1.9
8/20/01	97	12.7	5.2	1.1	1.3	1.0	1.8	7.9
Rainy Lake at Black Bay near International Falls, Site 16								
5/15/01	57	10.4	4.0	0.8	1.4	1.2	2.5	<3.0
8/20/01	66	11.5	4.5	1.0	1.5	1.2	2.8	<3.0
Rainy Lake at Black Bay (West) near International Falls, Site 44								
5/15/01	94	12.9	5.5	1.1	1.4	1.2	2.0	E2.5
8/20/01	104	13.6	5.6	1.2	1.4	1.1	2.2	7.7

Table 10. Nutrient analytical results by site, Voyageurs National Park, Minnesota, 2001-03.

[all units in milligrams per liter; --, not determined; <, less than; E, estimated]

Date	Dissolved nitrate nitrogen	Dissolved nitrite nitrogen	Dissolved nitrite plus nitrate nitrogen	Dissolved ammonia nitrogen	Dissolved ammonia plus organic nitrogen	Total ammonia plus organic nitrogen	Total phosphorus	Dissolved phosphorus	Dissolved ortho-phosphorus
Sand Point Lake below Harrison Narrows near Crane Lake, Site 7									
5/16/01	0.0	0.0	0.0	0.0	0.4	0.6	0.0	0.0	<0.007
8/21/01	0.0	0.0	0.0	0.0	0.6	0.6	0.0	0.0	<0.007
5/14/02	0.1	0.0	0.1	<0.015	0.4	0.5	0.0	0.0	<0.007
8/21/02	0.0	0.0	0.0	E0.011	0.4	0.5	0.0	0.0	<0.007
5/29/03	--	E0.002	<0.022	E0.010	0.4	0.6	0.0	0.0	<0.007
Namakan Lake near Ray, Site 14									
5/16/01	0.0	0.0	0.0	0.0	0.3	0.5	0.0	E0.005	<0.007
8/21/01	0.0	0.0	0.0	0.0	0.3	0.4	0.0	E0.003	<0.007
5/14/02	E0.09	E0.002	0.0	E0.014	0.3	0.4	0.0	0.0	<0.007
8/21/02	E0.053	E0.002	0.0	E0.009	0.3	0.5	0.0	0.0	<0.007
5/29/03	0.0	0.0	0.0	<0.015	0.3	0.4	0.0	E0.004	<0.007
Rainy Lake at Brule Narrows near International Falls, Site 5									
5/15/01	0.0	0.0	0.0	<0.002	0.3	0.4	0.0	0.0	<0.007
8/20/01	0.0	0.0	0.0	0.0	0.3	0.4	0.0	E0.003	<0.007
5/13/02	E0.085	E0.002	0.0	<0.015	0.3	0.4	0.0	0.0	<0.007
8/20/02	E0.092	E0.002	0.0	<0.015	0.3	0.4	0.0	0.0	<0.007
5/28/03	E0.038	E0.002	0.0	<0.015	0.3	0.4	0.0	0.0	<0.007
Kabetogama Lake at Mouth of Meadwood Bay near Ray, Site 11									
5/30/01	--	--	--	--	--	--	0.0	--	--
6/12/01	--	--	--	--	--	--	0.0	--	--
6/25/01	--	--	--	--	--	--	0.0	--	--
7/10/01	--	--	--	--	--	--	0.0	--	--
7/24/01	--	--	--	--	--	--	0.0	--	--
8/7/01	--	--	--	--	--	--	0.0	--	--
8/21/01	--	0.0	<0.005	0.0	0.5	0.7	0.0	0.0	<0.007
9/5/01	--	--	--	--	--	--	0.0	--	--
9/18/01	--	--	--	--	--	--	0.0	--	--
10/2/01	--	--	--	--	--	--	0.0	--	--
10/17/01	--	--	--	--	--	--	0.0	--	--
5/14/02	E0.033	E0.002	0.0	<0.015	0.3	0.5	0.0	0.0	<0.007
5/30/02	--	--	--	--	--	--	0.0	--	--
6/12/02	--	--	--	--	--	--	0.0	--	--
6/26/02	--	--	--	--	--	--	0.0	--	--
7/9/02	--	--	--	--	--	--	0.0	--	--
7/23/02	--	--	--	--	--	--	0.0	--	--
8/6/02	--	--	--	--	--	--	0.0	--	--
8/21/02	--	<0.002	<0.013	<0.015	0.4	0.8	0.0	0.0	0.0
9/5/02	--	--	--	--	--	--	0.0	--	--

Table 10. Nutrient analytical results by site, Voyageurs National Park, Minnesota, 2001-03—Contintued.

Date	Dissolved nitrate nitrogen	Dissolved nitrite nitrogen	Dissolved nitrite plus nitrate nitrogen	Dissolved ammonia nitrogen	Dissolved ammonia plus organic nitrogen	Total ammonia plus organic nitrogen	Total phosphorus	Dissolved phosphorus	Dissolved ortho-phospho-rus
				Kabetogama Lake at Mouth of Meadwood Bay near Ray, Site 11—Continued					
9/17/02	--	--	--	--	--	--	0.0	--	--
9/30/02	--	--	--	--	--	--	0.0	--	--
10/16/02	--	--	--	--	--	--	0.0	--	--
5/14/03	--	--	--	--	--	--	0.0	--	--
5/29/03	--	<0.002	<0.022	<0.015	0.3	0.6	--	0.0	<0.007
6/10/03	--	--	--	--	--	--	0.0	--	--
6/24/03	--	--	--	--	--	--	0.0	--	--
7/8/03	--	--	--	--	--	--	0.0	--	--
7/22/03	--	--	--	--	--	--	0.0	--	--
8/5/03	--	--	--	--	--	--	0.0	--	--
8/19/03	--	--	--	--	--	--	0.0	--	--
9/3/03	--	--	--	--	--	--	0.0	--	--
9/17/03	--	--	--	--	--	--	0.0	--	--
				Kabetogama Lake at Cemetary Island near Ray, Site 43					
5/17/01	--	<0.001	<0.005	0.0	0.3	0.5	0.0	0.0	<0.007
5/31/01	--	--	--	--	--	--	0.0	--	--
6/12/01	--	--	--	--	--	--	0.0	--	--
6/26/01	--	--	--	--	--	--	0.0	--	--
7/10/01	--	--	--	--	--	--	0.0	--	--
7/24/01	--	--	--	--	--	--	0.0	--	--
8/7/01	--	--	--	--	--	--	0.0	--	--
8/22/01	0.0	0.0	0.0	0.0	0.4	0.9	0.0	0.0	<0.007
9/5/01	--	--	--	--	--	--	0.0	--	--
9/18/01	--	--	--	--	--	--	0.0	--	--
10/2/01	--	--	--	--	--	--	0.0	--	--
10/17/01	--	--	--	--	--	--	0.0	--	--
5/14/02	--	<0.002	<0.013	<0.015	0.3	0.5	0.0	0.0	<0.007
5/30/02	--	--	--	--	--	--	0.0	--	--
6/12/02	--	--	--	--	--	--	0.0	--	--
6/26/02	--	--	--	--	--	--	0.0	--	--
7/9/02	--	--	--	--	--	--	0.0	--	--
7/23/02	--	--	--	--	--	--	0.0	--	--
8/6/02	--	--	--	--	--	--	0.0	--	--
8/21/02	--	<0.002	<0.013	0.0	0.4	0.7	0.0	0.0	0.0
9/5/02	--	--	--	--	--	--	0.0	--	--
9/17/02	--	--	--	--	--	--	0.0	--	--
9/30/02	--	--	--	--	--	--	0.0	--	--
10/16/02	--	--	--	--	--	--	0.0	--	--
5/14/03	--	--	--	--	--	--	0.0	--	--

Table 10. Nutrient analytical results by site, Voyageurs National Park, Minnesota, 2001-03—Contintued.

Date	Dissolved nitrate nitrogen	Dissolved nitrite nitrogen	Dissolved nitrite plus nitrate nitrogen	Dissolved ammonia nitrogen	Dissolved ammonia plus organic nitrogen	Total ammonia plus organic nitrogen	Total phosphorus	Dissolved phosphorus	Dissolved ortho-phospho-rus
Kabetogama Lake at Cemetary Island near Ray, Site 43 —Continued									
5/29/03	--	<0.002	<0.022	<0.015	0.3	0.5	--	0.0	<0.007
6/10/03	--	--	--	--	--	--	0.0	--	--
6/24/03	--	--	--	--	--	--	0.0	--	--
7/8/03	--	--	--	--	--	--	0.0	--	--
7/22/03	--	--	--	--	--	--	0.0	--	--
8/5/03	--	--	--	--	--	--	0.0	--	--
8/19/03	--	--	--	--	--	--	0.0	--	--
9/3/03	--	--	--	--	--	--	0.0	--	--
9/17/03	--	--	--	--	--	--	0.1	--	--
Kabetogama Lake near Grave Island near Ray, Site 45									
5/17/01	--	0.0	<0.005	0.0	0.3	0.5	0.0	0.0	<0.007
5/31/01	--	--	--	--	--	--	0.0	--	--
6/12/01	--	--	--	--	--	--	0.0	--	--
6/26/01	--	--	--	--	--	--	0.0	--	--
7/10/01	--	--	--	--	--	--	0.0	--	--
7/24/01	--	--	--	--	--	--	0.0	--	--
8/7/01	--	--	--	--	--	--	0.0	--	--
8/22/01	--	<0.001	0.0	0.0	0.4	1.1	0.0	0.0	<0.007
9/5/01	--	--	--	--	--	--	0.0	--	--
9/18/01	--	--	--	--	--	--	0.0	--	--
10/2/01	--	--	--	--	--	--	0.0	--	--
10/17/01	--	--	--	--	--	--	0.0	--	--
5/14/02	--	<0.002	0.0	<0.015	0.4	0.5	0.0	0.0	<0.007
6/12/02	--	--	--	--	--	--	0.0	--	--
6/26/02	--	--	--	--	--	--	0.0	--	--
7/9/02	--	--	--	--	--	--	0.0	--	--
7/23/02	--	--	--	--	--	--	0.0	--	--
8/6/02	--	--	--	--	--	--	0.1	--	--
8/21/02	--	<0.002	<0.013	0.0	0.4	0.8	0.0	0.0	0.0
9/5/02	--	--	--	--	--	--	0.0	--	--
9/17/02	--	--	--	--	--	--	0.0	--	--
9/30/02	--	--	--	--	--	--	0.1	--	--
10/16/02	--	--	--	--	--	--	0.0	--	--
5/14/03	--	--	--	--	--	--	0.0	--	--
5/29/03	--	<0.002	<0.022	<0.015	0.3	0.6	--	E0.004	<0.007
6/10/03	--	--	--	--	--	--	0.0	--	--
6/24/03	--	--	--	--	--	--	0.0	--	--
7/8/03	--	--	--	--	--	--	0.0	--	--
7/22/03	--	--	--	--	--	--	0.0	--	--

Table 10. Nutrient analytical results by site, Voyageurs National Park, Minnesota, 2001-03—Contintued.

Date	Dissolved nitrate nitrogen	Dissolved nitrite nitrogen	Dissolved nitrite plus nitrate nitrogen	Dissolved ammonia nitrogen	Dissolved ammonia plus organic nitrogen	Total ammonia plus organic nitrogen	Total phosphorus	Dissolved phosphorus	Dissolved ortho-phospho-rus
Kabetogama Lake near Grave Island near Ray, Site 45— Continued									
8/5/03	--	--	--	--	--	--	0.0	--	--
8/19/03	--	--	--	--	--	--	0.0	--	--
9/3/03	--	--	--	--	--	--	0.0	--	--
9/17/03	--	--	--	--	--	--	0.0	--	--
Rainy Lake at Black Bay Narrows near International Falls, Site 1									
5/15/01	--	0.0	<0.005	0.0	0.4	0.7	0.0	0.0	<0.007
5/29/01	--	--	--	--	--	--	0.0	--	--
6/11/01	--	--	--	--	--	--	0.0	--	--
6/25/01	--	--	--	--	--	--	0.0	--	--
7/9/01	--	--	--	--	--	--	0.0	--	--
7/23/01	--	--	--	--	--	--	0.0	--	--
8/6/01	--	--	--	--	--	--	0.0	--	--
8/20/01	--	0.0	<0.005	0.0	0.7	0.9	0.0	0.0	E0.005
9/4/01	--	--	--	--	--	--	0.0	--	--
9/17/01	--	--	--	--	--	--	0.0	--	--
10/1/01	--	--	--	--	--	--	0.0	--	--
10/16/01	--	--	--	--	--	--	0.0	--	--
5/13/02	--	E0.002	<0.013	<0.015	0.4	0.7	0.0	0.0	<0.007
5/28/02	--	--	--	--	--	--	0.0	--	--
6/11/02	--	--	--	--	--	--	0.0	--	--
6/24/02	--	--	--	--	--	--	0.0	--	--
7/8/02	--	--	--	--	--	--	0.0	--	--
7/22/02	--	--	--	--	--	--	0.0	--	--
8/5/02	--	--	--	--	--	--	0.0	--	--
8/20/02	0.0	0.0	0.0	0.0	0.6	0.9	0.0	0.0	0.0
9/4/02	--	--	--	--	--	--	0.0	--	--
9/16/02	--	--	--	--	--	--	0.0	--	--
10/2/02	--	--	--	--	--	--	0.0	--	--
10/15/02	--	--	--	--	--	--	0.0	--	--
5/13/03	--	--	--	--	--	--	0.0	--	--
5/28/03	E0.023	E0.002	0.0	<0.015	0.3	0.5	0.0	0.0	<.007
6/9/03	--	--	--	--	--	--	0.0	--	--
6/23/03	--	--	--	--	--	--	0.0	--	--
7/7/03	--	--	--	--	--	--	0.0	--	--
7/21/03	--	--	--	--	--	--	0.0	--	--
8/4/03	--	--	--	--	--	--	0.0	--	--
8/18/03	--	--	--	--	--	--	0.0	--	--
9/2/03	--	--	--	--	--	--	0.0	--	--
9/15/03	--	--	--	--	--	--	0.0	--	--

Table 10. Nutrient analytical results by site, Voyageurs National Park, Minnesota, 2001-03—Contintued.

Date	Dissolved nitrate nitrogen	Dissolved nitrite nitrogen	Dissolved nitrite plus nitrate nitrogen	Dissolved ammonia nitrogen	Dissolved ammonia plus organic nitrogen	Total ammonia plus organic nitrogen	Total phosphorus	Dissolved phosphorus	Dissolved ortho-phospho-rus
Rainy Lake at Black Bay near International Falls, Site 16									
5/15/01	--	0.0	<0.005	0.0	0.3	0.5	0.0	E0.006	<0.007
5/29/01	--	--	--	--	--	--	0.0	--	--
6/11/01	--	--	--	--	--	--	0.0	--	--
6/25/01	--	--	--	--	--	--	0.0	--	--
7/9/01	--	--	--	--	--	--	0.0	--	--
7/23/01	--	--	--	--	--	--	0.0	--	--
8/6/01	--	--	--	--	--	--	0.0	--	--
8/20/01	--	<0.001	0.0	0.0	0.3	0.6	0.0	0.0	<0.007
9/4/01	--	--	--	--	--	--	0.0	--	--
9/17/01	--	--	--’	--	--	--	0.0	--	--
10/1/01	--	--	--	--	--	--	0.0	--	--
10/16/01	--	--	--	--	--	--	0.0	--	--
5/13/02	--	E0.002	<0.013	<0.015	0.4	0.7	0.0	0.0	<0.007
5/28/02	--	--	--	--	--	--	0.0	--	--
6/11/02	--	--	--	--	--	--	0.0	--	--
6/24/02	--	--	--	--	--	--	0.0	--	--
7/8/02	--	--	--	--	--	--	0.0	--	--
7/22/02	--	--	--	--	--	--	0.1	--	--
8/5/02	--	--	--	--	--	--	0.1	--	--
8/20/02	0.0	0.0	0.0	E0.009	0.5	0.8	0.1	0.0	0.0
9/4/02	--	--	--	--	--	--	0.1	--	--
9/16/02	--	--	--	--	--	--	0.1	--	--
10/2/02	--	--	--	--	--	--	0.1	--	--
10/15/02	--	--	--	--	--	--	0.1	--	--
5/13/03	--	--	--	--	--	--	0.1	--	--
5/28/03	E0.012	E0.002	E0.014	E0.008	0.4	1.1	0.1	0.0	<0.007
6/9/03	--	--	--	--	--	--	0.1	--	--
Rainy Lake at Black Bay (West) near International Falls, Site 44									
5/15/01	0.0	0.0	0.0	0.0	0.6	0.8	0.0	0.0	<0.007
5/29/01	--	--	--	--	--	--	0.0	--	--
6/11/01	--	--	--	--	--	--	0.0	--	--
6/25/01	--	--	--	--	--	--	0.0	--	--
7/9/01	--	--	--	--	--	--	0.0	--	--
7/23/01	--	--	--	--	--	--	0.0	--	--
8/6/01	--	--	--	--	--	--	0.1	--	--
8/20/01	0.0	0.0	0.0	0.0	0.7	1.1	0.1	0.0	<0.007
9/4/01	--	--	--	--	--	--	0.1	--	--
9/17/01	--	--	--	--	--	--	0.1	--	--
10/1/01	--	--	--	--	--	--	0.0	--	--

Table 10. Nutrient analytical results by site, Voyageurs National Park, Minnesota, 2001-03—Contintued.

Date	Dissolved nitrate nitrogen	Dissolved nitrite nitrogen	Dissolved nitrite plus nitrate nitrogen	Dissolved ammonia nitrogen	Dissolved ammonia plus organic nitrogen	Total ammonia plus organic nitrogen	Total phosphorus	Dissolved phosphorus	Dissolved ortho-phospho-rus
Rainy Lake at Black Bay (West) near International Falls, Site 44—Continued									
10/16/01	--	--	--	--	--	--	0.0	--	--
5/13/02	--	0.0	<0.013	<0.015	0.6	0.9	0.0	0.0	<0.007
6/11/02	--	--	--	--	--	--	0.0	--	--
6/24/02	--	--	--	--	--	--	0.0	--	--
7/8/02	--	--	--	--	--	--	0.1	--	--
7/22/02	--	--	--	--	--	--	0.1	--	--
8/5/02	--	--	--	--	--	--	0.1	--	--
8/20/02	0.0	0.0	0.0	E0.013	0.5	0.7	0.1	0.0	0.0
9/4/02	--	--	--	--	--	--	0.1	--	--
9/16/02	--	--	--	--	--	--	0.1	--	--
10/2/02	--	--	--	--	--	--	0.0	--	--
10/15/02	--	--	--	--	--	--	0.1	--	--
5/13/03	--	--	--	--	--	--	0.1	--	--
5/28/03	E0.011	E0.002	E0.013	0.0	0.4	0.7	0.0	0.0	<0.007
6/9/03	--	--	--	--	--	--	0.1	--	--
6/23/03	--	--	--	--	--	--	0.1	--	--
7/7/03	--	--	--	--	--	--	0.2	--	--
7/21/03	--	--	--	--	--	--	0.1	--	--
8/4/03	--	--	--	--	--	--	0.1	--	--
8/18/03	--	--	--	--	--	--	0.1	--	--
9/2/03	--	--	--	--	--	--	0.1	--	--
9/15/03	--	--	--	--	--	--	0.1	--	--

Table 11. Chlorophyll analyical results by site, Voyageurs National Park, Minnesota, 2001-03

[all units in micrograms per liter; E, estimated; <, less than]

Date	Chlorophyll-*a*	Chlorophyll-*b*
Sand Point Lake below Harrison Narrows near Crane Lake, Site 7		
5/16/01	2.3	<0.1
8/21/01	0.2	<0.1
5/14/02	1.0	<0.1
8/21/02	3.0	<0.1
5/29/03	2.1	<0.1
Namakan Lake near Ray, Site 14		
5/16/01	2.0	<0.1
8/21/01	0.5	<0.1
5/14/02	2.1	<0.1
8/21/02	1.9	<0.1
5/29/03	1.4	<0.1
Rainy Lake at Brule Narrows near International Falls, Site 5		
5/15/01	3.6	E0.1
8/20/01	1.0	<0.1
5/13/02	1.1	<0.01
8/20/02	1.2	<0.1
5/28/03	1.1	<0.1
Kabetogama Lake at Mouth of Meadwood Bay near Ray, Site 11		
5/16/01	3.2	<0.1
5/30/01	1.2	<0.1
6/12/01	1.0	<0.1
6/25/01	2.9	<0.1
7/10/01	3.0	<0.1
7/24/01	4.8	<0.1
8/7/01	22.5	E0.3
8/21/01	4.4	<0.1
9/5/01	6.1	0.4
9/18/01	2.7	<0.1
10/2/01	2.8	<0.1
10/17/01	2.8	<0.1
5/14/02	2.7	<0.1
5/30/02	2.5	<0.1
6/12/02	1.2	<0.1
6/26/02	1.5	0.1
7/9/02	2.4	<0.1
7/23/02	3.6	<0.1
8/6/02	4.9	<0.1
8/21/02	22.1	<0.1
9/5/02	3.7	E0.5
9/17/02	E31.2	<0.1
9/30/02	22.8	<0.1
10/16/02	2.7	<0.1
5/14/03	2.7	<0.1
5/29/03	0.8	<0.1
6/10/03	1.4	<0.1
6/24/02	1.3	<0.1
7/8/03	1.6	<0.1

Table 11. Chlorophyll analyical results by site, Voyageurs National Park, Minnesota, 2001-03—Continued

Date	Chlorophyll-*a*	Chlorophyll-*b*
Kabetogama Lake at Mouth of Meadwood Bay near Ray, Site 11—Continued		
7/22/03	4.1	<0.1
8/5/03	E3.2	<0.1
8/19/03	E8.9	<0.1
9/3/03	E7.5	<0.1
9/17/03	E7.8	<0.1
Kabetogama Lake at Cemetary Island near Ray, Site 43		
5/17/01	2.1	<0.1
5/31/01	E1.6	<0.1
6/12/01	0.9	<0.1
6/26/01	1.9	<0.1
7/10/01	3.2	<0.1
7/24/01	3.0	<0.1
8/7/01	11.1	E0.2
8/22/01	19.4	<0.1
9/5/01	6.8	<0.1
9/18/01	9.0	0.2
10/2/01	7.0	<0.1
10/17/01	2.1	<0.1
5/14/02	6.6	<0.1
5/30/02	0.7	<0.1
6/12/02	0.4	<0.1
6/26/02	2.5	0.3
7/9/02	4.5	<0.1
7/23/02	5.1	<0.1
8/6/02	23.7	<0.1
8/21/02	4.9	<0.1
9/5/02	7.7	E0.4
9/17/02	E4.3	<0.1
9/30/02	7.0	<0.1
10/16/02	1.5	<0.1
5/14/03	1.7	<0.1
5/29/03	0.7	<0.1
6/10/03	0.9	<0.1
6/24/03	2.3	<0.1
7/8/03	3.4	<0.1
7/22/03	3.1	<0.1
8/5/03	3.5	<0.1
8/19/03	E13.0	<0.1
9/3/03	21.0	<0.1
9/17/03	7.6	<0.1
Kabetogama Lake near Grave Island near Ray, Site 45		
5/17/01	3.5	<0.1
5/31/01	2.0	<0.1
6/12/01	1.3	<0.1
6/26/01	2.1	<0.1
7/10/01	3.0	<0.1
7/24/01	3.6	<0.1

Table 11. Chlorophyll analyical results by site, Voyageurs National Park, Minnesota, 2001-03—Continued

Date	Chlorophyll-*a*	Chlorophyll-*b*
Kabetogama Lake near Grave Island near Ray, Site 45—Continued		
8/7/01	17.6	E0.2
8/22/01	21.4	<0.1
9/5/01	9.5	0.4
9/18/01	5.4	0.2
10/2/01	<0.1	<0.1
10/17/01	1.9	<0.1
5/14/02	2.2	<0.1
5/30/02	1.9	<0.1
6/12/02	1.7	<0.1
6/26/02	1.5	0.1
7/9/02	3.9	<0.1
7/23/02	5.2	<0.1
8/6/02	26.5	<0.1
8/21/02	7.6	<0.1
9/5/02	10.7	E1.0
9/17/02	E21.1	E0.1
9/30/02	67.3	<0.1
10/16/02	4.5	<0.1
5/14/03	2.1	<0.1
5/29/03	1.3	<0.1
6/10/03	0.9	<0.1
6/24/03	2.1	<0.1
7/8/03	2.8	<0.1
7/22/03	4.2	<0.1
8/5/03	E2.9	<0.1
8/19/03	E6.6	<0.1
9/3/03	E3.4	<0.1
9/17/03	E9.9	<0.1
Rainy Lake at Black Bay Narrows near International Falls, Site 1		
5/15/01	2.6	<0.1
5/29/01	1.5	<0.1
6/11/01	1.1	<0.1
6/25/01	3.2	<0.1
7/9/01	14.9	E0.2
7/23/01	12.5	<0.1
8/6/01	E2.6	E0.1
8/20/01	4.7	0.3
9/4/01	3.1	0.4
9/17/01	3.4	<0.1
10/1/01	4.8	0.2
10/16/01	5.5	<0.1
5/13/02	8.0	<0.1
5/28/02	2.0	<0.1
6/11/02	1.0	<0.1
6/24/02	3.3	0.2
7/8/02	2.6	<0.1
7/22/02	13.2	0.9
8/5/02	5.6	1.1
8/20/02	4.3	0.5

Table 11. Chlorophyll analyical results by site, Voyageurs National Park, Minnesota, 2001-03—Continued

Date	Chlorophyll-*a*	Chlorophyll-*b*
Rainy Lake at Black Bay Narrows near International Falls, Site 1—Continued		
9/4/02	5.7	E0.7
9/16/02	E5.0	<0.1
10/2/02	12.9	<0.1
10/15/02	2.4	<0.1
5/13/03	3.3	<0.1
5/28/03	1.4	<0.1
6/9/03	1.5	0.1
6/23/03	3.6	0.2
7/7/03	5.0	0.2
7/21/03	3.6	<0.1
8/4/03	E11.0	<0.1
8/18/03	E8.9	<0.1
9/2/03	E2.2	<0.1
9/15/03	E4.4	E0.2
Rainy Lake at Black Bay near International Falls, Site 16		
5/15/01	2.7	<0.1
5/29/01	1.4	<0.1
6/11/01	0.9	<0.1
6/25/01	1.8	<0.1
7/9/01	8.5	<0.1
7/23/01	8.5	<0.1
8/6/01	19.7	E0.3
8/20/01	2.9	<0.1
9/4/01	5.3	0.2
9/17/01	1.6	<0.1
10/1/01	6.5	0.2
10/16/01	5.4	E0.1
5/13/02	7.4	<0.1
5/28/02	1.5	<0.1
6/11/02	1.8	<0.1
6/24/02	1.8	0.2
7/8/02	2.4	<0.1
7/22/02	21.9	1.3
8/5/02	6.9	<0.1
8/20/02	7.8	<0.1
9/4/02	27.2	0.8
9/16/02	E17.3	<0.1
10/2/02	3.5	<0.1
10/15/02	2.8	<0.1
5/13/03	4.1	<0.1
5/28/03	2.6	<0.1
6/9/03	1.5	0.1
Rainy Lake at Black Bay (West) near International Falls, Site 44		
5/15/01	1.8	<0.1
5/29/01	E0.7	<0.1
6/11/01	1.0	<0.1
6/25/01	1.3	<0.1
7/9/01	4.2	E0.2

Table 11. Chlorophyll analyical results by site, Voyageurs National Park, Minnesota, 2001-03—Continued

Date	Chlorophyll-*a*	Chlorophyll-*b*
Rainy Lake at Black Bay (West) near International Falls, Site 44—Continued		
7/23/01	13.2	<0.1
8/6/01	0.9	0.1
8/20/01	7.1	0.4
9/4/01	2.7	0.5
9/17/01	4.7	<0.1
10/1/01	5.9	0.2
10/16/01	5.6	E0.1
5/13/02	3.0	<0.1
5/28/02	1.2	<0.1
6/11/02	2.0	<0.1
6/24/02	1.6	0.1
7/8/02	2.1	E0.2
7/22/02	6.0	1.1
8/5/02	9.7	1.4
9/4/02	3.8	E0.5
9/16/02	E47.8	<0.1
10/2/02	3.4	<0.1
10/15/02	3.0	<0.1
5/13/03	3.2	<0.1
5/28/03	1.6	<0.1
6/9/03	2.3	<0.10
6/23/03	2.6	0.2
7/7/03	5.4	0.5
7/21/03	14.0	<0.1
8/4/03	17.0	<0.1
8/18/03	E13.0	<0.1
9/2/03	E3.8	<0.1
9/15/03	E3.2	E0.1

Table 12. Chlorophyll-*a* and total phosphorus analytical results determined for water samples in Voyageurs National Park, Minnesota by the Natural Resource Research Institute, 2002-03.

[µg/L, micrograms per liter; mg/L, milligrams per liter]

Date	Chlorphyll-*a* (µg/L)	Total Phosphorus (mg/L)
Sand Point Lake below Harrison Narrows near Crane Lake, Site 7		
5/14/02	1.3	0.0
5/30/02	5.3	0.0
6/12/02	4.9	0.0
6/25/02	2.7	0.0
7/9/02	1.0	0.0
7/23/02	0.2	0.0
8/6/02	0.9	0.0
8/21/02	0.3	0.0
9/5/02	3.3	0.0
9/17/02	2.4	0.0
9/30/02	1.6	0.0
10/17/02	1.5	0.0
5/14/03	5.5	0.0
6/10/03	2.3	0.0
6/24/03	1.5	0.0
7/8/03	0.5	0.0
7/23/03	0.7	0.0
8/5/03	0.5	0.0
8/19/03	2.7	0.0
9/4/03	3.6	0.0
9/19/03	2.3	0.0
9/29/03	3.9	0.0
Namakan Lake near Ray, Site 14		
5/14/02	1.7	0.0
5/30/02	4.0	0.0
6/12/02	2.8	0.0
6/25/02	1.2	0.0
7/9/02	2.0	0.0
7/23/02	1.0	0.0
8/6/02	1.7	0.0
8/21/02	3.2	0.0
9/5/02	0.9	0.0
9/17/02	1.2	0.0
9/30/02	1.8	0.0
10/17/02	1.5	0.0
5/14/03	2.3	0.0
6/10/03	2.5	0.0
6/24/03	3.1	0.0
7/8/03	0.1	0.0
7/22/03	0.4	0.0
8/5/03	0.6	0.0
8/19/03	2.9	0.0
9/4/03	2.8	0.0
9/19/03	2.8	0.0
9/29/03	3.1	0.0

Table 12. Chlorophyll-a and total phosphorus analytical results determined for water samples in Voyageurs National Park, Minnesota by the Natural Resource Research Institute, 2002-03.—Continued.

Date	Chlorphyll-*a* (µg/L)	Total Phosphorus (mg/L)
Rainy Lake at Brule Narrows near International Falls, Site 5		
5/13/02	1.3	0.0
5/28/02	1.5	0.0
6/11/02	1.7	0.0
6/24/02	2.0	0.0
7/8/02	0.8	0.0
7/24/02	1.0	0.0
8/5/02	0.2	0.0
8/20/02	1.8	0.0
9/4/02	0.9	0.0
9/16/02	2.2	0.0
10/2/02	2.3	0.0
10/17/02	1.6	0.0
5/13/03	2.5	0.0
6/9/03	2.8	0.0
6/23/03	0.9	0.0
7/7/03	0.4	0.0
7/21/03	0.6	0.0
8/4/03	0.7	0.0
8/18/03	1.4	0.0
9/2/03	2.3	0.0
9/15/03	3.9	0.0
9/28/03	2.4	0.0
Kabetogama Lake at Mouth of Meadwood Bay near Ray, Site 11		
6/21/03	1.7	0.0
9/29/03	10.2	0.0
Kabetogama Lake at Cemetary Island near Ray, Site 43		
6/20/03	2.8	0.0
9/29/03	6.0	0.1
Kabetogama Lake near Grave Island near Ray, Site 45		
6/20/03	1.8	0.0
9/29/03	3.5	0.0
Rainy Lake at Black Bay Narrows near International Falls, Site 1		
9/28/03	7.0	0.1
Rainy Lake at Black Bay (West) near International Falls, Site 44		
9/28/03	11.2	0.2

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