Prepared in Cooperation with the National Park Service

Relation of Nutrient Concentrations, Nutrient Loading, and Algal Production to Changes in Water Levels in Kabetogama Lake, Voyageurs National Park, Northern Minnesota, 2008–09

Scientific Investigations Report 2011–5096

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

Cover photograph: Kabetogama Lake, August 2008, photograph
by Victoria Glenn Christensen, U.S. Geological Survey.

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Conversion Factors

SI to Inch/Pound

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	
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic meter (m^3)	6.290	barrel (petroleum, 1 barrel = 42 gal)
liter (L)	33.82	ounce, fluid (fl. oz.)
milliliter (mL)	0.003382	ounce, fluid (fl. oz.)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)
milligram (mg)	0.000003527	ounce, avoirdupois (oz)
kilogram (kg)	2.205	pound avoirdupois (lb)

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

$$°F=(1.8×°C)+32$$

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88), except where noted.

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

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

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

Abbreviations and Acronyms

ELISA	enzyme-linked immuno-sorbent assay
IJC	International Joint Commission
NRRI	Natural Resources Research Institute
NWQL	National Water Quality Laboratory
PVC	polyvinyl chloride
TSI	trophic state index
TSI CHY	trophic state index computed from chlorophyll-*a* concentrations
TSI TP	trophic state index computed from total-phosphorus concentrations
USGS	U.S. Geological Survey
WHO	World Health Organization

Relation of Nutrient Concentrations, Nutrient Loading, and Algal Production to Changes in Water Levels in Kabetogama Lake, Voyageurs National Park, Northern Minnesota, 2008–09

By Victoria G. Christensen (U.S. Geological Survey), Ryan P. Maki (National Park Service), and Richard L. Kiesling (U.S. Geological Survey)

Abstract

Nutrient enrichment has led to excessive algal growth in Kabetogama Lake, Voyageurs National Park, northern Minnesota. Water- and sediment-quality data were collected during 2008–09 to assess internal and external nutrient loading. Data collection was focused in Kabetogama Lake and its inflows, the area of greatest concern for eutrophication among the lakes of Voyageurs National Park. Nutrient and algal data were used to determine trophic status and were evaluated in relation to changes in Kabetogama Lake water levels following changes to dam operation starting in 2000. Analyses were used to estimate external nutrient loading at inflows and assess the potential contribution of internal phosphorus loading. Kabetogama Lake often was mixed vertically, except for a few occasionally stratified areas, including Lost Bay in the northeastern part of Kabetogama Lake. Stratification, combined with larger bottom-water nutrient concentrations, larger sediment phosphorus concentrations, and estimated phosphorus release rates from sediment cores indicate that Lost Bay may be one of several areas that may be contributing substantially to internal loading. Internal loading is a concern because nutrients may cause excessive algal growth including potentially toxic cyanobacteria. The cyanobacterial hepatotoxin, microcystin, was detected in 7 of 14 cyanobacterial bloom samples, with total concentrations exceeding 1.0 microgram per liter, the World Health Organization's guideline for finished drinking water for the congener, microcystin-LR. Comparisons of the results of this study to previous studies indicate that chlorophyll-*a* concentrations and trophic state indices have improved since 2000, when the rules governing dam operation changed. However, total-phosphorus concentrations have not changed significantly since 2000.

Introduction

Voyageurs National Park in northern Minnesota was established in 1975 "to preserve, for the inspiration and enjoyment of present and future generations, the outstanding scenery, geological conditions, and waterway system which constituted a part of the historic route of the Voyageurs" (Public Law 97–405). When Voyageurs National Park (hereinafter referred to as the Park) was established, water-quality conditions were not well documented. Visitor use in the Park includes boating along scenic water ways, fishing, and swimming. Aquatic systems support much of the Park's fauna, including fish, waterfowl, loons, eagles, beavers, and moose. Because about one-half the Park is water covered (fig. 1), recreational use of the Park is water based. Therefore, water quality is an essential element of the Voyageurs National Park environment with respect to the health of its ecosystem and visitor enjoyment, therefore water quality within the Park is of primary importance to maintaining the purposes for which the Park was established. Because water quality can change with time, periodic determinations of water quality are needed to assess current conditions and detect changes within the Park environment.

Nutrient enrichment has led to excessive algal growth in Kabetogama Lake in Voyageurs National Park. Previous studies have documented Kabetogama Lake to have larger nutrient and chlorophyll concentrations than the other large lakes in the Park (Payne, 1991; Christensen and others, 2004). Kabetogama Lake is shallower than the other large lakes and has polymictic circulation, or mixes more than twice per year. The polymictic circulation indicates a possible link between the frequent recirculation and the internal recycling of phosphorus. Microcystin-LR, a cyanotoxin, was detected with concentrations as large as 3.94 micrograms per liter (µg/L) in 2006 (Brian Kotak, Miette Environmental Consulting, written commun., October 15, 2006), which is greater than the World Health Organization's (2003) 1.0-µg/L standard for finished drinking water and is a concern for wildlife and residents who use Kabetogama Lake for drinking water.

Implementation of an order by 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, in January 2000 changed operating procedures (rule curves) for dams that regulate the two large reservoirs in Voyageurs National Park, Rainy Lake and Namakan Reservoir (Kallemeyn, 2000). Rule curves indicate bands of permitted maximum and minimum water levels allowed throughout the year (Christensen and others, 2004). The lakes were natural water bodies before they were dammed in the early 1900s, and these new rule curves were expected to restore a more natural water regime that would affect water levels, water quality, and trophic state. In particular, the new rule curves were expected to lower phosphorus loading into Namakan Reservoir (which includes Kabetogama Lake), by lessening the effects of drying and rewetting sediments from fluctuating water levels, reducing nutrient inputs resulting from littoral vegetation, and reducing nutrient concentrations because of increased volume (Kepner and Stottlemyer, 1998).

Although nutrient and chlorophyll-*a* data were collected from 2001 through 2003, conditions throughout the sampling period were unusual, with excessive precipitation in 2001 and 2002 and drought conditions in 2003 (Christensen and others, 2004). As a result, the levels of Namakan Reservoir and Rainy Lake were outside of the bounds of the 2000 Rule Curves for short periods during all 3 years of data collection. These unusual climatic conditions made it difficult to determine whether water quality and trophic state were affected by the rule-curve change. Therefore, additional data collection in 2008–09 was necessary to determine if the IJC's rule-curve change had achieved its purpose.

Water- and sediment-quality data were collected during 2008–09 by the U.S. Geological Survey (USGS) in cooperation with the National Park Service to better understand nutrient concentrations and loading, algal production, and their relation to changes in water levels in Kabetogama Lake. Specific objectives of this study were to (1) assess the contribution of nutrients from external (inflows) and internal sources (lake-bottom sediments), (2) determine the trophic state of Kabetogama Lake, (3) determine the extent to which algal blooms in Kabetogama Lake are producing microcystin, and (4) determine if the changes in water levels as a result of reservoir operation (2000 Rule Curves) are affecting nutrient enrichment (total phosphorus) and algal production (chlorophyll-*a*) in Kabetogama Lake. The IJC stated in its 2000 order that it was subject to review in 15 years (2015) to re-evaluate the effects of the new rule curves (Kallemeyn and others, 2003), making this study of nutrient cycling in Voyageurs National Park timely and beneficial.

Study Area

Kabetogama Lake is one of five lakes that make up the Namakan Reservoir (Kabetogama, Namakan, Sand Point, Crane, and Little Vermilion; fig. 1). These lakes are natural and hydrologically connected. Water flows from the Namakan Reservoir system into Rainy Lake at three locations—through the dams at Squirrel Falls 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 (fig. 1). Lake levels have been controlled by regulatory dams on Namakan Reservoir since the early 1900s (Kallemeyn and others, 2003).

When the Namakan Reservoir level reaches an elevation of 339.39 meters (m) (or 1,113.5 feet) above the North American Vertical Datum of 1988 (NAVD 88), water begins to spill over into Rainy Lake at Gold Portage (International Rainy Lake Board of Control and International Lake of the Woods Control Board, 1984). Streamflow records from 1984–98, before the 2000 Rule Curve change, for Gold Portage outlet from Kabetogama Lake near Ray, Minn. (site Q8 in figure 1; hereafter referred to as Gold Portage) indicate there had been flow through Gold Portage, on average, 253 days per year. Operating Namakan Reservoir at the midpoint (water level) of the 2000 Rule Curves, as directed by the IJC order, results in flow through Gold Portage for 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 (fig. 1), 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 documented for data collected during 1977–84 (Payne, 1991) and supporting data were collected during this 2008–09 study. The timing of hydrologic events in Namakan Reservoir was expected to change under the new rules, with peak lake-surface elevations and peak outflow occurring in late May to early June, rather than late June to early July.

Morphologically, Kabetogama Lake is typical of lakes located on rocks of the Precambrian shield. Kabetogama Lake has irregular shorelines with numerous rock outcrops and islands. The maximum depth of Kabetogama Lake is about 24 m, and the mean depth is about 9 m (Kallemeyn and others, 2003). Kabetogama Lake is the largest of the five Namakan Reservoir Lakes and covers 10,425 hectares. Thermal stratification occurs infrequently in Kabetogama Lake (Christensen and others, 2004). When thermal stratification does occur, dissolved oxygen concentrations below the thermocline usually are at levels where fish can exhibit symptoms of distress (Kallemeyn and others, 2003). The lake typically is ice covered for about 5 or 6 months per year, with ice-up occurring in mid- to

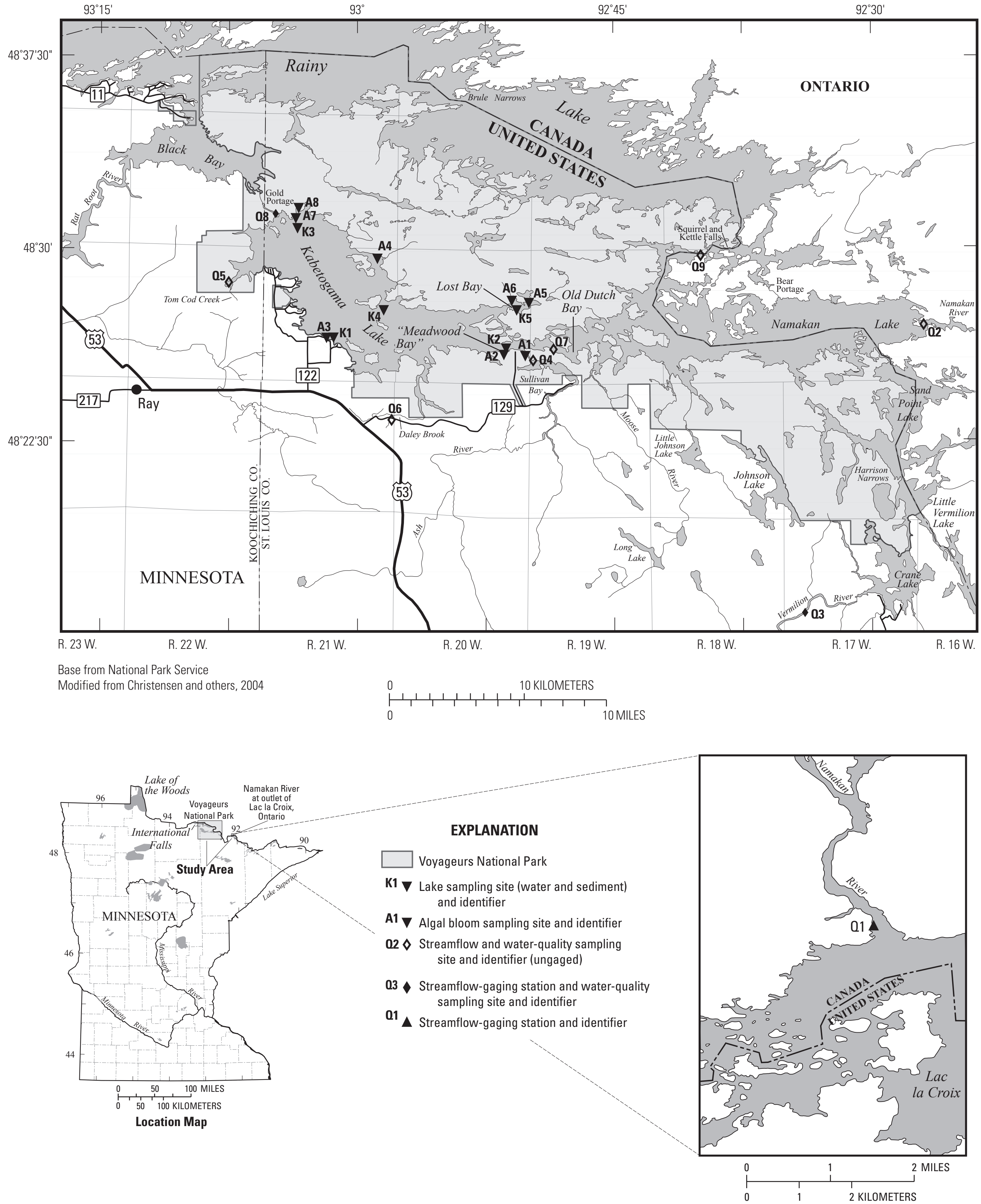

Figure 1. Location of Voyageurs National Park, sampling sites, and streamflow-gaging stations, Minnesota, 2008–09.

late November and ice-out occurring about April 28 (Minnesota Climatology Working Group, 2009).

The climate in the Kabetogama Lake area is continental with moderately warm summers and long, cold winters. The frost-free season ranges from 110 to 130 days (Kallemeyn and others, 2003). Average snowfall for the International Falls climate station is 172 centimeters (cm), average temperature is 2.9 degrees Celsius (°C), and total annual precipitation is 61 cm (Minnesota Climatology Working Group, 2010). Dry conditions were reported in most of northeastern Minnesota during the 2008–09 study period (Minnesota Climatology Working Group, 2009); however, annual precipitation measured at International Falls was more than the average of 61 cm for the period of record (1906–2010) in 2008 (70 cm) and 2009 (65 cm). Winter snowpack values for 2007–08 (243 cm) and 2008–09 (319 cm) were substantially greater than the average of 172 cm for the period of record (1905–2010).

Background and Previous Studies

The USGS conducted water-quality studies during 1977–84 and 2001–03. The earlier study indicated that the water bodies at the western edge of the Park (Kabetogama Lake and Black Bay in Rainy Lake) were eutrophic, having high algal productivity that produced blue-green algae (cyanobacteria) blooms (Payne, 1991). The later study indicated significant decreases in chlorophyll-*a* concentrations and trophic state indices for Kabetogama Lake and Black Bay compared to the 1977–84 study (Christensen and others, 2004); however, total-phosphorus concentrations did not significantly decrease, and Kabetogama Lake still experienced yearly blue-green algal blooms (Kallemeyn and others, 2003). These yearly blooms may be due, in part, to internal phosphorus loading. Phosphorus release from bottom sediments has been determined to be a substantial nutrient source in several lakes in Minnesota (Larsen and others, 1981) and across the United States (Welch and Spyridakis, 1972; Mueller and Ruddy, 1993). The degree to which bottom sediment acts as a nutrient source in Kabetogama Lake is unknown. Sediment commonly acts as a sink for nutrients and other substances. However, if conditions change, such as water levels or stratification, the sediment may serve as a source by liberating phosphorus into the water, which further stimulates the growth of cyanobacteria and algae, exacerbating the eutrophication problem. Additional problems may arise when algal blooms decay leading to oxygen depletion, which can cause fish mortality from lack of oxygen, and from the liberation of toxic substances or phosphorus that were bound to oxidized sediments (Chorus and Bartram, 1999).

Recent analysis of an existing, lead-210 dated sediment core from Kabetogama Lake provided evidence that the lake gradually has shifted to a higher trophic state, particularly since the 1960s (Kling, 2005). The proportion of Chrysophytes, which generally are representative of more oligotrophic conditions, has decreased as diatoms have become more prevalent. Diatom abundance generally has increased since the early 1970s, indicating increased nutrients and production. Also, cyanobacterial compositions have shifted with a decrease in diversity of *Anabaena*-dominated blooms accompanied by more consistent pulses of *Aphanizomenon* akinetes. *Anabaena* and *Aphanizomenon* are two cyanobacteria that may produce cyanotoxins, which are a potential human-health risk and may cause waterborne disease when ingested and may cause water contact disease through recreational exposure (Chorus and Bartram, 1999). *Anabaena* are adapted to relatively high light conditions, and *Aphanizomenon* are adapted to relatively low light conditions (de Nobel and others, 1998). Therefore, this apparent shift may be indicative of changing light conditions in the lake.

Kabetogama Lake is of more immediate concern than the other large lakes in the Park because it is shallower and has polymictic circulation, which makes the bottom sediment more susceptible to resuspension because of wind or boating. According to the most recent creel survey, Kabetogama Lake receives more angler hours than other Park lakes (Talmage, 2005, 2006). Sediment resuspension and periodic anoxia may cause frequent recirculation of phosphorus in Kabetogama. Total-phosphorus concentrations in Kabetogama Lake generally were greater for 1977–83 (Payne, 1991) and 2002–03 (Christensen and others, 2004) than in other large lakes in the Park. Greater mean total-phosphorus concentrations in summer (compared to spring concentrations) indicate that there is an input of phosphorus during the summer season from either external (inflow or precipitation) or internal (lake-sediment or algae) sources (Payne, 1991).

The southwest shore of Kabetogama Lake is not part of the Park and, therefore, the shore is open for development. The numerous homes, cabins, and resorts along the roughly 19 kilometers of shoreline are a potential source for nutrients. Residential and commercial areas on Ash River (fig. 1), which flows into Kabetogama Lake from the south, also are a source of nutrients (Payne, 1991). Problems associated with cyanobacteria may increase in areas experiencing population growth without concomitant sewage treatment (Chorus and Bartram, 1999; Wetzel, 2001). As a result, additional development on Kabetogama Lake may cause additional eutrophication, thereby threatening the lake’s water quality, ecology, and recreational value.

Wetland vegetation studies (Meeker and Harris, 2009) indicated that changes in plant community assemblages occurred in Kabetogama Lake between 1987 and 2002–05. In Namakan Reservoir, the effects of having water levels that were lower than natural levels before 2000 were most apparent at the depth that was exposed annually to the effects of desiccation and disturbance from ice formation in the sediments (Wilcox and Meeker, 1991). The results of these wetland vegetation studies indicate that a more natural regime (such as the 2000 Rule Curves) would provide a more structurally diverse aquatic community.

A paleolimnological study (National Park Service Project Management Information System No. 9415, Mark Edlund, Science Museum of Minnesota, written commun., July 2010) of cores collected in the large lakes of Voyageurs National Park may help put the results of this study in historical context. The paleolimnological study indicated that the greatest changes in the diatom communities of the Namakan Reservoir and Rainy Lake came during a period of heavy logging in this region (early 19th century), after the damming of this system in the early 1900s, and recently during a period of regional warming. The diatom communities of Rainy Lake, Namakan Reservoir, and Lac la Croix (a control lake in the paleolimnological study, inset in fig. 1) indicate similar shifts in diatom communities (species turnover) from approximately 1980 to 2008. This phenomenon has been observed consistently in 200 paleolimnological records from the northern hemisphere and appears to be climate-related (Rühland and others, 2008).

Numerous studies within Voyageurs National Park have been conducted to serve as a baseline to compare to post-2000 Rule Curve samples. Hargis (1981) measured chlorophyll-*a* concentrations in the summer of 1979, Kepner and Stottlemyer (1988) collected water-quality data during 1985 and 1986, and Payne reported on water-quality samples collected in 1977–84 (Payne, 1991) and again in July 1999 (Payne, 2000). Kepner and Stottlemyer's (1988) total-phosphorus mass-balance model for Kabetogama Lake predicted a decrease in spring peak total-phosphorus concentrations and smaller chlorophyll concentrations because of the rule-curve change.

Purpose and Scope

The purpose of this report is to describe nutrient concentrations and loading, algal production, and their relation to changes in water levels in Kabetogama Lake during 2008–09. Streamflow, water levels, and the trophic state of Kabetogama Lake also are described.

Data were collected at 22 sites, which included 5 sites within Kabetogama Lake, 9 inflow or outflow sites, and 8 sites where event-based algal bloom samples were collected. Water-quality data were collected at the 5 lake sites and 8 of the 9 inflow or outflow sites. Sediment-quality data were collected at the five lake sites. Data collected during 2008–09 are described and compared to data collected for two previous USGS studies (Payne, 1991; Christensen and others, 2004).

Methods

The sampling design for this study of Kabetogama Lake consisted of several components. Some historical sites were chosen in order to make comparisons with current (2008–09) conditions, and some new sites were chosen where there were scarce or no data. Five lake sites and nine inflow or outflow sites were selected. Samples for some sites were collected only in May and August to correspond with historical sample collection dates; whereas samples for the remainder of the lake, inflow, and outflow sites generally were collected monthly during the open water season. In addition, samples were collected from algal blooms as they occurred, resulting in eight additional sites (table 1). Water- and sediment-quality samples were collected from the lake sites. Additional sediment was collected from four of these sites for analysis of phosphorus release.

Streamflow Measurements

Streamflow was measured in May 2008, May 2009, and August 2009 at selected inflow and outflow sites (table 1). Streamflow measurements were made according to methods described in Turnipseed and Sauer (2010) and Mueller and Wagner (2009). The Namakan River at the outlet of Lac La Croix, Ontario, Canada (site Q1; hereafter referred to as Namakan River, inset in fig. 1), Vermilion River near Crane Lake, Minn. (site Q3; hereafter referred to as Vermilion River), and Gold Portage outlet (site Q8) are USGS streamflow-gaging stations, and therefore streamflow data were available for these sites throughout the study period (USGS National Water Information System, *http://waterdata.usgs.gov/nwis*).

Water-Quality Data Collection and Laboratory Analyses

Five lake sampling sites were selected for analysis of water quality in Kabetogama Lake. Lake water samples were collected from the euphotic zone and near the sediment-water interface. Water-quality data also were evaluated at inflows and outflows. Water-quality data collection methods followed standard techniques (Wilde and Radtke, 1998). Historical sites were resampled where possible, and these sites are identified in table 1. Samples also were collected at times of the year when samples were historically collected (May and August). This ensured comparability of data while minimizing the spatial and seasonal differences in the dataset. In addition, to estimate nutrient loading and retention, sampling was conducted at the inflows to Namakan Reservoir—Namakan River (site Q2) and Vermilion River (site Q3)—and at inflows to Kabetogama Lake—Sullivan Bay Narrows, near Ash River, Minn. (site Q4; hereafter referred to as Sullivan Bay), Kabetogama Lake, mouth of Tom Cod Creek, near Ray, Minn. (site Q5; hereafter referred to as Tom Cod Creek), Daley Brook at Co. Rd. 129 near Kabetogama, Minn. (site Q6; hereafter referred to as Daley Brook), and Kabetogama Lake, east end, near Old Dutch Bay, Minn. (site Q7; hereafter referred to as the narrows near Old Dutch Bay)—and at the outflows—Gold Portage outlet (site Q8) and Namakan Lake at Squirrel Narrows, near Kettle Falls, Minn. (site Q9; hereafter referred to as Kettle Falls) (fig. 1).

Limnological characteristics of Kabetogama Lake were examined at three existing sites in Kabetogama Lake (sites K2, K3, K4; fig. 1) for comparison to historical values. Limnological characteristics included profiles of physical properties and

Table 1. Sampling sites in Voyaguers National Park, Minnesota, 2008–09.

[DD MM SS, degrees, minutes, and seconds; --, not applicable]

Site name (fig. 1)	Site number in figures	Historical site numbers[1]	U.S. Geological Survey identification number	Latitude (DD MM SS)	Longitude (DD MM SS)
Lake sites					
Kabetogama Lake near Gappas Landing near Ray, Minn.	K1	9	482642093011901	48 26 42	93 01 19
Kabetogama Lake at mouth of Meadwood Bay near Ray, Minn.	K2	11	482607092511701	48 26 07	92 51 17
Kabetogama Lake at Cemetary Island near Ray, Minn.[2]	K3	43	483012093035001	48 30 12	93 03 50
Kabetogama Lake near Grave Island near Ray, Minn.	K4	45	482731092574701	48 27 31	92 57 47
Kabetogama Lake at Lost Bay near Ray, Minn.	K5	--	482747092503001	48 27 47	92 50 30
Inflow or outflow sites					
Namakan River at outlet of Lac La Croix, Ontario, Canada[3]	Q1	--	05128000	48 21 14	92 13 01
Namakan Lake at mouth of Namakan River, Ontario, Canada	Q2	20	482709092264601	48 27 09	92 26 46
Vermilion River near Crane Lake, Minn.[3]	Q3	--	05129115	48 15 53	92 33 57
Kabetogama Lake, Sullivan Bay Narrows, near Ash River, Minn.[2]	Q4	--	482554092500301	48 25 53.8	92 50 02.89
Kabetogama Lake, mouth of Tom Cod Creek, near Ray, Minn.[1,2]	Q5	--	482846093073001	48 28 46.33	93 07 29.5
Daley Brook at Co. Rd. 129 near Kabetogama, Minn.	Q6	--	05129287	48 23 26.73	92 57 53.74
Kabetogama Lake, east end, near Old Dutch Bay, Minn.	Q7	--	482611092483801	48 26 11.26	92 48 37.95
Gold Portage outlet from Kabetogama Lake near Ray, Minn.[2,3]	Q8	--	05129290	48 31 28	93 04 29
Namakan Lake at Squirrel Narrows, near Kettle Falls, Minn.	Q9	--	482946092394301	48 29 45.90	92 39 42.56
Algal bloom sites					
Kabetogama Lake, Sullivan Bay NW, near Ash River, Minn.	A1	--	482542092493701	48 25 42	-92 49 37
Kabetogama Lake at Ash River Landing near Ash River, Minn.	A2	--	482604092511801	48 26 04	-92 51 18
Kabetogama Lake near Kabetogama Visitor Center near Kabetogama, Minn.	A3	--	482640093013901	48 26 40	-93 01 39
Kabetogama Lake at Ellsworth Rock Garden near Kabetogama, Minn.	A4	--	482947092584401	48 29 47	-92 58 44
Kabetogama Lake at Ek Lake Trail near Ash River, Minn.	A5	--	482804092494701	48 28 3.5	-92 49 47
Kabetogama Lake at Eks Bay near Ash River, Minn.	A6	--	482808092504901	48 28 8.1	-92 50 48.6
Kabetogama Lake west of Bald Rock Bay near Ray, Minn.	A7	--	483118093033601	48 31 18.1	-93 3 35.7
Kabetogama Lake at Bald Rock Bay near Ray, Minn.	A8	--	483146093032201	48 31 46.2	-93 3 22.4

[1] Christensen and others, 2004; Payne, 1991.

[2] Algal samples also collected at this site.

[3] U.S. Geological Survey streamflow-gaging station.

measurement of processes that could affect trophic state, such as phosphorus release from sediment. The sites were sampled in May and August by USGS and National Park Service personnel, and by National Park Service personnel in June, July, and September. Samples were collected near the surface and were analyzed to determine concentrations of alkalinity, nutrients, and chlorophyll. Vertical profiles of specific conductance, pH, water temperature, and dissolved oxygen concentration were measured at each lake site using methods for field measurements in still water presented in Wilde and Radtke (1998). Secchi-disk transparency (Wetzel, 2001) was measured at each vertical profile location to estimate photic depth.

Water samples were collected near the sediment-water interface at sites in Kabetogama Lake (lake sites K1–K5 in table 1) in May and August to determine constituent differences between sediment and the lake water and for comparison to water collected near the surface. These samples were collected using a Kemmerer (Lind, 1974) or Van Dorn (Van Dorn, 1956) sampler, and samples were analyzed to determine concentrations of alkalinity and nutrients (including the dissolved phases), as well as physical properties (specific conductance, pH, water temperature, and dissolved oxygen concentration). Water samples were processed in a field laboratory. Water samples were filtered and preserved as required. Alkalinity was determined by incremental titration at the field laboratory.

Water samples collected at the lake, inflow, and outflow sites were analyzed by the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, and the Natural Resources Research Institute (NRRI) Laboratory in Duluth, Minnesota. Method information, long-term method detection levels, and method detection limits for the two laboratories are given in table 2. Dissolved concentrations are those analyzed

Table 2. Method information for constituents analyzed in water samples from Voyaguers National Park, Minnesota, 2008–09.

[mg/L, milligrams per liter; --, not analyzed; µg/L, micrograms per liter]

Constituent	National Water Quality Laboratory		Natural Resources Research Institute	
	Method	Long-term method detection level[1]	Method	Method detection limit[2]
Dissolved nitrite nitrogen	Colorimetry (Fishman, 1993)	0.001 mg/L	--	--
Dissolved nitrite plus nitrate nitrogen	Colorimetry by cadmium reduction-diazolization (Fishman, 1993)	.020 mg/L	Cadmium reduction (SM-4500-NO_3^{-1}) (American Public Health Association, 1999)	0.004 mg/L
Dissolved ammonia, as nitrogen	Colorimetry, salicylate-hypochlorate (Fishman, 1993)	.01 mg/L	Phenol hypochlorite and (or) its salycilate modification (Patton and Kryskalla, 2003)	.004 mg/L
Total nitrogen	Alkaline persulfate digestion (Patton and Kryskalla, 2003)	.05 mg/L	Persulfate digestion (American Public Health Association, 1999)	.02 mg/L
Total phosphorus	EPA 365.1 (U.S. Environmental Protection Agency, 1993)	.004 mg/L	Persulfate digestion (American Public Health Association, 1999)	.004 mg/L
Dissolved phosphorus	--	--	SM 4500-PE (American Public Health Association, 1999)	.004 mg/L
Dissolved orthophosphorus	Colorimetry, phosphomolybdate (Fishman, 1993)	.004 mg/L	SM 4500-PE (American Public Health Association, 1999)	.004 mg/L
Chlorophyll-*a*	Fluorometric (Arar and Collins, 1997)	.1 µg/L	Spectrophotometric (Ameel and others, 1998)	1.0 µg/L

[1] The long-term method detection level is derived by determining the standard deviation of a minimum of 24 method detection limit spike sample measurements for an extended time (Childress and others, 1999).

[2] The minimum detection limit is the minimum concentration of a substance that can be measured and reported with a 99-percent confidence that the analyte concentration is greater than 0 (U.S. Environmental Protection Agency, 2002).

for a filtered sample (0.45-micron), whereas total concentrations were determined for a whole water sample.

Sediment Data Collection and Laboratory Analyses

Immediately following the collection of the water from the bottom of the lake, sediment samples were collected using a stainless steel Eckman dredge grab sampler at sites K1–K5 (table 1). Sediment samples helped to determine the potential flux of constituents to the lake water. Approximately the upper 4 cm of bottom sediment (where exchange across the sediment-water interface occurs) were collected and analyzed for solid-phase chemical composition. Special techniques were adapted specifically for this study.

Sediment samples were sent to Test America Laboratory, in Arvada, Colorado. These samples were analyzed for ammonia (method 350.1), total Kjeldahl nitrogen (method 351.2), nitrite plus nitrate (method 353.2), orthophosphorus (method 365.3), and total phosphorus (method 365.3) by using methods described in U.S. Environmental Protection Agency (1983).

Additional sediment samples were collected to determine phosphorus release from sediments. This sediment was collected with a Wildco Model 191-A12 stainless steel box corer (box size: 150 by 150 by 230 millimeters) fitted with an acrylic sleeve. The box corer was lowered to approximately 2–3 m above the surface of the sediment using a small crane fitted with a cable retrieve. The box corer was then allowed to free-fall into the sediment. The free fall of a coring device may cause disturbance of the upper layers of sediment, however, a free fall from this height allowed for full penetration into the soft sediments of the lake while maintaining 4–6 cm of overlying water. Cores were brought on to the deck of the boat and immediately subsampled using polycarbonate push cores. Four replicate push cores were collected simultaneously from each box core, sealed with polyvinyl chloride (PVC) caps, and stored on ice in an upright position for transport to the lakeside field laboratory.

The replicate push cores were collected using 4-cm diameter, 30-cm long thin-walled polycarbonate tubes. Each core was capped on the top and bottom with tight-fitting PVC caps. After collection, cores were transported to the lakeside field laboratory and incubated under ambient water temperature in an environmental chamber. Initial nutrient concentrations were measured from overlying water from one of the replicate cores after 1 hour in the environmental chamber. The push-core samplers allowed the core sample to be collected intact and undisturbed, preserving the sediment-water interface throughout the 24-hour incubation period. After incubation for 24 hours, overlying water was decanted from each core, filtered through 0.45-micron disc filters, and frozen until analysis for dissolved phosphorus and nitrate. Penn and others (2000) described release rates in anoxic cores that were constant for about the first 7 days, and therefore a 24-hour incubation period was deemed sufficient. Nutrient release rates for Kabetogama Lake locations were calculated as the difference between final and initial concentrations scaled to sediment surface area and duration of incubation. The rates from the deepest locations are likely to be the maximum rates (Penn and others, 2000).

Algal Sampling and Laboratory Analyses

Twenty lake-surface samples (10 per year) were collected in August or September and analyzed for phytoplankton (including cyanobacteria), cell density, and taxonomic identity. Of the 20 lake-surface samples, 6 were collected at randomly chosen lake or inflow sites (Q4, Q5, K3, and Q8), whereas 14 samples were collected where there was visible accumulation of algae (sites A1–A8). Each 500-milliliter (mL) sample was collected from the lake surface, chilled, and treated with 1-percent Lugol’s solution. Samples were analyzed by BSA Laboratories, Beachwood, Ohio, using the membrane filter technique (McNabb, 1960). This technique preserves cell structure, allowing good resolution so that samples can be examined and photographed at high magnifications.

Seven lake-surface samples were collected each year from areas with visible algae accumulation to determine total microcystin concentration. Samples were collected according to methods described in Graham and others (2008) and analyzed at the USGS Kansas Organic Geochemistry Research Laboratory in Lawrence, Kansas. Samples were analyzed by enzyme-linked immuno-sorbent assay (ELISA) with Abraxis ELISA kits. Cyanobacterial cells were lysed (whereby cell membranes are destroyed, releasing the toxins) by three sequential freeze-thaw cycles to determine total toxin concentrations. Abraxis ELISA does not differentiate between microcystin congeners (for example, between microcystin-LR and microcystin-RR) (Fischer and others, 2001; Graham and others, 2010).

Quality Assurance

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 and assess the quality of the sample data. The quality-assurance plan for this study followed USGS guidelines (Brunett and others, 1997). Field instruments were maintained according to manufacturers’ guidelines, calibration standards were properly stored, field measurements were recorded in the field, and all field sampling equipment was cleaned before use according to the National Field Manual guidelines (Wilde and Radtke, 1998). Calibration of portable field instruments was undertaken at the start of each day. Quality-control samples were collected and analyzed in order to document the variability associated with sample collection. Quality-control samples consisting of replicates, blanks, and spikes were analyzed.

Table 3. Field blank concentrations for water samples collected from Kabetogama Lake sites, Voyaguers National Park, Minnesota, 2008–09.

[All samples analyzed at Natural Resources Research Institute, Duluth, Minn.; mg/L, milligrams per liter; µg/L, micrograms per liter; <, less than; --, not analyzed]

Constituent	Date sampled (month/day/year)				
	7/15/2008	8/4/2008	5/11/2009	7/14/2009	8/13/2009
Dissolved nitrite plus nitrate nitrogen (mg/L)	0.010	<0.004	<0.004	0.022	0.012
Dissolved ammonia nitrogen (mg/L)	.005	<.004	.005	.034	.031
Total nitrogen (mg/L)	<.02	<.02	<.02	<.02	<.02
Total phosphorus (mg/L)	<.004	<.004	<.004	<.004	<.004
Dissolved phosphorus (mg/L)	<.004	<.004	.008	<.004	.006
Dissolved orthophosphorus (mg/L)	<.004	<.004	<.004	<.004	<.004
Chlorophyll-*a* (µg/L)	--	--	--	<1.0	--

Effectiveness of equipment cleaning and sample processing was assessed by laboratory analysis of five field blanks sent to NRRI Laboratory. Laboratory blank water was processed in the field with the same collection bottles, filtering devices, and methods as for native water samples. Concentrations for most blank samples collected in 2008 and 2009 were less than the NRRI method detection limit, with notable exceptions on July 14, 2009, and August 13, 2009 (table 3). Dissolved nitrite plus nitrate and dissolved ammonia concentrations were several times the method detection limit. Environmental samples collected from Meadwood Bay on July 14, 2009, and August 13, 2009, may have been affected by contamination and it is important to consider this possible contamination when evaluating the results of this study.

For this study, within-site variability associated with sample collection and analysis was determined through the collection of concurrent replicate samples from Kabetogama Lake at mouth of Meadwood Bay near Ray, Minn. (site K2; hereafter referred to as Meadwood Bay) on June 17, 2008, and June 16, 2009. Samples were collected following procedures described by Payne (1991) and Christensen and others (2004) for comparability to historical data. Results of the analysis of the replicate samples are shown in table 4. Relative percentage difference (*RPD*) was calculated with the equation:

$$RPD = \frac{sample\ 1 - sample\ 2}{\frac{sample\ 1 + sample\ 2}{2}} \text{ x } 100$$

where *sample* 1 and *sample* 2 are concentrations of the first and second replicate samples, respectively.

A typical quality-control objective for precision of replicate samples is a maximum relative percent difference of 20 percent (Taylor, 1987). The median relative percent difference was less than 20 percent for all constituents combined; however, paired samples analyzed for total-ammonia and chlorophyll-*a* concentrations had median relative percent differences of 47 and 38 percent, respectively. It is important to consider the difference in ammonia and chlorophyll-*a* concentrations between replicate samples when interpreting the data. Total-nitrogen and total-phosphorus concentrations had low relative percent differences (2.4 and 12 percent, respectively).

Split replicate samples collected on May 11, 2009, were sent to NWQL and NRRI for laboratory comparison. There were no differences (all concentrations were less than the long-term method detection levels) between laboratories for results of ammonia, nitrite plus nitrate, and orthophosphorus. Total nitrogen and total phosphorus differences were 20 percent and 12 percent, respectively. Results from the two water-quality laboratories were combined, unless the analytical methods and performance were different. Chlorophyll concentrations, for example, were not combined because of the differences in analytical methods (table 2). The “E” or estimated

Table 4. Median relative percentage differences for nutrient and chlorophyll-*a* concentrations in replicate samples collected at Kabetogama Lake at the mouth of Meadwood Bay near Ray, Minn., Voyaguers National Park, Minnesota, June 17, 2008, and June 16, 2009.

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

Constituent	Median relative percentage difference	Pairs of replicate samples
Dissolved nitrite plus nitrate nitrogen (mg/L)	3.0	2
Dissolved ammonia nitrogen (mg/L)	47	2
Total nitrogen (mg/L)	2.4	2
Total phosphorus (mg/L)	12	2
Dissolved phosphorus (mg/L)	0	2
Dissolved orthophosphorus (mg/L)	0	2
Chlorophyll-*a* (µg/L)	38	2

remark code in this report is used to signify measured concentrations that fall below twice the long-term method detection level (for NWQL) or the method detection limit (for NRRI).

Data Analysis

Kabetogama Lake may have responded differently to the 2000 Rule Curves compared to other Park lakes because it is more susceptible to internal phosphorus loading. The estimation of internal and external loads may help explain Kabetogama Lake's response to the new rule curves in much clearer terms. Therefore, nutrient loading to Kabetogama Lake was estimated in order to assess the relative importance of external sources and to investigate the potential for internal loading. The external sources are assumed to be primarily the Namakan and Vermilion Rivers (through the narrows between Namakan and Kabetogama Lake) and other surface-water inflows (Tom Cod Creek, Daley Brook, and Ash River and the developed southern shore). The primary internal source is assumed to be phosphorus release from bottom sediment. The internal and external sources of nutrients were estimated separately and then compared to indicate their importance to the overall nutrient availability in the lake. External instantaneous phosphorus loads were estimated at inflows, such as the Namakan River (site Q1) and Vermilion River (site Q3), and at outflows, such as Gold Portage outlet (site Q8) and Kettle Falls (site Q9). Nutrient loads were calculated only for the dates in May (high flow) and August (low flow) when sufficient streamflow data were collected. Nutrient loads were calculated by multiplying instantaneous concentrations (in milligrams per liter) by instantaneous streamflow (in cubic meters per second) and a conversion factor (86.4) to obtain loading in kilograms per day (kg/d).

Reservoir water levels (controlled at Squirrel and Kettle Falls, fig. 1) were compared to those specified in the 2000 Rule Curves. Because these water levels have not adhered strictly to the 2000 Rule Curves, statistical analyses (rank sum tests, Helsel and Hirsch, 1992) were performed to determine if levels were significantly different than pre-2000 levels. Nutrient concentrations, before and after the rule-curve change, also were compared in this manner. Algal production (chlorophyll-*a*) and nutrient enrichment (total phosphorus) were assessed by comparing concentrations and trophic state indicators (Carlson, 1977) to pre-2000 conditions.

Nutrient Concentrations and Loading, Algal Production, and Their Relation to Changes in Water Levels

The 2000 Rule Curves were expected to restore a more natural water regime that would affect water levels, water quality, and trophic status in lakes in Voyageurs National Park. Water- and sediment-quality data were collected during 2008–09 to better understand nutrient concentrations and loading, algal production, and their relation to changes in water levels in Kabetogama Lake. Nutrient concentrations and algal production (chlorophyll-*a* concentrations) were analyzed in water samples collected from Kabetogama Lake sites and inflow and outflow sites. Nutrient concentrations were analyzed in bottom-sediment samples collected from the Kabetogama Lake sites. Nutrient loading was estimated to assess the contribution of nutrients from external (inflows) and internal sources (lake-bottom sediments). Algal community composition and microcystin concentrations were analyzed in 20 lake-surface samples to determine the extent to which algal blooms in Kabetogama Lake are producing microcystin. Nutrient and algal data were used to determine trophic state and were evaluated in relation to changes in Kabetogama Lake water levels following changes to dam operation starting in 2000.

Streamflow and Lake Water Levels

Water generally flows through Voyageurs National Park from the southeast to the northwest along the United States and Canadian border. Water flows into Kabetogama Lake from Ash River, Tom Cod Creek, and Daley Brook to the south, and from a few other minor tributaries. However, the largest potential source of water to Kabetogama Lake is from Namakan Lake to the east. Water flows from the Namakan River and the Vermilion River into Namakan Lake and these two sources provide about 80 percent of the inflow to Namakan Reservoir (Christensen and others, 2004). Although the highest flow into Namakan Reservoir was from Namakan River (as measured at site Q1; table 5) and Vermilion River (site Q3), the hydrologic system is complex and it is difficult to determine how much of the flow from these two sources is transported into Kabetogama Lake through the narrows near Old Dutch Bay (site Q7; fig. 1).

During 2008–09, water flowed in an unpredictable pattern in both directions between Kabetogama Lake and Namakan Lake. For the streamflow measurement made in May 2008, water flowed west from Namakan Lake to Kabetogama Lake. During May and August 2009, water flowed east, from Kabetogama Lake to Namakan Lake (table 5). The measurement made in August 2009 had multidirectional flow: for some sections and depths, the water flow was to the east, and for others it was to the west. The variability in flow direction complicates the computation of nutrient loads. Based on the volume of water flowing through the narrows near Old Dutch Bay in 2008 and 2009, the narrows is the largest potential input of nutrients (from the upstream Namakan Lake, Namakan River, and Vermilion River) to Kabetogama Lake other than internal loading. However, Kabetogama Lake also may be a substantial source of nutrients to Namakan Lake (as seen from flow at site Q7 in May 2009 and August 2009).

Water flows out of 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 as measured at site Q9 (table 5).

Lake levels have been controlled by dams on Namakan Reservoir since the early 1900s (Kallemeyn and others, 2003). Because some of the lakes of the Namakan Reservoir system are international waters, private sector dam operators have had to maintain lake levels with a series of IJC rule curves beginning in 1949 (Kallemeyn and others, 2003). In order to better regulate water levels, the IJC modified the rule curves in 1970. The fluctuations under the 1970 Rule Curves were greater than those that are currently allowed under the 2000 Rule Curves. New rule curves were implemented on January 6, 2000, for regulating water levels on Rainy Lake and Namakan Reservoir after multiple detrimental ecosystem effects were attributed to the 1970 Rule Curves and formally presented to the IJC (Kallemeyn and others, 2003). The requisite maximum and minimum water levels as defined by the IJC for Namakan Reservoir are shown in figure 2. The actual water levels for Namakan Reservoir at Gold Portage, on the west end of Kabetogama Lake, and at Squirrel and Kettle Falls on the northern side of Namakan Lake (fig. 1) during the study period, 2008–09, also are shown.

During 2008, the maximum rule-curve water levels were exceeded from May 12 through July 7, 2008, by as much as 0.329 m (June 15, 2008; fig. 2). Minor exceedances also occurred on a few days in fall 2008 and spring 2009

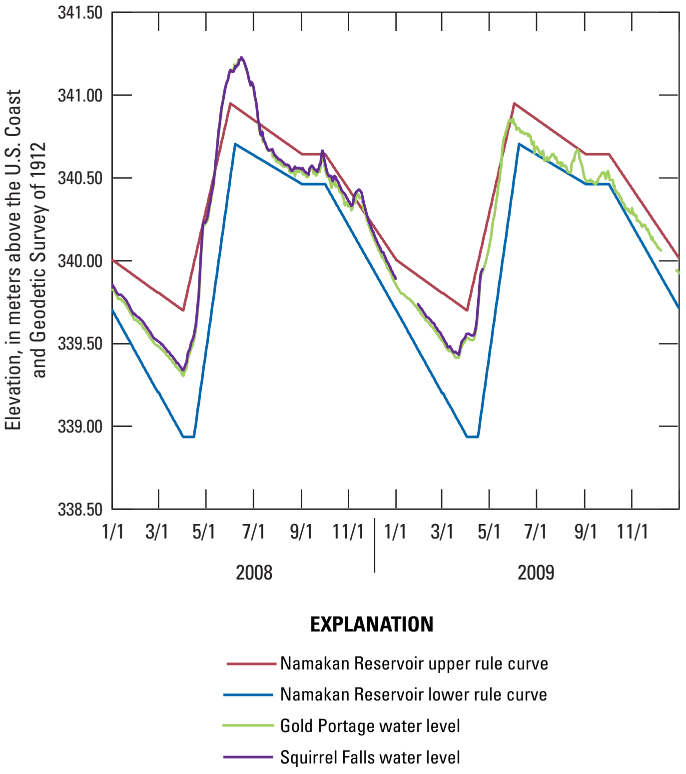

Figure 2. International Joint Commission 2000 Rule Curves and lake levels for Namakan Reservoir, Voyageurs National Park, Minnesota, 2008–09.

Table 5. Instantaneous streamflow measurements or streamflow from gaging-station records for sites affecting Voyageurs National Park, Minnesota, 2008–09.

[Streamflow is reported in cubic meters per second. --, not measured]

Site name	Site number (fig. 1)	U.S. Geological Survey identification number	May 2008	May 2009	August 2009
Namakan River at outlet of Lac La Croix, Ontario, Canada[1]	Q1	05128000	405	376	106
Namakan Lake at Mouth of Namakan River, Ontario, Canada	Q2	482709092264601	--	--	--
Vermilion River near Crane Lake, Minn.[1]	Q3	05129115	90.6	56.6	11.2
Kabetogama Lake, Sullivan Bay Narrows, near Ash River, Minn.[2]	Q4	482554092500301	11	-2.68	5.24
Kabetogama Lake, Mouth of Tom Cod Creek, near Ray, Minn.	Q5	482846093073001	.36	.385	.00857
Daley Brook at Co. Rd. 129 near Kabetogama, Minn.	Q6	05129287	.436	.297	.0305
Kabetogama Lake, east end, near Old Dutch Bay, Minn.[3]	Q7	482611092483801	30.3	-86.0	-70.2
Gold Portage outlet from Kabetogama Lake near Ray, Minn.[1]	Q8	05129290	15.6	12.0	14.6
Namakan Lake at Squirrel Narrows, near Kettle Falls, Minn.	Q9	482946092394301	368	374	--

[1] U.S. Geological Survey streamflow-gaging station.

[2] Negative streamflow indicates water flowing out of Kabetogama towards Ash River.

[3] Negative streamflow indicates water flowing out of Kabetogama Lake towards Namakan Lake.

Table 6. Median values of selected physical properties and alkalinity concentrations in water samples, Voyageurs National Park, Minnesota, 2008–09.

[Measurements shown here are those recorded near the surface; ºC, degrees Celsius; m, meters; µS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; HCO_3, bicarbonate; number of samples in parenthesis]

Site name	Site number (fig. 1)	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)
Lake sites								
Kabetogama Lake near Gappas Landing near Ray, Minn.	K1	18.3(5)	2.2(1)	87(5)	8.0(5)	9.2(5)	35(5)	43(4)
Kabetogama Lake at mouth of Meadwood Bay near Ray, Minn.	K2	18.8(7)	1.9(4)	86(7)	7.5(7)	9.4(7)	34(5)	53(3)
Kabetogama Lake at Cemetary Island near Ray, Minn.	K3	18.3(7)	2.5(4)	87(7)	7.7(7)	9.0(7)	36(6)	44(4)
Kabetogama Lake near Grave Island near Ray, Minn.	K4	16.8(7)	2.4(4)	90(7)	7.4(7)	9.9(7)	37(6)	46(4)
Kabetogama Lake at Lost Bay near Ray, Minn.	K5	18.8(5)	2.0(1)	87(5)	8.1(5)	9.4(5)	35(4)	43(3)
Inflow or outflow sites								
Namakan Lake at mouth of Namakan River, Ontario, Canada	Q2	18.5(5)	2.1(2)	43(5)	7.8(5)	9.4(5)	12(5)	9(4)
Vermilion River near Crane Lake, Minn.	Q3	18.1(6)	1.5(3)	100(5)	7.1(6)	9.6(5)	26(6)	26(3)
Kabetogama Lake, Sullivan Bay Narrows, near Ash River, Minn.	Q4	18.9(7)	1.4(4)	150(7)	8.0(7)	9.3(7)	70(6)	84(4)
Kabetogama Lake, mouth of Tom Cod Creek, near Ray, Minn.	Q5	14.4(5)	1.3(1)	150(5)	7.4(5)	9.6(5)	74(5)	84(4)
Daley Brook at Co. Rd. 129 near Kabetogama, Minn.	Q6	13.4(4)	1.3(1)	210(4)	7.5(4)	7.6(4)	85(3)	154(2)
Kabetogama Lake, east end, near Old Dutch Bay, Minn.	Q7	14.9(4)	2.2(3)	65(3)	7.4(4)	9.5(4)	23(3)	25(2)
Gold Portage outlet from Kabetogama Lake near Ray, Minn.	Q8	15.9(8)	2.4(4)	86(8)	7.8(8)	9.7(8)	35(6)	42(2)
Namakan Lake at Squirrel Narrows, near Kettle Falls, Minn.	Q9	15.0(6)	3.1(4)	49(7)	7.2(7)	8.9(6)	15(5)	19(3)

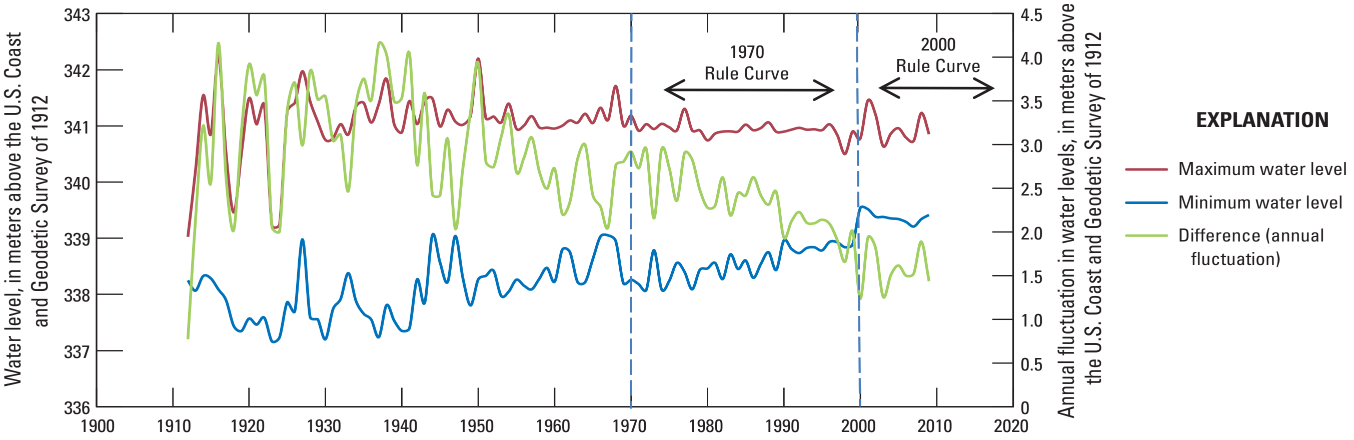

Figure 3. Minimum and maximum annual water levels and fluctuations, Kabetogama Lake, Voyageurs National Park, Minnesota, 1912–2009.

(October 8–23, 2008, and May 17–27, 2009; fig. 2). Water levels were not lower than the lower rule curve during the study period.

In order to put 2008–09 water levels into historical context, Kabetogama Lake levels for the period of record were obtained from Matt DeWolfe, Lake of the Woods Secretariat (written commun, April 20, 2010). The annual maximum and minimum lake levels by year and the annual difference between the maximum and minimum are shown in figure 3. The annual fluctuation in water levels began to change in the mid-1980s when dam operators started to target the middle of the rule curve, rather than the extremes (Meeker and Harris, 2009). Wilcox rank-sum tests (Helsel and Hirsch, 1992) were performed on the two datasets (1970–99 and 2000–09) to test the significance (*p*-value of 0.05) of the differences in water-level fluctuation shown in figure 3. Pre-rule curve (1970–99) water-level fluctuations were significantly greater (*p*-value <0.001) than water-level fluctuations during 2000–2009. The difference between the annual water-level fluctuations between the two time periods appears to be the result of a substantial increase in the minimum water level.

Physical Properties of Water Samples

Physical properties of water temperature, Secchi-disk transparency, specific conductance, pH, dissolved oxygen concentrations, and alkalinity concentrations were measured at the Kabetogama Lake sites (K1–K5), inflow sites (Q2–Q6), and outflow sites (Q7–Q8). The median values of selected physical properties and alkalinity concentrations for Kabetogama Lake, inflow, and outflow sites are shown in table 6. The median values in table 6 are for surface readings only.

Secchi-disk transparency varied among sites during 2008–09. Secchi-disk transparencies for inflows generally were shallower than transparencies for other lake sites and outflow sites (table 6), indicating that the water entering Kabetogama is less transparent than the receiving water. Specific conductance and alkalinity values generally were largest for inflow sources on the south end of Kabetogama Lake—Sullivan Bay (site Q4), Tom Cod Creek (site Q5), and Daley Brook (site Q6). Larger specific conductance and alkalinity values may be the result of clay deposits, rich in soluble minerals, found to the south and west of Kabetogama Lake, which were left behind by glacial Lake Agassiz (Kallemeyn and others, 2003).

The water in between Kabetogama and Namakan Lakes (at site Q7 at the narrows near Old Dutch Bay; fig. 1) indicates a mixture of Kabetogama and Namakan water. The specific conductance and alkalinity values at site Q7 were 65 microsiemens per centimeter at 25°C (µS/cm) and 23 milligrams per liter (mg/L), respectively; whereas median specific conductance values in Kabetogama Lake were larger, ranging from 86–90 µS/cm and smaller at the two Namakan Lake sites (sites Q2 and Q9), with median values of 43 and 49 µS/cm. Alkalinity concentrations were similar, with the median concentration at site Q7 in between concentrations for Kabetogama and Namakan Lakes (table 6).

Lake profiles of water temperature, specific conductance, pH, and dissolved oxygen concentration were collected at Kabetogama Lake sites (K1–K5) during sampling conducted in 2008–09. Lake profile data are available online at *http://waterdata.usgs.gov/mn/nwis/qw*. In general, values of water temperature, specific conductance, pH, and dissolved oxygen concentrations either remained the same or decreased gradually with depth.

Temperature and dissolved oxygen profiles are important because they indicate vertical mixing of the lake. The profiles generally did not show evidence of a strong thermal stratification, but anoxic conditions (dissolved oxygen concentrations less than 5 mg/L) did occur at several sites in August 2008 and 2009 (fig. 4). This is important because anoxic conditions facilitate nutrient release. Thermal stratification inhibits mixing, and the oxygen in the bottom layer gets depleted,

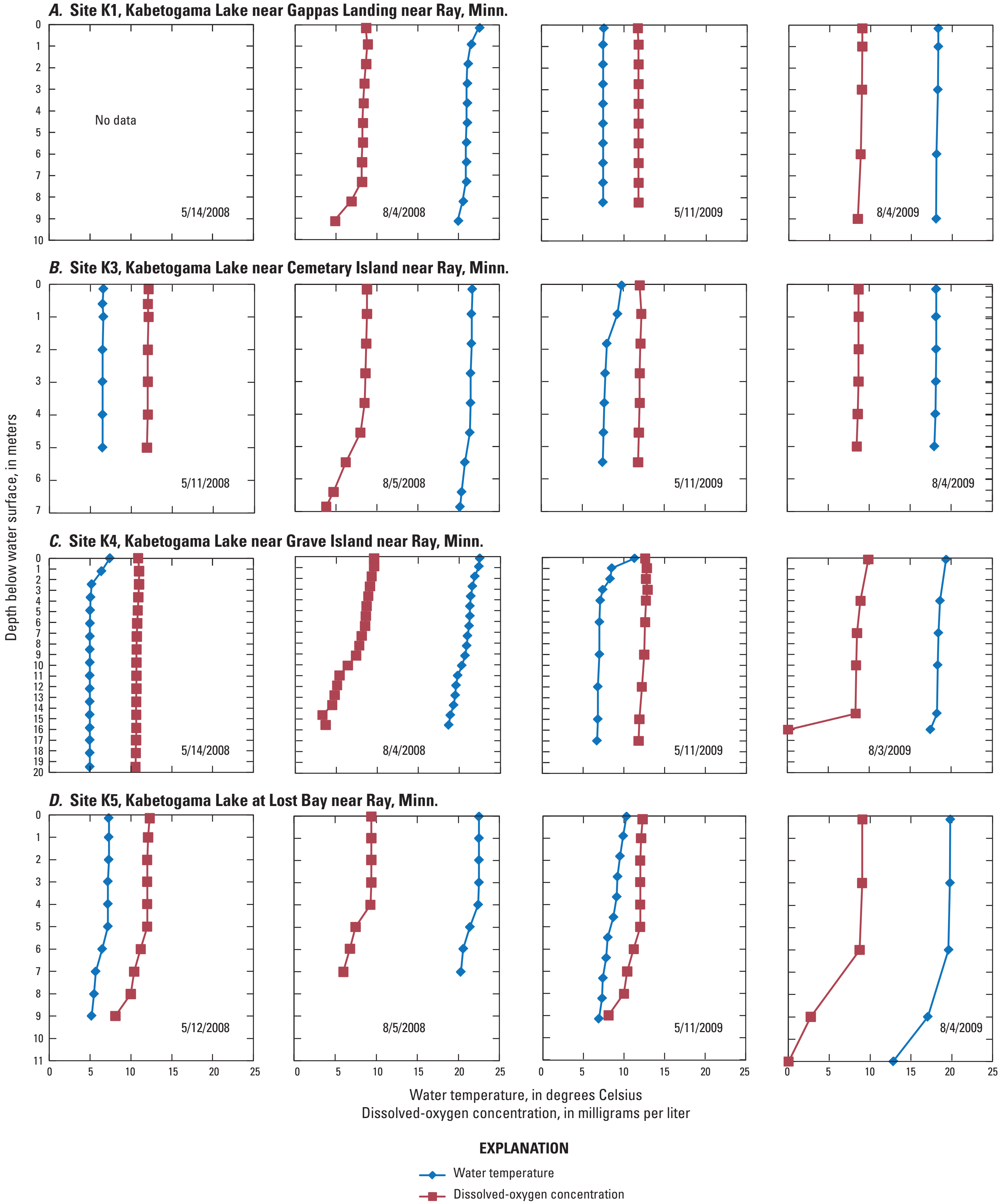

Figure 4. Water temperature and dissolved oxygen profiles for four sites in Kabetogama Lake, Voyageurs National Park, Minnesota, 2008–09: *A*, near Gappas Landing near Ray, Minn.; *B*, at Cemetary Island near Ray, Minn.; *C*, near Grave Island near Ray, Minn., and; *D*, at Lost Bay near Ray, Minn.

as materials in the bottom sediments decay. This decay also releases nutrients into the water.

Nutrient Concentrations in Water Samples

Nitrogen and phosphorus are essential for the growth and reproduction of plants. Large inputs of nitrogen and phosphorus into the aquatic environment can cause excessive algal growth. These large algal blooms may include toxic cyanobacteria. The death of large algal blooms may deplete dissolved oxygen concentrations, stress aquatic organisms, and reduce the aesthetic value of the water. Therefore, prevention or mitigation of excessive nutrient concentrations into surface water is desirable, especially where sensitive aquatic organisms may be present (Christensen and others, 2004).

Nutrient concentrations were analyzed in samples collected from the 5 lakes sites (K1–K5) and 8 inflow or outflow sites (Q2–Q9) (table 7). Median dissolved ammonia concentrations generally were 0.02 mg/L or less, with the exceptions of bottom-water samples collected near Grave Island (site K4) and at Lost Bay (site K5). Median dissolved nitrite plus nitrate concentrations were largest in samples from Kettle Falls (site Q9) and bottom-water samples at Meadwood Bay (site K2). Dissolved nitrite concentrations generally were small, ranging from 0.001 to 0.002 mg/L. Dissolved nitrite only was analyzed in one sample per site and nitrite results are not included in this report, but are available online at *http://waterdata.usgs.gov/mn/nwis/qw*. Median total-nitrogen concentrations were uniform throughout Kabetogama Lake (from 0.43 to 0.49 mg/L), except for bottom-water samples at Lost Bay (site K5), which had a median concentration of 0.55 mg/L. Inflow concentrations of total nitrogen were larger than median lake concentrations at Vermilion River (site Q3), Sullivan Bay (site Q4), Tom Cod Creek (site Q5), and Daley Brook (site Q6)—all sources on the southern side of Voyageurs National Park.

Median dissolved-orthophosphorus concentrations for all lake sites were less than 0.006 mg/L with the exception of bottom samples at Lost Bay (site K5), which had a median concentration of 0.013 mg/L. Some of the inflows had slightly larger dissolved-phosphorus concentrations than the lake sites. For example, Tom Cod Creek (site Q5) samples had a median concentration of 0.014 mg/L. Total-phosphorus concentrations had a similar pattern with the largest median concentration of 0.046 mg/L in the bottom-water samples from Lost Bay (site K5), followed by a median concentration of 0.044 mg/L at Tom Cod Creek (site Q5).

Total-phosphorus concentrations for near-surface (top) samples from Kabetogama Lake are shown in figure 5. Only sites that were sampled monthly during the open water season are shown. During 2008 and 2009, total-phosphorus concentrations generally increased from June through September. An exception to the general increase was the July 14, 2009, samples from Kabetogama Lake near Grave Island near Ray, Minn. (site K4; hereafter referred to as Grave Island), which

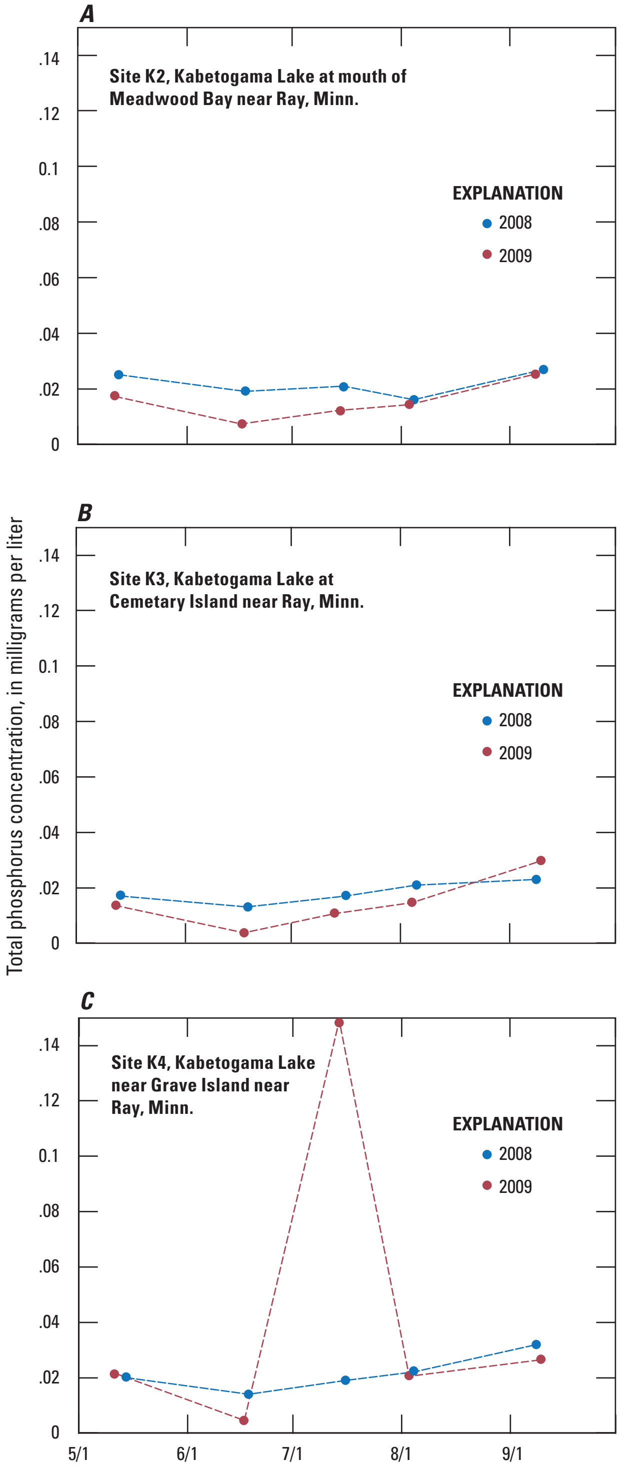

Figure 5. Total-phosphorus concentrations for near-surface water samples, Voyageurs National Park, Minnesota, 2008–09, for selected Kabetogama Lake sites: *A*, at mouth of Meadwood Bay near Ray, Minn., *B*, at Cemetary Island near Ray, Minn., and *C*, near Grave Island near Ray, Minn.

Table 7. Median concentrations for selected nutrients in water samples, Voyageurs National Park, Minnesota, 2008–09.

[All concentrations are in milligrams per liter. Number of samples in parenthesis; E, estimated; <, less than]

Site name	Site number in figures	Location of sample collection[1]	Dissolved ammonia	Dissolved nitrite plus nitrate	Total nitrogen	Dissolved ortho-phosphorus	Dissolved phosphorus	Total phosphorus
Lake sites								
Kabetogama Lake near Gappas Landing near Ray, Minn.	K1	top	0.02(4)	0.005(5)	0.43(5)	E0.001(5)	0.006(4)	0.019(5)
		bottom	.02(3)	.002(4)	.44(4)	E.001(4)	.005(3)	.019(4)
Kabetogama Lake at mouth of Meadwood Bay near Ray, Minn.	K2	top	.01(10)	.006(10)	.49(10)	.002(10)	.005(9)	.018(10)
		bottom	.02(2)	.043(3)	.45(3)	.002(3)	.006(2)	.018(3)
Kabetogama Lake at Cemetary Island near Ray, Minn.	K3	top	.01(8)	.003(10)	.44(10)	E.001(10)	.006(9)	.016(10)
		bottom	.01(3)	<.0004(4)	.45(4)	E.001(4)	.006(3)	.017(4)
Kabetogama Lake near Grave Island near Ray, Minn.	K4	top	.01(8)	.003(10)	.48(10)	.002(10)	.005(9)	.022(10)
		bottom	.03(4)	.024(4)	.48(4)	.006(3)	.006(3)	.017(4)
Kabetogama Lake at Lost Bay near Ray, Minn.	K5	top	.01(4)	.003(5)	.46(5)	.002(5)	.006(4)	.020(5)
		bottom	.04(5)	.007(5)	.55(5)	.013(5)	.026(4)	.046(5)
Inflow or outflow sites								
Namakan River at mouth of Namakan River, Ontario, Canada	Q2		0.02(4)	0.03(5)	0.38(5)	0.003(5)	0.005(4)	0.011(5)
Vermilion River near Crane Lake, Minn.	Q3		.02(10)	.012(10)	.57(10)	.004(10)	.01(9)	.018(10)
Kabetogama Lake, Sullivan Bay Narrows, near Ash River, Minn.	Q4		.02(10)	.004(10)	.70(10)	.003(10)	.008(9)	.026(10)
Kabetogama Lake, mouth of Tom Cod Creek, near Ray, Minn.	Q5		.02(5)	.011(5)	1.15(5)	.005(5)	.014(4)	.044(5)
Daley Brook at Co. Rd. 129 near Kabetogama, Minn.	Q6		.02(4)	.013(4)	.66(4)	.006(4)	.010(3)	.021(4)
Kabetogama Lake, east end, near Old Dutch Bay, Minn.	Q7		.01(4)	.012(5)	.47(5)	.002(5)	.008(4)	.021(5)
Gold Portage outlet from Kabetogama Lake near Ray, Minn.	Q8		.01(9)	.003(10)	.45(10)	.003(10)	.005(9)	.018(10)
Namakan Lake at Squirrel Narrows, near Kettle Falls, Minn.	Q9		.02(9)	.062(10)	.43(10)	.006(10)	.004(9)	.011(10)

[1] For lake samples, top samples were collected within 1 meter of the surface, and bottom samples were collected within 1 meter of the sediment-water interface.

Table 8. Concentrations of nutrients in bottom-sediment samples from Kabetogama Lake, Voyageurs National Park, Minnesota, 2008–09.

[All units in milligrams per kilogram. --, no data]

Date (month/day/year)	Ammonia	Total Kjeldahl nitrogen	Nitrite plus nitrate	Orthophosphorus	Total phosphorus
Kabetogama Lake near Gappas Landing near Ray, Minn. (site K1, fig. 1, 482642093011901)					
5/14/2008	1.8	5,800	--	0.9	760
8/4/2008	9.0	7,100	4	1.2	90
5/13/2009	3.9	2,300	3	1.0	550
Kabetogama Lake at mouth of Meadwood Bay near Ray, Minn. (site K2, fig. 1, 482607092511701)					
5/12/2008	0.2	2.4	--	0.2	120
Kabetogama Lake at Cemetary Island near Ray, Minn. (site K3, fig. 1, 483012093035001)					
5/13/2008	3.0	6,100	6	1.6	890
8/5/2008	7.2	11,000	7	1.8	820
5/11/2009	2.1	6,800	1	1.2	700
8/5/2009	11	760	12	2	760
Kabetogama Lake near Grave Island near Ray, Minn. (site K4, fig. 1, 482731092574701)					
5/14/2008	3.2	5,900	14	2.1	1,000
8/4/2008	12	1,000	8	1.9	190
5/11/2009	5.4	12,000	13	1.8	760
8/5/2009	53	7,100	6	1.7	740
Kabetogama Lake at Lost Bay near Ray, Minn. (site K5, fig. 1, 482747092503001)					
5/12/2008	1.6	11,000	2	1.3	820
8/5/2008	5.7	10,000	10	2.6	920
5/11/2009	7.6	6,300	33	2.5	780

had a total-phosphorus concentration of 0.149 mg/L. Because this concentration was substantially larger than previous total-phosphorus concentrations for this site (see, for example, Christensen and others, 2004), sample contamination was suspected. However, the field blank concentration for July 14, 2009, was less than 0.004 mg/L for total phosphorus. Therefore, biological contamination from zooplankton or algal colonies may have occurred, having a substantial effect on the total-phosphorus concentration.

Increasing mean total-phosphorus concentrations in the summer may be an indicator of internal load in polymictic lakes, even in upper water layers (Nurnberg, 2009). However, this study was limited in length and scope. A study of longer duration and larger extent would be needed to assess nutrient sources that accurately reflect the hydrologic variability of several years and the extent of anoxia in bottom waters throughout the lake.

Nutrient Loading

Nutrient loading was estimated to assess the contribution of nutrients from external (inflows) and internal (lake-bottom sediment) sources. Instantaneous phosphorus loads were estimated, and lake-bottom sediments were analyzed to determine internal loading.

Instantaneous Phosphorus Load Estimates

One indicator of internal load in stratified and polymictic lakes is negative retention—more total phosphorus leaving than entering the lake (Nurnberg, 2009). Instantaneous phosphorus loads were estimated for selected sites (Q2–Q9) during May 2008, May 2009, and August 2009 (fig. 6). Because of the complexity of the Namakan Reservoir system, the net phosphorus load is difficult to assess. Water flow changed direction in Sullivan Bay (site Q4) and Old Dutch Bay (site Q7; fig. 6), indicating that a substantial amount of mixing is occurring between water bodies. Considering the Namakan Reservoir system as a whole, the retention in May 2008 was negative (fig. 6*A*), whereas the retention in May and August 2009 was positive (fig. 6*B* and 6*C*). Considering Kabetogama Lake only, positive retention occurred in May 2008, whereas negative retention occurred in May and August 2009. The negative retention that occurred in 2009 is a possible indicator of internal loading to Kabetogama Lake; however, definitive

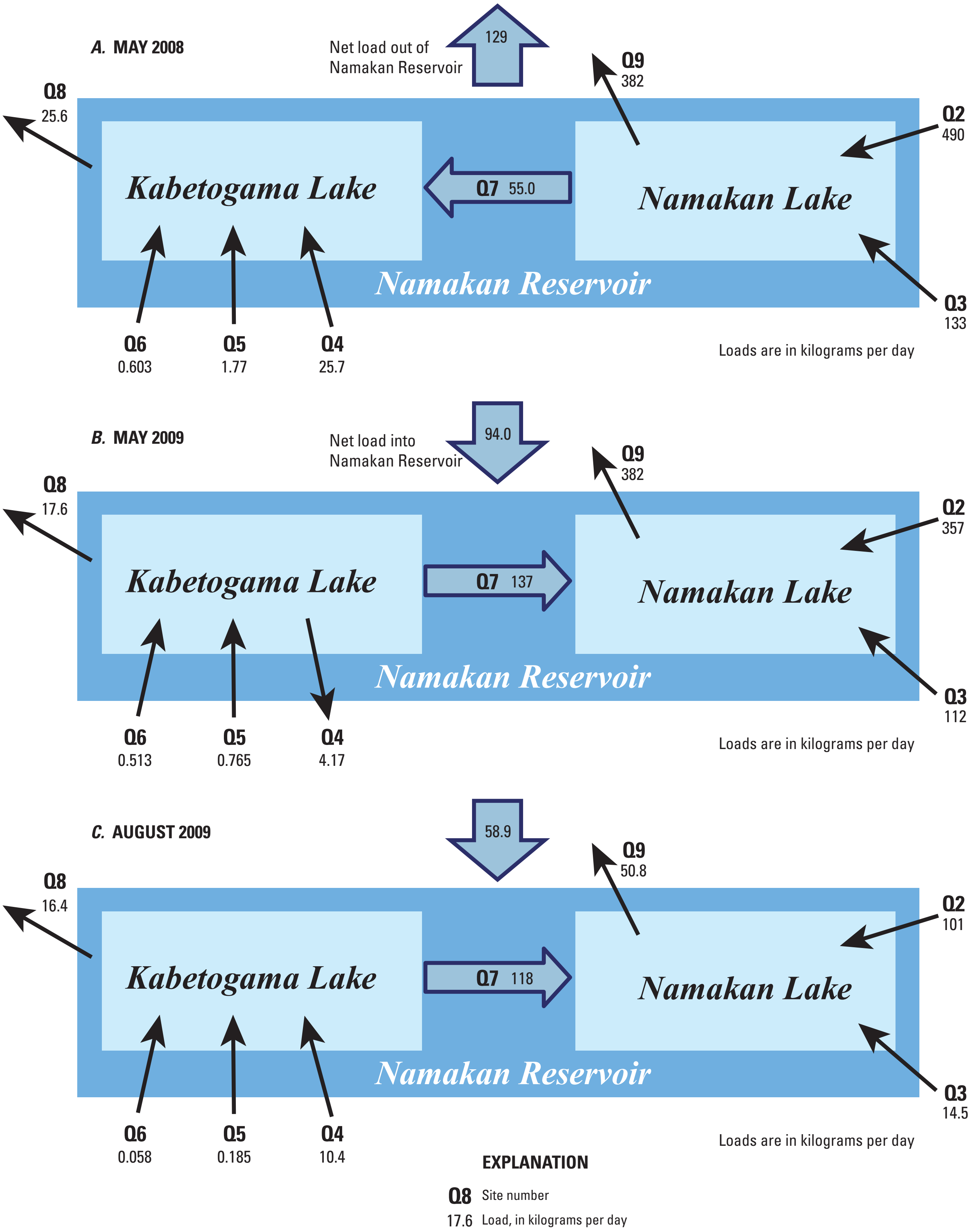

Figure 6. Schematic showing phosphorus loads at selected sites affecting 2 of the 5 lakes in the Namakan Reservoir, Voyageurs National Park, Minnesota, 2008–09.

conclusions about the effect of internal loading cannot be made based on the sparse sampling locations and times.

Despite larger concentrations of total phosphorus entering Kabetogama Lake from sites to the south (for example, Tom Cod Creek, site Q5; table 7), these sites have a minimal effect on the Namakan Reservoir system (fig. 6). However, the effect on Kabetogama Lake can be substantial. During May 2008, sources to the south contributed 34 percent of the phosphorus load to Kabetogama Lake (sites Q4, Q5, and Q6; fig. 6). During high- and low-flow conditions in 2009, the sources to the south of Kabetogama contributed 100 percent of the external total-phosphorus load to Kabetogama Lake. This analysis of phosphorus loading also illustrates the importance of quantifying the phosphorus being transported between Kabetogama and Namakan Lakes (site Q7, fig. 6). If the conditions during measurements made in 2008 and 2009 are typical, then it is likely that the eutrophic Kabetogama Lake will have an effect on Namakan Lake.

The seasonal difference in total phosphorus loads appears to be substantial, with reduced phosphorus loads for most sites during August (fig. 6*C*) compared to May (figs. 6*A*, *B*). The substantially smaller total phosphorus loads in August than in May, despite larger in-lake phosphorus concentrations occurring throughout the summer, may be an indication of the effect of internal load.

Characteristics of Lake-Bottom Sediments and Internal Loading

The difficulty in distinguishing between internal and external phosphorus sources makes assessing the effects of internal phosphorus loading challenging, particularly in polymictic lakes (Nurnberg, 2009). This is because of the vertically mixed water column. Because of its shallow depth, Kabetogama Lake is more likely to be eutrophic than other lakes in Voyageurs National Park. A shallow depth means less water volume, dilution, and assimilative capacity from external loads (Vollenweider, 1975). When compared to the other large lakes in Voyageurs National Park, the shallow depth of Kabetogama Lake also means that wind and boating activities may circulate water near the bottom sediment and may return nutrients from the sediments to the water column during the warm summer months; therefore, examining the concentrations of nutrients in bottom sediment of Kabetogama Lake was important.

Bottom sediment was sampled at five locations in Kabetogama Lake (table 8). Samples were collected in May and August to coincide with water-quality and historical sampling dates. Sampling occurred at lake sites with historical samples (sites K1, K2, K3, and K4) and at Lost Bay (site K5). Of the five Kabetogama Lake sites, Grave Island (site K4, fig. 1) generally had the largest concentrations of ammonia, total Kjeldahl nitrogen, and total phosphorus in sediment; whereas Lost Bay (site K5) generally had the largest concentrations of nitrite plus nitrate and orthophosphorus in sediment (table 8). These data indicate that the Grave Island and Lost Bay areas may be important sites for internal loading. These two sites are the two deepest lake sites sampled with depths of about 15 and 12 m, respectively. Deeper areas of the lake may have little or no oxygen during summer stratification.

Large nutrient concentrations in bottom sediment and sediment-water interface samples could indicate a release of nutrients from bottom sediment (Mueller and Ruddy, 1993). Release of phosphorus from bottom sediment was estimated by assessing phosphorus released from incubating sediment core samples from sites K1, K3, K4, and K5, collected in 2008 and 2009 (fig. 8). Insufficient sediment was collected from site K2 and it was excluded from the analysis of phosphorus release. The phosphorus release rates varied widely and were largest at Cemetary Island (site K3) and Grave Island (site K4). Part of the difference may be because of collection dates—2008 and 2009 samples were collected in August, with the exception of the sample collected in Lost Bay, which was collected in May. Nonetheless, the phosphorus release

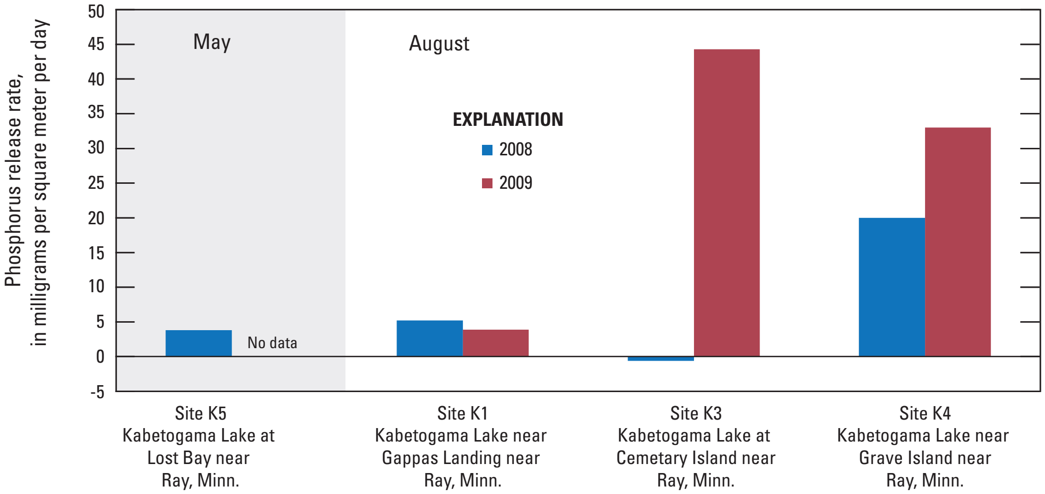

Figure 7. Phosphorus release for selected sites in Kabetogama Lake, Voyageurs National Park, Minnesota, 2008–09.

measurements clearly indicate a potential for phosphorus release from bottom sediments.

Internal phosphorus loading from sediment commonly represents the main summer phosphorus load to lakes (Nurnberg, 2009) and can have a measureable effect on the water quality of the lake. Phosphorus release rates in the literature also are variable (Borges and others, 2009; Callendar, 1982; Nurnberg, 1984; Nurnberg, 2009). The range of phosphorus release rates for Kabetogama Lake cores (fig. 7) is similar to values from other North American lakes. Fischer and Wood (2004) reported relatively low phosphorus release rates of -1.7 to 2.0 milligrams per square meter per day (mg/m^2/d) for Upper Klamath Lake in Oregon; whereas Penn and others (2000) reported phosphorus release rates ranging from about -1.0 to 45 mg/m^2/d for cores collected from Onondaga Lake in New York.

One issue with comparing phosphorus release rates with those in the literature is that several different methods may be used to estimate phosphorus release. For example, *in situ* flux and core incubations (Nurnberg, 2009) may be used, and different temperatures may be used for core incubations (Callendar, 1982). Insufficient samples were collected during 2008 and 2009 to determine the total internal phosphorus load for Kabetogama Lake. However, phosphorus release rates give an indication that internal phosphorus loading may be substantial when the lake is stratified and that internal loading may be an important source of phosphorus to the overlying water. Although Lake Kabetogama is polymictic, it is occasionally stratified in certain areas such as Lost Bay. Nurnberg (1984) reported values for annual internal phosphorus load from 54 oxic and 33 anoxic lakes in North America and Europe. If the annual phosphorus loads in Nurnberg (1984) are divided by 365, the loads range from -3.7 to 0.5 mg/m^2/d for oxic lakes and from 2.95 to 11.5 mg/m^2/d for anoxic lakes. Because most sediment samples from Kabetogama Lake were collected in August when deep areas were most likely to be stratified, Kabetogama Lake internal phosphorus loads from some sites are on the high end of those reported in the literature, by as much as 45 mg/m^2/d (fig. 7) for an anoxic site.

Table 9. Summary of chlorophyll-*a* concentrations in water samples, Voyageurs National Park, Minnesota, 2008–09.

[All units in micrograms per liter]

Site name	Site number in figures	Number of samples	Minimum	Maximum	Mean	Median
Lake sites						
Kabetogama Lake near Gappas Landing near Ray, Minn.	K1	5	1.8	8.0	4.5	3.8
Kabetogama Lake at mouth of Meadwood Bay near Ray, Minn.	K2	9	.8	8.4	4.0	3.8
Kabetogama Lake at Cemetary Island near Ray, Minn.	K3	10	.8	9.5	3.6	2.8
Kabetogama Lake near Grave Island near Ray, Minn.	K4	10	1.9	31.8	6.4	3.8
Kabetogama Lake at Lost Bay near Ray, Minn.	K5	5	1.1	10.9	6.1	7.4
Inflow or outflow sites						
Namakan Lake at mouth of Namakan River, Ontario, Canada	Q2	3	0.9	2.2	1.6	1.6
Vermilion River near Crane Lake, Minn.	Q3	7	.3	3.1	1.5	1.6
Kabetogama Lake, Sullivan Bay Narrows, near Ash River, Minn.	Q4	10	1.1	10.9	6.1	7.4
Kabetogama Lake, mouth of Tom Cod Creek, near Ray, Minn.	Q5	2	.4	5.4	2.9	2.9
Daley Brook at Co. Rd. 129 near Kabetogama, Minn.	Q6	2	1.1	2.0	1.6	1.6
Kabetogama Lake, east end, near Old Dutch Bay, Minn.	Q7	3	3.3	6.8	5.2	5.5
Gold Portage outlet from Kabetogama Lake near Ray, Minn.	Q8	7	.4	8.9	3.0	2.8
Namakan Lake at Squirrel Narrows, near Kettle Falls, Minn.	Q9	9	.5	9.6	2.5	1.9

Algal Production

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 from the effect of sunlight and chlorophyll. These carbohydrates undergo a series of complex reactions to form compounds from which plant biomass is made. Chlorophyll-*a* concentrations can be simple indicators of algal biomass (production) in surface water.

Chlorophyll-*a* concentrations were analyzed in water samples collected from the 5 lakes sites (K1–K5) and 8 inflow or outflow sites (Q2–Q9). Concentrations are available online at *http://waterdata.usgs.gov/mn/nwis/qw*.

Chlorophyll-*a* concentrations vary seasonally (fig. 8) with peak concentrations normally occurring in late summer. Kabetogama Lake sites near Gappas Landing near Ray, Minn. (site K1; hereafter referred to as Gappas Landing), at Meadwood Bay (site K2), and at Cemetary Island near Ray, Minn. (site K3; hereafter referred to as Cemetary Island) maintained low chlorophyll-*a* concentrations (less than 10 µg/L) during 2008–09. One sample collected at Grave Island (site K4) had a chlorophyll-*a* concentration of 31.8 µg/L (fig. 8). Two other areas of concern for larger chlorophyll-*a* concentrations are Kabetogama Lake at Sullivan Bay (site Q4) and Lost Bay (site K5), which had median chlorophyll-*a* concentrations of 7.4 µg/L. Sullivan Bay (site Q4) and Lost Bay (K5) were sites with large total phosphorus concentrations (table 7). Concurrent total-phosphorus and chlorophyll-*a* concentration peaks may indicate algae as a potential source of total phosphorus or increased algal production in response to phosphorus loading. 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-*a* concentrations may be associated with sampling date (Hanna and Peters, 1991).

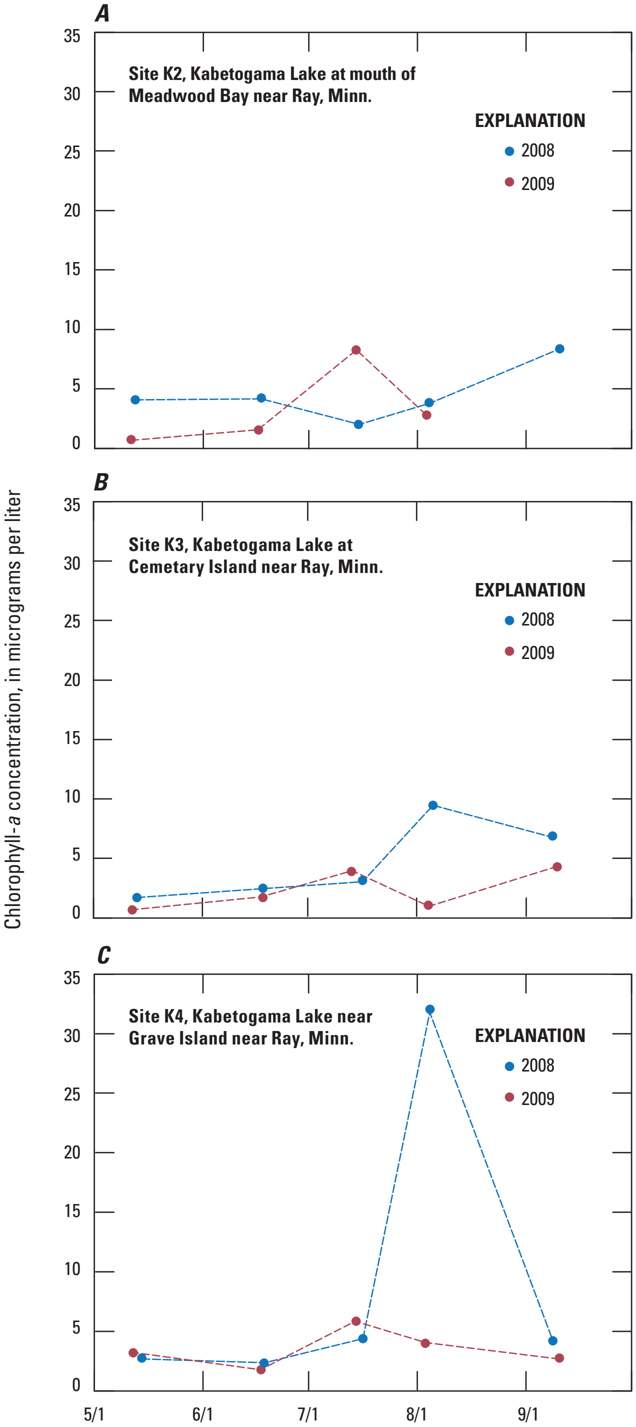

Figure 8. Chlorophyll-*a* concentrations in water samples at selected Kabetogama Lake sites, Voyageurs National Park, Minnesota, 2008–09.

Trophic State

Federal requirements for “fishable” and “swimmable” waters have resulted in numerous efforts to classify a lake’s trophic state (Carlson and Simpson, 1996). Nutrient concentrations, chlorophyll-*a* concentrations, and transparency measurements normally are used in these classification systems. For this study, trophic state indices (TSIs) were computed using equations developed by Carlson (1977). 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 TSI is a simple numeric index that can be related to the traditional typological scheme of Naumann (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). This continuum may be more useful for assessing the change of lake trophic state throughout time and in comparisons between similar lakes.

TSI values were computed from chlorophyll-*a* concentrations in this study. An evaluation of TSI values calculated from data collected during a previous Voyageurs Lake study (Payne, 1991) indicated that TSI values computed from chlorophyll-*a*

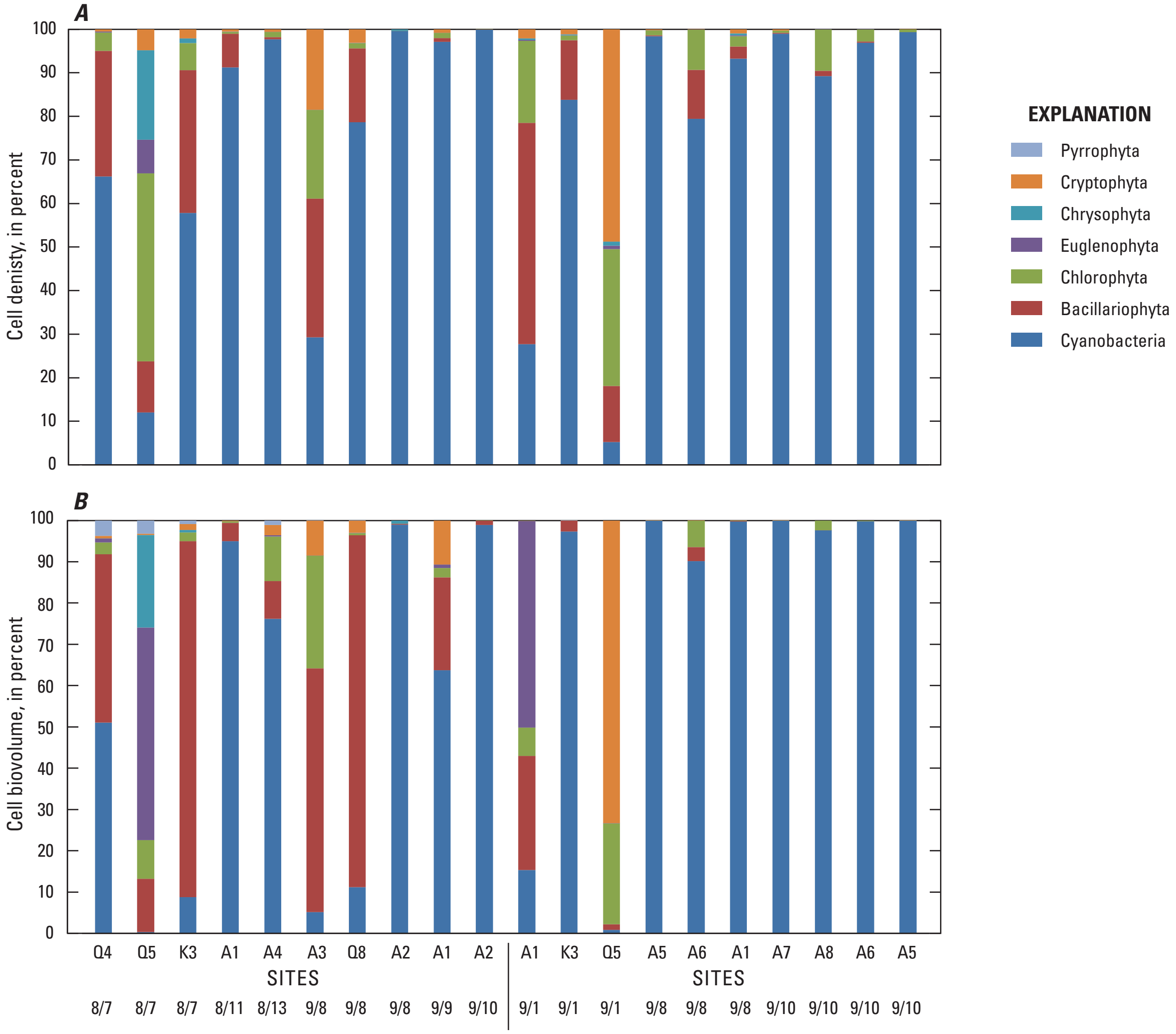

Figure 9. Distribution of algal taxa at sites in Kabetogama Lake by *A*, cell density, and *B*, cell biovolume. Details on sampling sites shown in figure 1 and table 1.

concentrations (TSI CHY) might be preferable to TSI values computed from total-phosphorus concentrations (TSI TP). At times data from lakes in Voyageurs National Park do not match Carlson's regression equation that related chlorophyll-*a* concentrations to total-phosphorus concentrations. In addition, TSI values based on Secchi-disk transparency were not used because soluble organic substances color some of the Park's water bodies and affect the TSI indices calculated with Secchi-disk transparency (Payne, 1991).

TSI values based on chlorophyll-*a* concentrations (TSI CHY) ranged from 27 to 80 during the 2008–09 study. Kabetogama Lake had a mean TSI CHY value of 51 in 2008 and 44 in 2009. For comparison of TSI to previous studies, TSI CHY also was calculated using only the August chlorophyll-*a* concentrations, resulting in a TSI CHY of 54. Based on these values, this lake would be considered mesotrophic to eutrophic (Carlson, 1977). However, individual TSI values would classify some sites as eutrophic to hypereutrophic during the late summer.

Algal Community Composition and Microcystin Concentrations

Algal blooms negatively affect recreational activities and also may produce toxins that poison aquatic and terrestrial animals (Graham and others, 2008). Twenty lake-surface samples (10 per year) were collected in August or September and analyzed for phytoplankton (including cyanobacteria), cell density, and taxonomic identity. Six of these samples were collected at randomly chosen lake or inflow sites (Q4, Q5, K3, and Q8), whereas 14 samples were collected where there was visible accumulation of algae (sites A1–A8).

More than 200 algal taxa (indicated by genus in appendix) were collected among all sites in Kabetogama

Lake during 2008–09. Most of the taxa collected were in the division Bacillariophyta (diatoms), followed by Chlorophyta (green algae) and Cyanobacteria (blue-green algae). Algal taxa richness values (number of taxa collected at a site) ranged from 10 to 53 taxa.

Algal cell density and biovolume are indicators of algal standing crop (Christensen and others, 2004). Algal density is the number of algal cells per unit volume, and algal density commonly highlights the smaller cells, such as some cyanobacteria, that are large in number but have a small cell volume. Generally, Cyanobacteria was the division with the largest density. The exceptions were Tom Cod Bay (site Q5, August 7, 2008, and September 1, 2009) where Chlorophyta had the largest density and Kabetogama Lake near the Kabetogama Visitors Center near Kabetogama, Minn. (site A3, September 8, 2008) where Bacillariophyta had the largest density.

Biovolume is a measure of the algal cell volume per unit area volume. Total algal biovolume was largest for a bloom sample collected from Kabetogama Lake at Ek Lake Trail near Ash River, Minn. (site A5, fig. 1) on September 10, 2009 (appendix). Algal biovolume was dominated by Cyanobacteria at most sites (appendix, fig. 9). Tom Cod Creek (site Q5, fig. 1) was an exception where Euglenophyta or Cryptophyta dominated. The other exceptions were the sites that were dominated by Bacillariophyta (sites K3, A3, and Q8 in 2008, fig. 1). Algal biovolumes generally were larger for samples collected in 2009 than for samples collected in 2008. These differences can result from differences in nutrient and light availability, temperature, hydrology, or timing of sample collection. For this study, 6 of 10 algal community composition samples were collected from blooms in 2008, whereas 8 of 10 algal community composition samples were collected from blooms in 2009.

Cyanobacteria are a concern because they can produce toxins. Cyanobacteria were present in every algal sample collected for algal taxa identification during 2008–09. Microcystin is a cyanotoxin that is produced by at least 13 cyanobacterial genera (Graham and others, 2008). Cyanobacteria known to produce microcystin, such as *Anabaena* species, *Microcystis*, and *Oscillatoria*, were detected in all water samples collected from Kabetogama Lake during 2008–09.

The total microcystin concentrations determined by ELISA for this study are a surrogate for the toxicity of the sample. The World Health Organization (WHO) guideline for microcystin toxicity is reported in terms of microcystin-LR, one of the 80 different congeners of microcystin identified (Chorus and Bartram, 1999). Most variants of microcystin are toxic (Chorus and Bartram; 1999); however, microcystin-LR is used as a guideline for toxicity because it occurs widely and the chemical standard for microcystin-LR was the earliest to be commercially available.

Because of the health risk of microcystin, sampling was conducted on the algal blooms in Kabetogama Lake to determine how frequently microcystin occurs and if the concentrations are a concern. Total microcystin was analazyed in 14 lake samples during 2008–09 (fig. 10). All samples were collected from algal bloom sites (table 1) when visible algal growth was present with the exception of one sample in 2008

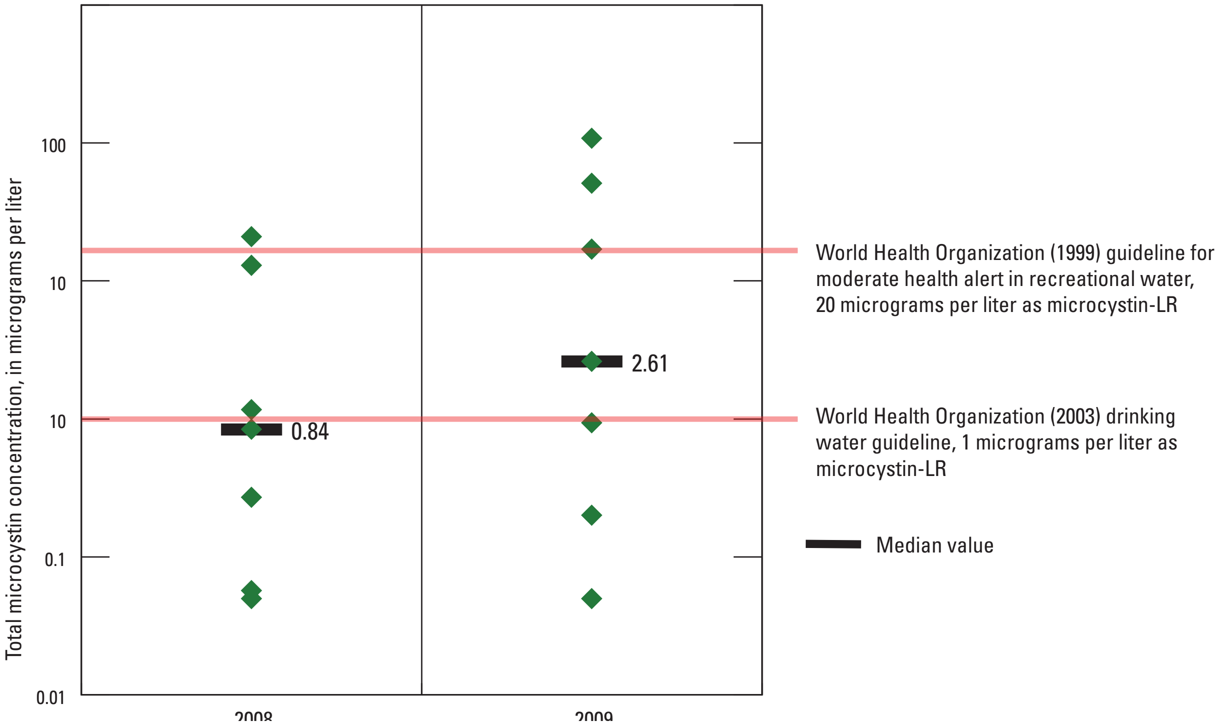

Figure 10. Microcystin concentrations at selected sites in Kabetogama Lake, Voyageurs National Park, Minnesota, 2008–09.

that was collected at Gold Portage (site Q8) when visible algal growth was present. Concentrations are available online at *http://waterdata.usgs.gov/mn/nwis/qw*. Cyanobacterial blooms persist in water supplies that contain adequate levels of nitrogen and phosphorus (World Health Organization, 2003). Samples collected from Kabetogama Lake in 2009 had total microcystin concentrations as great as 110 µg/L. Microcystin-LR is a congener of total microcystin. The WHO guideline for microcystin-LR concentrations in finished drinking water is 1 µg/L (World Health Organization, 2003). When microcystin-LR is present at concentrations as great as 10 µg/L, the WHO recommends initiating additional surveillance of the bloom site and providing information about the toxins to recreational users (Chorus and Bartram, 1999). The WHO (Chorus and Bartram, 1999) lists 20 µg/L as the guideline for a moderate health alert in recreational water for microcystin. Based on the total microcystin concentrations determined in this study, the microcystin levels in Kabetogama Lake may be a concern for residents who use it as a source for drinking water and for Park visitors who use the lake for contact recreation.

Seventy-eight percent of bloom samples analyzed (11 of 14) had detectable microcystin concentrations and 50 percent (7 of 14) of the samples contained concentrations that exceeded the WHO guideline of 1 µg/L in finished drinking water. Two samples (September 8, 2008, at site A2 and September 10, 2009, at site A5) were in the WHO high risk category (concentrations greater than 20 µg/L) for recreational exposure. These microcystin concentrations can cause adverse health consequences for some recreational users (Chorus and Bartram, 1999), ranging from skin irritation to liver injury.

Microcystin concentrations are temporally variable (Graham and others, 2008). For example, a sample collected from Kabetogama Lake at Ek's Bay near Ash River, Minn. (site A6) on September 8, 2009, had a total microcystin concentration of 0.9 µg/L, less than WHO's guideline for drinking water. However, when the same bloom was sampled 2 days later, the microcystin concentration was 110 µg/L.

Relation to Changes in Water Levels

As described in the section "Streamflow and Lake Water Levels," pre-rule curve (1970–99) water-level fluctuations were significantly greater than water-level fluctuations during 2000–2009. The difference between the annual water-level fluctuations between the two periods can be attributed to a substantial increase in the minimum water level after the 2000 Rule Curve change.

Numerous studies that were conducted before the 2000 Rule Curve change provide a baseline for comparison to data collected after the 2000 Rule Curve change. Hargis (1981) measured chlorophyll-*a* concentrations in the summer of 1979. Kepner and Stottlemyer (1988) converted the Hargis (1981) data to lake-wide means and compared the data to their own data collected in 1985 and 1986. Payne reported on samples collected in 1977–1984 (Payne, 1991) and again in July 1999 (Payne, 2000). Most of the pre-2000 USGS data were collected during May and August. Therefore, May and August data from the current (2008–09) study and from Christensen and others (2004) were used to compare with data from the pre-2000 studies (1978–83; fig. 11). Because not all sites were sampled during the baseline studies, changes in Kabetogama Lake are evaluated by using data from Meadwood Bay (site K2). Wilcox rank tests indicated no statistical differences between Secchi-disk transparency or total-phosphorus concentrations between the two periods. Additional analysis was attempted by separating the May and August data, but no statistical difference for Secchi-disk transparency or total-phosphorus concentrations were determined.

Chlorophyll-*a* concentrations were smaller after the 2000 Rule Curve change and the difference was marginally statistically significant (*p*=0.04). Chlorophyll-*a* concentrations before 2008 were determined using the fluorometric method (Arar and Collins, 1997). Although the fluorometric method is more sensitive than the spectrophotometric method (table 2), several authors do not recommend the fluorometric method (Weber and others, 1986) and these two groups of chlorophyll-*a* data may not be directly comparable. However, Christensen and others (2004) compared pre-2000 and post-2000 with chlorophyll-*a* data in which the same analytical methods were used. Comparing data collected using the same methods, Christensen and others (2004) also documented smaller chlorophyll-*a* concentrations after the 2000 Rule Curve change.

Table 10. Comparison of mean August trophic state index values based on chlorophyll-*a* analysis for Kabetogama Lake, Voyageurs National Park, Minnesota.

Year	Reference	Trophic state index
1979	Hargis, 1981	65
1985	Kepner and Stottlemeyer, 1988	58
1986	Kepner and Stottlemeyer, 1988	64
1979–83	Payne, 1991	58
2001–03	Christensen and others, 2004	53
2008–09	Current study	54

The average TSI value for lake sites K2, K3, and K4 during August was 54. This value was compared to TSI values from previous studies (table 10). If data for the Gappas Landing site (K1) are added to the analysis, the TSI value for the current study is 52. In general, TSI values for Kabetogama Lake have decreased since 1979. However, all TSI values in table 10 indicate that Kabetogama Lake remains eutrophic.

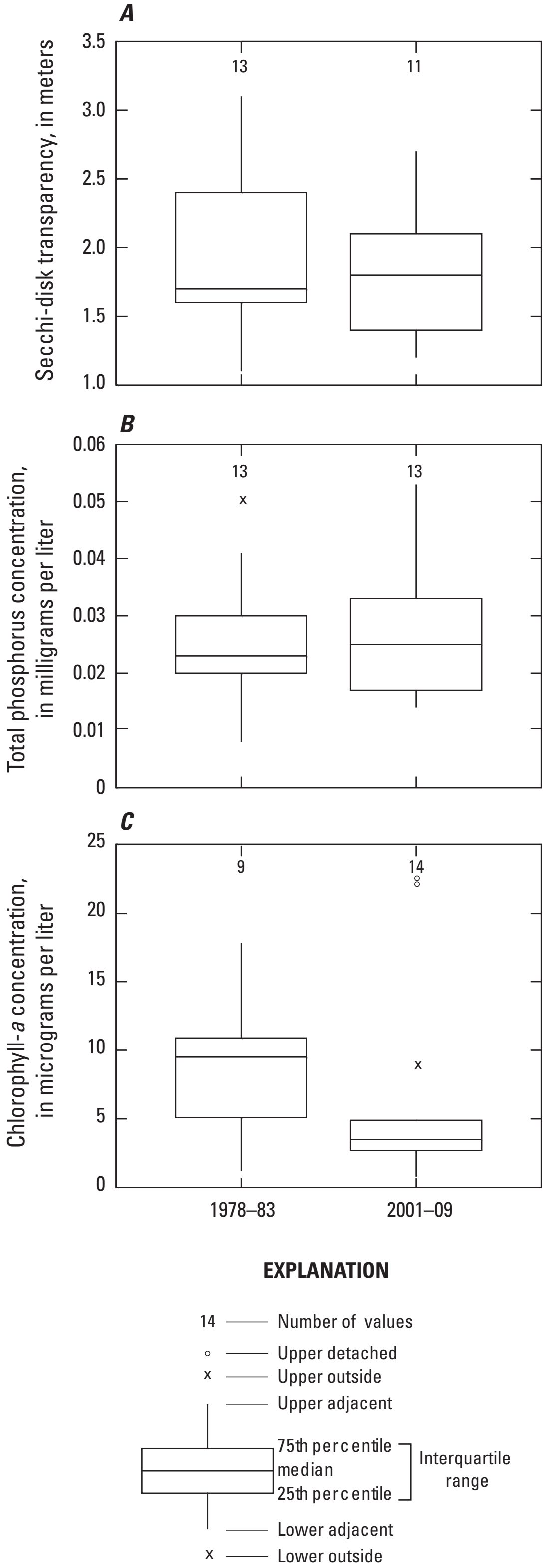

Figure 11. Boxplots comparing historical Kabetogama Lake baseline concentrations (1978–83) to 2001–03 and 2008–09 concentrations. *A*, Secchi-disk transparency. *B*, total phosphorus. *C*, chlorophyll-*a*.

Synopsis of Water-Quality Conditions at Lake Kabetogama, 2008–09

Understanding the effect of water level on water quality in lakes and reservoirs is an important component in lake and reservoir management. The National Park Service and Voyageurs National Park have gained a detailed understanding of the issues involving changes in lake level and their relation to eutrophication. Alteration, degradation, and eutrophication of surface water favor cyanobacterial dominance, and increase the risk of toxins in the water. This study can provide information to water managers that may prevent detrimental effects on aquatic organisms, such as the disruption of fish populations. The information provided in this study also is useful to concerned residents relying on Kabetogama Lake as a drinking-water source.

Nutrient concentrations were larger in some of the inflow sites on the southern shore of Kabetogama Lake than in lake surface samples (table 7). However, because some of these streams had low streamflow, phosphorus loads from these sites were small relative to the Namakan and Vermilion Rivers (fig. 6).

Bottom-water samples from Lost Bay (site K5), in particular, had substantially larger nutrient concentrations than water samples collected from the surface during August when bottom waters were anoxic (table 7). The Lost Bay site also had the largest average concentrations for 4 of the 5 nutrients analyzed in bottom sediments (table 8). A larger concentration in bottom sediment and sediment-water interface samples could indicate a release of nutrients from bottom sediments (Mueller and Ruddy, 1993). These data, combined with results of analyses of core incubation samples (fig. 7), indicate that phosphorus release from sediments may be a substantial source of phosphorus to Kabetogama Lake. Phosphorus release may be particularly substantial in depositional areas such as Lost Bay. The long-term (1930–1996) prevailing wind direction at the International Falls weather station is west-northwest (*http://www.ncdc.noaa.gov*). However, the prevailing wind direction at the Kabnam remote automated weather station is from the south-southwest at 8.2 kilometers per hour (period of record 2003–09; data available at *http://www.raws.dri.edu*). The difference between the two stations may be partially because of missing data at the Kabnam station during the winter months. The Kabnam station data, therefore, may be more indicative of conditions during the open water season. A possible explanation for augmented deposition in Lost Bay (fig. 1) is the bay's orientation and the prevalence of these winds from the south and west. These winds may carry water laden with algal material and nutrients.

The release of phosphorus from bottom sediments can result in larger concentrations in the hypolimnion than the epilimnion, where nutrients are quickly utilized by phytoplankton (Head and others, 1999). In stratified areas of Kabetogama Lake, a vertical separation of optimal light and nutrient conditions may develop. This light and nutrient gradient may be exploited by gas-vacuole cyanobacteria that can move vertically in the water column (Ganf and Oliver, 1982). These phenomena may be indications that release of phosphorus from bottom sediment is the controlling factor for cyanobacterial production. This internal loading and its effect on the phytoplankton community has been observed in other case studies (Harris, 1986) and migration of cyanobacteria into the water column may cause cyanobacterial blooms (Carey and others, 2009).

Kling (2005) provided paleolimnological evidence that Kabetogama Lake had been shifting gradually to a higher trophic state as indicated by an increase in diatom abundance and a decrease in Chrysophytes. In fact, Chrysophytes were a small portion of the cell density and biovolume of samples collected during this study (fig. 9; appendix), whereas most of the taxa collected were Bacillariophyta (diatoms). However, Cyanobacteria had the largest density and biovolume in all but two samples. Kling (2005) also noted a paleolimnological shift in Cyanobacteria towards *Aphanizomenon* and *Anabaena*. Similarly, both genera were detected frequently during this study (appendix) and these genera are a concern because they can produce cyanotoxins. One of these cyanotoxins, microcystin, was detected at concentrations greater than the method reporting limit of 0.10 µg/L in 11 of the 14 bloom samples collected during this study (fig. 10). A concentration of 110 µg/L was detected in one bloom sample. The WHO lists 20 µg/L as the guideline for a moderate health alert in recreational water for microcystin-LR and recommends changes in surveillance for algal blooms with concentrations greater than 10 µg/L (Chorus and Bartram, 1999).

Kabetogama Lake is shallower than the other large Park lakes and has polymictic circulation, which indicates a possible link between frequent recirculation and the internal recycling of phosphorus. Therefore, Kabetogama potentially has had a different response to the 2000 Rule Curve change than other Park lakes. Larger annual internal phosphorus loads are normally expected from stratified lakes, such as Namakan Lake, because of the extent and duration of anoxic conditions; some algae would be able to access this phosphorus and bring it into the epilimnion, but this load may manifest as a pulse during turnover. Periodic internal loading in Kabetogama Lake may be more immediately bioavailable.

The difference in total-phosphorus concentrations in samples collected from Kabetogama Lake before and after the 2000 Rule Curve change was not statistically significant. A possible explanation for relatively unchanged phosphorus concentrations may be changes in residence time. Residence time reflects the amount of time is takes for water to move through a system. The movement of water through a system affects water chemistry and the biology of organisms inhabiting them (Wetzel, 2001), and a change in residence time may affect phosphorus concentrations. Kallemeyn and others (2003) reported a residence time for the Namakan Reservoir system of 235 days. With all other variables equal, a lake with a smaller volume (such as Kabetogama Lake) would have a shorter residence time; however, because there are two outlets to Kabetogama Lake and multidirectional flow between lakes of the system, Kabetogama Lake may act like a backwater area to the larger Namakan Reservoir. Residence times were not calculated for Kabetogama Lake because of the complex hydrology of the Namakan Reservoir system.

Despite the lack of change in total-phosphorus concentrations, chlorophyll-*a* concentrations and TSI values are smaller for samples collected after 2000. The decrease in chlorophyll-*a* concentrations and TSI values reinforces the results of the 2001–03 study (Christensen and others, 2004). Chlorophyll-*a* and total-phosphorus concentrations continue (2011) to be monitored in Kabetogama Lake and other large Park lakes by Voyageurs National Park personnel.

This study was designed to estimate external nutrient loading at inflows and assess the potential for internal phosphorus loading. The results of this study may help Voyageurs National Park personnel determine if water-quality changes have occurred since the International Joint Commission (IJC) changed the rules governing dam operation in 2000. Because of the study's intense focus on Kabetogama Lake, researchers and managers may better understand the effect of the new hydrologic regime on the unique situation in one of the Park's most eutrophic lakes. This information is critical because the IJC will decide whether to keep or change these rules in 2015 based, in part, on the effects of the rules on the aquatic ecosystem.

Summary

Kabetogama Lake is one of five lakes that make up the Namakan Reservoir in Voyageurs National Park in northern Minnesota. Nutrient enrichment has led to excessive algal growth in Kabetogama Lake. Implementation of an order by the International Joint Commission, the international body that sets the rules for the operation of dams on waters shared by the United States and Canada, in January 2000 changed operating procedures (rule curves) for dams that regulate the two large reservoirs in Voyageurs National Park, Rainy Lake and Namakan Reservoir. Rule curves show bands of permitted maximum and minimum water levels allowed throughout the year. These new rule curves were expected to restore a more natural water regime that would affect water levels, water quality, and trophic status. Kabetogama Lake is the greatest concern for eutrophication among the lakes in Voyageurs National Park due, in part, to its shallow depth and frequent mixing, and development and other nutrient sources on the southern shore.

Water-quality, sediment-quality, and streamflow data were collected at 22 sites in Voyageurs National Park during 2008–09 by the U.S. Geological Survey (USGS) in cooperation with the National Park Service to better understand nutrient concentrations and loading, algal production, and their relation to changes in water levels in Kabetogama Lake. Nutrient concentrations and algal production (chlorophyll-*a* concentrations) were analyzed in water samples collected from Kabetogama Lake sites and inflow and outflow sites. Nutrient concentrations were analyzed in bottom-sediment samples collected from the Kabetogama Lake sites. Nutrient loading was estimated to assess the contribution of nutrients from external (inflows) and internal sources (lake-bottom sediments). Algal community composition and microcystin concentrations were analyzed in 20 lake-surface samples to determine the extent to which algal blooms in Kabetogama Lake are producing microcystin. Nutrient and algal data were used to determine trophic status and were evaluated in relation to changes in Kabetogama Lake water levels following changes to dam operation starting in 2000.

In general, nutrient concentrations were larger at the inflows than at lake sites and outflows. Bottom-water samples, from Lost Bay in particular, had large nutrient concentrations that may be indicative of internal loading in Kabetogama Lake. Instantaneous phosphorus loads into the Namakan Reservoir system indicate that inputs may exceed outputs, although the hydrologic system is complex and flow of water through the system is difficult to assess.

Sediment nutrient concentrations were largest at the two deepest lake sites (near Grave Island and in Lost Bay), indicating that these may be important areas for internal loading. Internal loading also was indicated as a potential source of phosphorus when core incubation samples were analyzed for phosphorus release from sediments—sites near Cemetary Island and near Grave Island had the largest phosphorus release rates. Internal loading is a concern because nutrients may cause excessive algal growth including potentially toxic cyanobacteria.

Trophic state indices computed from chlorophyll-*a* concentrations ranged from 27 to 80 with mean values of 51 in 2008 and 44 in 2009, classifying Kabetogama Lake as mesotrophic to eutrophic. Cyanobacteria were present in every algal sample collected. Cyanobacteria generally were the division with the largest cell density and biovolume at lake sites. Seventy-eight percent of bloom samples had detectable total microcystin concentrations and 50 percent had concentrations that exceeded the World Health Organization's guideline of 1.0 microgram per liter for finished drinking water for microcystin-LR, a microcystin congener. Two samples were in the World Health Organization's high-risk category for recreational exposure. Although total phosphorus has not decreased in surface samples, chlorophyll-*a* concentrations and trophic state index values were smaller for Kabetogama Lake since the 2000 Rule Curve took effect.

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Appendix

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—

[cells/L, cells per liter; μm^3/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (μm^3/L)
Kabetogama Lake, Sullivan Bay Narrows, near Ash River, Minn. (site Q4, fig. 1, 482554092500301)					
8/7/2008	*Asterionella formosa*	Bacillariophyta	16	6.84E+05	2.31E+08
8/7/2008	*Aulacoseira alpigena*	Bacillariophyta	289	1.24E+07	6.99E+08
8/7/2008	*Aulacoseira granulata*	Bacillariophyta	42	1.80E+06	2.21E+09
8/7/2008	*Aulacoseira japonica*	Bacillariophyta	61	2.61E+06	1.23E+09
8/7/2008	*Fragilaria crotonensis*	Bacillariophyta	12	4.36E+04	2.40E+07
8/7/2008	*Geissleria decussis*	Bacillariophyta	1	4.28E+04	1.92E+07
8/7/2008	*Stephanocyclus meneghiniana*	Bacillariophyta	11	4.71E+05	3.12E+08
8/7/2008	*Stephanodiscus niagarae*	Bacillariophyta	1	2.00E+02	4.11E+06
8/7/2008	*Ankistrodesmus convolutus*	Chlorophyta	1	3.63E+03	1.14E+06
8/7/2008	*Coelastrum astroideum*	Chlorophyta	11	4.71E+05	6.65E+06
8/7/2008	*Coelastrum microporum*	Chlorophyta	22	9.41E+05	1.06E+08
8/7/2008	*Crucigenia* sp.	Chlorophyta	4	1.71E+05	1.54E+07
8/7/2008	*Pediastrum duplex* var. *gracilimum*	Chlorophyta	16	5.81E+04	7.99E+06
8/7/2008	*Pediastrum tetras*	Chlorophyta	8	3.42E+05	1.22E+07
8/7/2008	*Pyramimonas tetrarhynchus*	Chlorophyta	4	1.71E+05	1.58E+08
8/7/2008	*Quadrigula lacustris*	Chlorophyta	3	1.28E+05	6.05E+06
8/7/2008	*Sphaerocystis schroeteri*	Chlorophyta	8	3.42E+05	2.24E+07
8/7/2008	*Dinobryon* sp.	Chrysophyta	42	8.40E+03	5.15E+05
8/7/2008	*Rhodomonas* sp..	Cryptophyta	8	3.42E+05	7.45E+07
8/7/2008	*Anabaena circinalis*	Cyanobacteria	318	1.36E+07	5.77E+08
8/7/2008	*Anabaenopsis circularis*	Cyanobacteria	146	6.25E+06	4.91E+09
8/7/2008	*Chroococcus* sp.	Cyanobacteria	4	1.71E+05	4.03E+06
8/7/2008	*Aphanizomenon* sp.	Cyanobacteria	170	7.27E+06	3.08E+08
8/7/2008	*Dactylococcopsis acicularis*	Cyanobacteria	22	9.41E+05	7.39E+07
8/7/2008	*Limnothrix* sp.[1]	Cyanobacteria	240	1.03E+07	4.03E+07
8/7/2008	*Snowella* sp.	Cyanobacteria	66	2.82E+06	1.18E+07
8/7/2008	*Euglena gracilis*	Euglenophyta	2	7.26E+03	1.10E+07
8/7/2008	*Trachelomonas hispida*	Euglenophyta	20	7.26E+04	8.41E+07
8/7/2008	*Trachelomonas volvocina*	Euglenophyta	11	4.00E+04	1.34E+07
8/7/2008	*Ceratium* sp.	Pyrrophyta	1	3.63E+03	1.97E+07
8/7/2008	*Glenodinium* sp.	Pyrrophyta	1	4.28E+04	4.13E+08
	Total		1,561	6.25E+07	1.16E+10
Kabetogama Lake, Mouth of Tom Cod Creek, near Ray, Minn. (site Q5, fig. 1, 482846093073001)					
8/7/2008	*Achnanthidium minutissimum*	Bacillariophyta	1	5.48E+03	3.12E+06
8/7/2008	*Aulacoseira granulata*	Bacillariophyta	44	2.41E+05	2.43E+08
8/7/2008	*Cocconeis placentula*	Bacillariophyta	4	2.19E+04	1.36E+07
8/7/2008	*Cymbella* sp.	Bacillariophyta	1	5.48E+03	3.85E+06
8/7/2008	*Epithemia turgida*	Bacillariophyta	1	2.00E+02	5.28E+05
8/7/2008	*Eunotia* sp.	Bacillariophyta	1	2.00E+02	1.02E+06

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; μm^3/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (μm^3/L)
Kabetogama Lake, Mouth of Tom Cod Creek, near Ray, Minn. (site Q5, fig. 1, 482846093073001)—Continued					
8/7/2008	*Fragilaria capucina*	Bacillariophyta	4	2.19E+04	2.11E+07
8/7/2008	*Gomphonema acuminatum*	Bacillariophyta	1	2.00E+02	1.00E+05
8/7/2008	*Gomphonema exiguum*	Bacillariophyta	1	5.48E+03	1.31E+06
8/7/2008	*Navicula bryophila*	Bacillariophyta	1	5.48E+03	5.43E+05
8/7/2008	*Placoneis elginensis*	Bacillariophyta	1	3.63E+03	4.55E+06
8/7/2008	*Navicula kuelbsii*	Bacillariophyta	1	5.48E+03	2.07E+06
8/7/2008	*Navicula* sp.	Bacillariophyta	1	5.48E+03	2.71E+06
8/7/2008	*Navicula tridentula*	Bacillariophyta	1	5.48E+03	8.40E+05
8/7/2008	*Navicula trivialis*	Bacillariophyta	3	1.65E+04	1.08E+07
8/7/2008	*Nitzschia gracilis*	Bacillariophyta	1	3.63E+03	3.45E+06
8/7/2008	*Nitzschia pura*	Bacillariophyta	1	5.48E+03	1.03E+06
8/7/2008	*Nitzschia subacicularis*	Bacillariophyta	2	1.10E+04	3.37E+06
8/7/2008	*Psammothidium sacculum*	Bacillariophyta	1	5.48E+03	5.17E+05
8/7/2008	*Stephanocyclus meneghiniana*	Bacillariophyta	2	1.10E+04	3.13E+06
8/7/2008	*Synedra ulna*	Bacillariophyta	1	5.48E+03	1.23E+06
8/7/2008	*Characium gracilipes*	Chlorophyta	1	5.48E+03	3.33E+05
8/7/2008	*Chlamydomonas* sp.	Chlorophyta	29	1.59E+05	4.26E+07
8/7/2008	*Coelastrum microporum*	Chlorophyta	17	9.32E+04	3.56E+07
8/7/2008	*Crucigeniella irregularis*	Chlorophyta	16	3.20E+03	3.84E+04
8/7/2008	*Crucigenia quadrata*	Chlorophyta	16	5.81E+04	1.57E+06
8/7/2008	*Crucigenia* sp.	Chlorophyta	4	2.19E+04	2.19E+05
8/7/2008	*Dictyosphaerium pulchellum*	Chlorophyta	48	2.63E+05	3.72E+06
8/7/2008	*Pyramimonas tetrarhynchus*	Chlorophyta	133	7.29E+05	1.26E+08
8/7/2008	*Quadrigula lacustris*	Chlorophyta	2	1.10E+04	1.25E+05
8/7/2008	*Scenedesmus acuminatus*	Chlorophyta	4	8.00E+02	3.77E+04
8/7/2008	*Sphaerocystis schroeteri*	Chlorophyta	12	6.58E+04	1.76E+07
8/7/2008	*Staurastrum* sp.	Chlorophyta	1	5.48E+03	4.86E+06
8/7/2008	*Dinobryon* sp.	Chrysophyta	61	3.35E+05	6.13E+07
8/7/2008	*Mallomonas alpina*	Chrysophyta	2	1.10E+04	1.87E+06
8/7/2008	*Mallomonas* sp.	Chrysophyta	60	3.29E+05	4.96E+08
8/7/2008	*Rhodomonas* sp.	Cryptophyta	29	1.59E+05	8.33E+06
8/7/2008	*Anabaenopsis* sp.	Cyanobacteria	17	9.32E+04	3.30E+06
8/7/2008	*Aphanizomenon* sp.	Cyanobacteria	15	8.23E+04	5.17E+05
8/7/2008	*Dactylococcopsis acicularis*	Cyanobacteria	3	1.65E+04	4.30E+06
8/7/2008	*Leptolyngbya* sp.	Cyanobacteria	37	2.03E+05	1.59E+05
8/7/2008	*Euglena gracilis*	Euglenophyta	8	4.39E+04	4.41E+07
8/7/2008	*Lepocinclis ovum*	Euglenophyta	1	3.63E+03	2.43E+06
8/7/2008	*Lepocinclis* sp.	Euglenophyta	1	5.48E+03	5.34E+06
8/7/2008	*Phacus curvicauda*	Euglenophyta	3	1.65E+04	9.56E+07

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm³/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^yy^; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (µm³/L)
Kabetogama Lake, Mouth of Tom Cod Creek, near Ray, Minn. (site Q5, fig. 1, 482846093073001)—Continued					
8/7/2008	*Phacus* sp.	Euglenophyta	1	3.63E+03	1.26E+07
8/7/2008	*Trachelomonas achanthostoma*	Euglenophyta	13	7.13E+04	9.20E+08
8/7/2008	*Trachelomonas armata*	Euglenophyta	2	1.10E+04	1.20E+08
8/7/2008	*Trachelomonas hispida*	Euglenophyta	3	1.65E+04	4.30E+07
8/7/2008	*Trachelomonas varians*	Euglenophyta	1	5.48E+03	1.08E+06
8/7/2008	*Trachelomonas volvocina*	Euglenophyta	14	7.68E+04	4.02E+07
8/7/2008	*Peridinium* sp.	Pyrrophyta	1	5.48E+03	7.99E+07
8/7/2008	*Ophiocytium parvulum*	Xanthophyta	1	2.00E+02	2.69E+04
	Total		630	3.29E+06	2.49E+09
Kabetogama Lake at Cemetary Island, near Ray, Minn. (site K3, fig. 1, 483012093035001)					
8/7/2008	*Achnanthidium minutissimum*	Bacillariophyta	1	3.56E+04	3.28E+06
8/7/2008	*Asterionella formosa*	Bacillariophyta	24	8.72E+04	3.27E+07
8/7/2008	*Aulacoseira alpigena*	Bacillariophyta	4	8.00E+02	6.79E+04
8/7/2008	*Aulacoseira ambigua*	Bacillariophyta	114	4.06E+06	3.86E+09
8/7/2008	*Aulacoseira granulata*	Bacillariophyta	221	7.88E+06	4.49E+09
8/7/2008	*Diploneis parma*	Bacillariophyta	1	2.00E+02	0.00E+00
8/7/2008	*Epithemia adnata*	Bacillariophyta	1	2.00E+02	1.89E+05
8/7/2008	*Gomphonema acuminatum*	Bacillariophyta	1	3.56E+04	8.88E+06
8/7/2008	*Neidium affine*	Bacillariophyta	1	3.63E+03	0.00E+00
8/7/2008	*Stephanocyclus meneghiniana*	Bacillariophyta	4	8.00E+02	8.04E+05
8/7/2008	*Stephanodiscus niagarae*	Bacillariophyta	3	1.07E+05	1.94E+09
8/7/2008	*Synedra ulna*	Bacillariophyta	2	4.00E+02	9.33E+05
8/7/2008	*Tabellaria flocculosa*	Bacillariophyta	92	1.84E+04	6.60E+06
8/7/2008	*Ankistrodesmus falcatus*	Chlorophyta	4	1.43E+05	8.51E+06
8/7/2008	*Chlamydomonas* sp.	Chlorophyta	1	3.63E+03	2.53E+06
8/7/2008	*Crucigenia quadrata*	Chlorophyta	16	5.70E+05	1.37E+07
8/7/2008	*Crucigenia* sp.	Chlorophyta	15	5.35E+05	1.44E+07
8/7/2008	*Dictyosphaerium pulchellum*	Chlorophyta	92	1.84E+04	5.20E+05
8/7/2008	*Kirchneriella lunaris* var. *dianae*	Chlorophyta	18	6.42E+05	1.21E+08
8/7/2008	*Pediastrum integrum* var. *priva*	Chlorophyta	8	2.91E+04	3.14E+05
8/7/2008	*Pyramimonas tetrarhynchus*	Chlorophyta	8	2.85E+05	8.36E+07
8/7/2008	*Quadrigula closteroides*	Chlorophyta	4	1.45E+04	2.57E+05
8/7/2008	*Scenedesmus abundans* var. *brevicauda*	Chlorophyta	2	7.26E+03	3.04E+04
8/7/2008	*Scenedesmus arcuatus* var. *capitatus*	Chlorophyta	1	2.00E+02	1.23E+04
8/7/2008	*Scenedesmus quadricauda* var. *maximus*	Chlorophyta	8	2.91E+04	3.65E+05
8/7/2008	*Sphaerocystis schroeteri*	Chlorophyta	16	5.81E+04	3.80E+06
8/7/2008	*Westella botryoides*	Chlorophyta	52	1.04E+04	6.81E+05
8/7/2008	*Dinobryon* sp.	Chrysophyta	8	2.85E+05	4.85E+07
8/7/2008	*Mallomonas alpina*	Chrysophyta	3	1.07E+05	2.66E+07

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm³/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^yy; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (µm³/L)
Kabetogama Lake at Cemetary Island, near Ray, Minn. (site K3, fig. 1, 483012093035001)—Continued					
8/7/2008	*Rhodomonas* sp.	Cryptophyta	22	7.84E+05	1.71E+08
8/7/2008	*Anabaenopsis circularis*	Cyanobacteria	134	4.78E+06	4.69E+08
8/7/2008	*Aphanizomenon* sp.	Cyanobacteria	109	3.89E+06	1.65E+08
8/7/2008	*Dactylococcopsis acicularis*	Cyanobacteria	3	1.07E+05	1.61E+07
8/7/2008	*Limnothrix* sp.[1]	Cyanobacteria	359	1.28E+07	4.02E+08
8/7/2008	*Ceratium hirundinella*	Pyrrophyta	1	3.63E+03	1.03E+08
	Total		1,353	3.73E+07	1.20E+10
Kabetogama Lake at Ellsworth Rock Garden near Kabetogama, Minn. (site A4, fig. 1, 482947092584401)					
8/13/2008	*Achnanthidium exiguum*	Bacillariophyta	1	1.53E+04	2.52E+06
8/13/2008	*Achnanthidium minutissimum*	Bacillariophyta	4	6.11E+04	3.17E+06
8/13/2008	*Amphipleura pellucida*	Bacillariophyta	3	3.77E+04	7.47E+07
8/13/2008	*Asterionella formosa*	Bacillariophyta	1	1.53E+04	1.08E+07
8/13/2008	*Aulacoseira granulata*	Bacillariophyta	4	6.11E+04	1.54E+07
8/13/2008	*Aulacoseira* sp.	Bacillariophyta	4	6.11E+04	4.75E+06
8/13/2008	*Cocconeis placentula*	Bacillariophyta	5	7.64E+04	3.06E+07
8/13/2008	*Cyclostephanos dubius*	Bacillariophyta	1	4.00E+02	4.02E+05
8/13/2008	*Cyclotella ocellata*	Bacillariophyta	1	1.53E+04	7.26E+06
8/13/2008	*Diploneis parma*	Bacillariophyta	1	1.53E+04	2.78E+07
8/13/2008	*Encyonema minutum*	Bacillariophyta	1	7.26E+03	9.69E+05
8/13/2008	*Epithemia adnata*	Bacillariophyta	1	7.26E+03	5.09E+06
8/13/2008	*Epithemia* sp.	Bacillariophyta	11	1.68E+05	1.23E+08
8/13/2008	*Fragilaria capucina*	Bacillariophyta	6	9.17E+04	1.67E+07
8/13/2008	*Fragilaria crotonensis*	Bacillariophyta	3	4.58E+04	2.46E+07
8/13/2008	*Gomphonema acuminatum*	Bacillariophyta	1	4.00E+02	1.31E+05
8/13/2008	*Navicula capitatoradiata*	Bacillariophyta	1	7.26E+03	8.76E+06
8/13/2008	*Navicula cryptotonella*	Bacillariophyta	1	1.53E+04	1.26E+07
8/13/2008	*Navicula* sp.	Bacillariophyta	1	1.53E+04	3.96E+06
8/13/2008	*Nitzschia perminuta*	Bacillariophyta	1	7.26E+03	1.47E+06
8/13/2008	*Planothidium lanceolatum*	Bacillariophyta	1	1.53E+04	2.34E+06
8/13/2008	*Reimeria sinuata*	Bacillariophyta	7	1.07E+05	5.88E+06
8/13/2008	*Rhoicosphenia curvata*	Bacillariophyta	2	1.45E+04	1.11E+08
8/13/2008	*Rhopalodia gibba*	Bacillariophyta	4	6.11E+04	3.05E+08
8/13/2008	*Synedra tenera*	Bacillariophyta	2	3.06E+04	8.64E+06
8/13/2008	*Synedra ulna*	Bacillariophyta	2	8.00E+02	9.90E+06
8/13/2008	*Chlamydomonas* sp.	Chlorophyta	2	3.06E+04	1.35E+07
8/13/2008	*Crucigenia tetrapedia*	Chlorophyta	12	1.83E+05	4.40E+06
8/13/2008	*Kirchneriella contorta*	Chlorophyta	15	2.29E+05	2.88E+06
8/13/2008	*Kirchneriella lunaris* var. *dianae*	Chlorophyta	10	7.26E+04	1.06E+06
8/13/2008	*Oedogonium* sp.	Chlorophyta	48	1.92E+04	7.10E+08

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm^3/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (µm^3/L)
	Kabetogama Lake at Ellsworth Rock Garden near Kabetogama, Minn. (site A4, fig. 1, 482947092584401)—Continued				
8/13/2008	*Pandorina* sp.	Chlorophyta	21	3.21E+05	4.54E+06
8/13/2008	*Pyramimonas tetrarhynchus*	Chlorophyta	45	6.88E+05	4.32E+07
8/13/2008	*Scenedesmus acutiformis*	Chlorophyta	4	6.11E+04	1.02E+06
8/13/2008	*Scenedesmus opoliensis*	Chlorophyta	4	2.91E+04	4.87E+05
8/13/2008	*Tetraedron minimum*	Chlorophyta	1	1.53E+04	1.65E+06
8/13/2008	*Ulothrix subtilissima*	Chlorophyta	50	7.64E+05	1.90E+08
8/13/2008	*Rhodomonas* sp.	Cryptophyta	79	1.21E+06	2.22E+08
8/13/2008	*Anabaena circinalis*	Cyanobacteria	2,976	4.55E+07	1.61E+09
8/13/2008	*Anabaenopsis circularis*	Cyanobacteria	274	4.19E+06	1.30E+09
8/13/2008	*Anabaenopsis* sp.	Cyanobacteria	218	3.33E+06	1.67E+09
8/13/2008	*Aphanocapsa* sp.	Cyanobacteria	883	1.35E+07	1.91E+08
8/13/2008	*Aphanizomenon* sp.	Cyanobacteria	236	3.61E+06	9.06E+07
8/13/2008	*Leptolyngbya* sp.	Cyanobacteria	32	4.89E+05	1.15E+06
8/13/2008	*Limnothrix* sp.[1]	Cyanobacteria	7,569	1.16E+08	1.82E+09
8/13/2008	*Microcystis aeruginosa*	Cyanobacteria	78	1.19E+06	7.80E+07
8/13/2008	*Oscillatoria* sp.	Cyanobacteria	460	7.03E+06	8.83E+07
8/13/2008	*Trachelomonas acanthostoma*	Euglenophyta	1	4.00E+02	4.84E+05
8/13/2008	*Trachelomonas volvocina*	Euglenophyta	3	4.58E+04	2.75E+07
8/13/2008	*Ceratium hirundinella*	Pyrrophyta	1	7.26E+03	9.96E+07
	Total		13,092	1.99E+08	8.99E+09
	Kabetogama Lake near Kabetogama Visitor's Center near Kabetogama, Minn. (site A3, fig. 1, 482640093013901)				
9/8/2008	*Achnanthidium minutissimum*	Bacillariophyta	1	2.67E+04	2.08E+06
9/8/2008	*Asterionella formosa*	Bacillariophyta	1	2.67E+04	2.00E+07
9/8/2008	*Aulacoseira granulata*	Bacillariophyta	271	7.25E+06	4.81E+09
9/8/2008	*Cocconeis placentula*	Bacillariophyta	3	8.02E+04	2.08E+08
9/8/2008	*Cyclostephanos dubius*	Bacillariophyta	1	2.67E+04	1.27E+07
9/8/2008	*Cyclotella distinguenda*	Bacillariophyta	5	1.82E+04	1.04E+07
9/8/2008	*Cyclotella pseudostelligera*	Bacillariophyta	3	8.02E+04	2.02E+07
9/8/2008	*Encyonema silesiacum*	Bacillariophyta	1	2.67E+04	1.16E+07
9/8/2008	*Epithemia turgida*	Bacillariophyta	1	2.67E+04	1.44E+08
9/8/2008	*Fragilaria capucina*	Bacillariophyta	4	1.07E+05	1.34E+08
9/8/2008	*Gomphonema* sp.	Bacillariophyta	2	7.26E+03	3.14E+06
9/8/2008	*Nitzschia palea*	Bacillariophyta	1	3.63E+03	6.21E+05
9/8/2008	*Nitzschia pumila*	Bacillariophyta	1	3.63E+03	2.18E+06
9/8/2008	*Rhoicosphenia curvata*	Bacillariophyta	1	2.00E+02	3.17E+04
9/8/2008	*Sellaphora pupula*	Bacillariophyta	1	2.00E+02	8.95E+04
9/8/2008	*Stephanodiscus niagarae*	Bacillariophyta	4	1.07E+05	1.49E+09
9/8/2008	*Coelastrum microporum*	Chlorophyta	28	5.60E+03	3.67E+05
9/8/2008	*Coleochaete* sp.	Chlorophyta	412	8.24E+04	1.62E+07

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm³/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (µm³/L)
Kabetogama Lake near Kabetogama Visitor's Center near Kabetogama, Minn. (site A3, fig. 1, 482640093013901)—Continued					
9/8/2008	*Cosmarium* sp.	Chlorophyta	1	2.00E+02	5.86E+04
9/8/2008	*Crucigenia tetrapedia*	Chlorophyta	1	2.67E+04	1.20E+06
9/8/2008	*Kirchneriella contorta*	Chlorophyta	3	1.09E+04	1.14E+05
9/8/2008	*Oedogonium* sp.	Chlorophyta	14	5.08E+04	2.99E+09
9/8/2008	*Pyramimonas tetrarhynchus*	Chlorophyta	10	2.67E+05	1.85E+08
9/8/2008	*Scenedesmus acutiformis*	Chlorophyta	4	8.00E+02	3.02E+04
9/8/2008	*Scenedesmus* sp.	Chlorophyta	4	1.45E+04	1.83E+05
9/8/2008	*Rhodomonas* sp.	Cryptophyta	169	4.52E+06	9.84E+08
9/8/2008	*Anabaena circinalis*	Cyanobacteria	13	3.48E+05	4.09E+07
9/8/2008	*Anabaenopsis* sp.	Cyanobacteria	41	1.10E+06	1.72E+08
9/8/2008	*Aphanizomenon* sp.	Cyanobacteria	74	1.98E+06	5.59E+07
9/8/2008	*Dactylococcopsis acicularis*	Cyanobacteria	3	1.09E+04	4.79E+05
9/8/2008	*Limnothrix* sp.[1]	Cyanobacteria	37	9.89E+05	1.55E+07
9/8/2008	*Microcystis aeruginosa*	Cyanobacteria	744	2.70E+06	3.06E+08
9/8/2008	*Oscillatoria* sp.	Cyanobacteria	164	3.28E+04	8.24E+06
9/8/2008	*Euglena* sp.	Euglenophyta	1	2.00E+02	3.39E+05
9/8/2008	*Ceratium hirundinella*	Pyrrophyta	1	2.00E+02	1.45E+06
	Total		2,025	1.99E+07	1.16E+10
Gold Portage outlet from Kabetogama Lake near Ray, Minn. (site Q8, fig. 1, 05129290)					
9/8/2008	*Achnanthidium minutissimum*	Bacillariophyta	1	2.67E+04	1.43E+06
9/8/2008	*Asterionella formosa*	Bacillariophyta	6	1.60E+05	1.24E+08
9/8/2008	*Aulacoseira granulata*	Bacillariophyta	288	7.70E+06	9.48E+09
9/8/2008	*Cocconeis placentula*	Bacillariophyta	2	5.35E+04	1.94E+07
9/8/2008	*Cyclostephanos dubius*	Bacillariophyta	1	3.63E+03	2.00E+00
9/8/2008	*Cyclotella distinguenda*	Bacillariophyta	1	2.67E+04	5.38E+06
9/8/2008	*Cyclotella ocellata*	Bacillariophyta	9	2.41E+05	1.60E+08
9/8/2008	*Cyclotella pseudostelligera*	Bacillariophyta	1	2.67E+04	1.05E+07
9/8/2008	*Cyclotella* sp.	Bacillariophyta	1	2.67E+04	1.05E+07
9/8/2008	*Cymbella* sp.	Bacillariophyta	2	7.26E+03	2.42E+06
9/8/2008	*Encyonema silesiacum*	Bacillariophyta	1	3.63E+03	1.74E+06
9/8/2008	*Epithemia adnata*	Bacillariophyta	1	2.00E+02	1.17E+05
9/8/2008	*Fragilaria capucina*	Bacillariophyta	10	2.67E+05	5.04E+07
9/8/2008	*Gomphonema* sp.	Bacillariophyta	1	2.00E+02	3.32E+04
9/8/2008	*Navicula* sp.	Bacillariophyta	1	3.63E+03	3.29E+06
9/8/2008	*Nitzschia acicularis*	Bacillariophyta	2	7.26E+03	7.74E+06
9/8/2008	*Stephanodiscus niagarae*	Bacillariophyta	1	3.63E+03	4.54E+07
9/8/2008	*Synedra ulna*	Bacillariophyta	1	3.63E+03	1.10E+07
9/8/2008	*Ankistrodesmus falcatus*	Chlorophyta	14	2.80E+03	1.94E+05
9/8/2008	*Coelastrum astroideum*	Chlorophyta	8	2.91E+04	4.11E+05

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm^3/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (µm^3/L)
Gold Portage outlet from Kabetogama Lake near Ray, Minn. (site Q8, fig. 1, 05129290)—Continued					
9/8/2008	*Crucigenia tetrapedia*	Chlorophyta	4	1.07E+05	9.63E+06
9/8/2008	*Kirchneriella contorta*	Chlorophyta	8	2.91E+04	1.82E+05
9/8/2008	*Pyramimonas tetrarhynchus*	Chlorophyta	11	2.94E+05	3.85E+07
9/8/2008	*Scenedesmus acutiformis*	Chlorophyta	4	1.07E+05	1.79E+06
9/8/2008	*Scenedesmus opoliensis*	Chlorophyta	4	1.45E+04	1.83E+05
9/8/2008	*Tetraedron victoriae* var. *major*	Chlorophyta	1	3.63E+03	8.72E+06
9/8/2008	*Westella botryoides*	Chlorophyta	5	1.00E+03	6.55E+04
9/8/2008	*Rhodomonas* sp.	Cryptophyta	59	1.58E+06	3.44E+08
9/8/2008	*Anabaena circinalis*	Cyanobacteria	4	1.07E+05	1.26E+07
9/8/2008	*Aphanocapsa delicatissima*	Cyanobacteria	796	2.89E+06	1.50E+06
9/8/2008	*Aphanizomenon* sp.	Cyanobacteria	477	1.28E+07	5.41E+08
9/8/2008	*Dactylococcopsis acicularis*	Cyanobacteria	4	1.07E+05	7.06E+06
9/8/2008	*Limnothrix* sp.[1]	Cyanobacteria	612	1.64E+07	2.57E+08
9/8/2008	*Microcystis aeruginosa*	Cyanobacteria	275	7.35E+06	4.81E+08
9/8/2008	*Trachelomonas hispida*	Euglenophyta	2	7.26E+03	6.94E+06
9/8/2008	*Trachelomonas scabra* var. *longicollis*	Euglenophyta	1	3.63E+03	9.13E+05
9/8/2008	*Trachelomonas* sp.	Euglenophyta	1	2.67E+04	7.06E+06
9/8/2008	*Ceratium hirundinella*	Pyrrophyta	1	2.00E+02	1.74E+06
	Total		2,621	5.03E+07	1.17E+10
Kabetogama Lake, Sullivan Bay, NW near Ash River, Minn. (site A1, fig. 1, 482542092493701)					
8/11/2008	*Achnanthidium minutissimum*	Bacillariophyta	2	1.45E+04	6.39E+05
8/11/2008	*Amphora veneta*	Bacillariophyta	2	1.45E+04	5.86E+06
8/11/2008	*Asterionella formosa*	Bacillariophyta	3	2.18E+04	1.00E+07
8/11/2008	*Aulacoseira alpigena*	Bacillariophyta	309	2.20E+07	2.21E+09
8/11/2008	*Aulacoseira granulata*	Bacillariophyta	104	4.16E+04	4.18E+07
8/11/2008	*Aulacoseira japonica*	Bacillariophyta	53	3.85E+05	2.55E+08
8/11/2008	*Cyclostephanos dubius*	Bacillariophyta	6	4.28E+05	2.00E+00
8/11/2008	*Epithemia adnata*	Bacillariophyta	1	4.00E+02	6.92E+05
8/11/2008	*Fragilaria crotonensis*	Bacillariophyta	6	4.36E+04	5.13E+07
8/11/2008	*Navicula margalithii*	Bacillariophyta	1	4.00E+02	8.29E+05
8/11/2008	*Navicula pseudolanceolata*	Bacillariophyta	1	4.00E+02	7.54E+05
8/11/2008	*Pinnularia* sp.	Bacillariophyta	1	4.00E+02	5.73E+05
8/11/2008	*Planothidium lanceolatum*	Bacillariophyta	1	7.13E+04	7.39E+06
8/11/2008	*Synedra tenera*	Bacillariophyta	2	1.43E+05	2.28E+07
8/11/2008	*Coelastrum microporum*	Chlorophyta	8	5.81E+04	8.22E+05
8/11/2008	*Crucigeniella irregularis*	Chlorophyta	14	9.98E+05	4.49E+07
8/11/2008	*Crucigenia quadrata*	Chlorophyta	16	6.40E+03	1.73E+05
8/11/2008	*Gloeocystis ampla*	Chlorophyta	4	1.60E+03	1.81E+05
8/11/2008	*Pediastrum duplex* var. *reticulatum*	Chlorophyta	8	3.20E+03	1.01E+06
8/11/2008	*Pyramimonas tetrarhynchus*	Chlorophyta	1	7.13E+04	1.88E+07

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm^3/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (µm^3/L)
Kabetogama Lake, Sullivan Bay, NW near Ash River, Minn. (site A1, fig. 1, 482542092493701)—Continued					
8/11/2008	*Sphaerocystis schroeteri*	Chlorophyta	8	5.81E+04	1.56E+07
8/11/2008	*Tetraedron* sp.	Chlorophyta	1	7.13E+04	1.37E+08
8/11/2008	*Westella botryoides*	Chlorophyta	24	1.74E+05	2.47E+06
8/11/2008	*Rhodomonas* sp.	Cryptophyta	24	1.71E+06	8.96E+07
8/11/2008	*Anabaena circinalis*	Cyanobacteria	665	4.74E+07	3.35E+09
8/11/2008	*Anabaenopsis* sp.	Cyanobacteria	126	8.98E+06	1.41E+09
8/11/2008	*Aphanizomenon* sp.	Cyanobacteria	33	2.35E+06	3.70E+07
8/11/2008	*Dactylococcopsis fascicularis*	Cyanobacteria	4	2.91E+04	2.19E+06
8/11/2008	*Limnothrix* sp.[1]	Cyanobacteria	3,036	2.16E+08	5.10E+10
8/11/2008	*Trachelomonas charkowiensis*	Euglenophyta	1	5.71E+03	1.80E+07
8/11/2008	*Trachelomonas dybowskii*	Euglenophyta	1	7.26E+03	1.34E+07
8/11/2008	*Trachelomonas volvocina*	Euglenophyta	2	1.45E+04	1.01E+07
	Total		4,468	3.02E+08	5.88E+10
Kabetogama Lake, Sullivan Bay, NW near Ash River, Minn. (site A1, fig. 1, 482542092493701)					
9/9/2008	*Amphora fogediana*	Bacillariophyta	2	7.26E+03	4.92E+06
9/9/2008	*Aulacoseira alpigena*	Bacillariophyta	34	6.61E+05	3.77E+08
9/9/2008	*Aulacoseira granulata*	Bacillariophyta	2	3.89E+04	1.11E+08
9/9/2008	*Aulacoseira japonica*	Bacillariophyta	33	6.42E+05	4.26E+08
9/9/2008	*Cyclostephanos dubius*	Bacillariophyta	9	1.75E+05	2.00E+00
9/9/2008	*Diploneis elliptica*	Bacillariophyta	1	2.00E+02	5.28E+04
9/9/2008	*Eunotia* sp.	Bacillariophyta	1	1.94E+04	5.46E+07
9/9/2008	*Fragilaria capucina*	Bacillariophyta	4	7.78E+04	1.44E+07
9/9/2008	*Fragilaria crotonensis*	Bacillariophyta	36	1.31E+05	2.23E+08
9/9/2008	*Fragilaria nanana*	Bacillariophyta	2	3.89E+04	1.20E+08
9/9/2008	*Gomphonema angustum*	Bacillariophyta	1	2.00E+02	3.44E+05
9/9/2008	*Planothidium lanceolatum*	Bacillariophyta	2	3.89E+04	1.28E+07
9/9/2008	*Staurosira construens*	Bacillariophyta	6	1.17E+05	4.03E+07
9/9/2008	*Synedra tenera*	Bacillariophyta	2	3.89E+04	2.38E+07
9/9/2008	*Actinastrum* sp.	Chlorophyta	76	2.76E+05	1.44E+07
9/9/2008	*Ankistrodesmus falcatus*	Chlorophyta	13	4.72E+04	4.89E+06
9/9/2008	*Coelastrum microporum*	Chlorophyta	20	7.26E+04	4.75E+06
9/9/2008	*Crucigenia quadrata*	Chlorophyta	8	1.56E+05	7.00E+06
9/9/2008	*Dictyosphaerium pulchellum*	Chlorophyta	41	7.97E+05	1.13E+07
9/9/2008	*Kirchneriella contorta*	Chlorophyta	2	3.89E+04	4.07E+05
9/9/2008	*Kirchneriella obesa* var. *major*	Chlorophyta	77	2.80E+05	1.32E+07
9/9/2008	*Pyramimonas tetrarhynchus*	Chlorophyta	30	5.83E+05	5.96E+07
9/9/2008	*Scenedesmus arcuatus*	Chlorophyta	8	1.56E+05	1.22E+07
9/9/2008	*Scenedesmus brasiliensis*	Chlorophyta	16	3.11E+05	3.91E+06
9/9/2008	*Scenedesmus opoliensis* var. *contacta*	Chlorophyta	4	7.78E+04	6.52E+05

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm^3/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (µm^3/L)
Kabetogama Lake, Sullivan Bay, NW near Ash River, Minn. (site A1, fig. 1, 482542092493701)—Continued					
9/9/2008	*Scenedesmus* sp.	Chlorophyta	4	7.78E+04	2.20E+06
9/9/2008	*Staurastrum* sp.	Chlorophyta	2	7.26E+03	5.36E+06
9/9/2008	*Westella botryoides*	Chlorophyta	4	7.78E+04	1.10E+06
9/9/2008	*Rhodomonas* sp.	Cryptophyta	101	1.96E+06	6.68E+08
9/9/2008	*Anabaena circinalis*	Cyanobacteria	85	3.09E+05	3.64E+07
9/9/2008	*Aphanizomenon* sp.	Cyanobacteria	9,525	1.85E+08	3.49E+09
9/9/2008	*Dactylococcopsis fascicularis*	Cyanobacteria	18	3.50E+05	2.31E+07
9/9/2008	*Limnothrix* sp.[1]	Cyanobacteria	2,341	4.55E+07	4.29E+08
9/9/2008	*Snowella* sp.	Cyanobacteria	136	2.64E+06	1.38E+06
9/9/2008	*Phacus* sp.	Euglenophyta	1	2.00E+02	2.04E+06
9/9/2008	*Trachelomonas charkowiensis*	Euglenophyta	1	1.94E+04	4.02E+07
9/9/2008	*Trachelomonas varians*	Euglenophyta	3	1.09E+04	7.59E+06
	Total		12,651	2.41E+08	6.25E+09
Kabetogama Lake at Ash River Landing near Ash River, Minn. (site A2, fig. 1, 482604092511801)					
9/8/2008	*Aulacoseira granulata*	Bacillariophyta	15	3.00E+04	1.99E+07
9/8/2008	*Fragilaria capucina*	Bacillariophyta	1	3.63E+04	8.47E+06
9/8/2008	*Stephanodiscus niagarae*	Bacillariophyta	1	2.00E+03	1.15E+08
9/8/2008	*Chlamydomonas* sp.	Chlorophyta	5	1.00E+04	5.24E+06
9/8/2008	*Westella botryoides*	Chlorophyta	5	1.00E+04	6.55E+05
9/8/2008	*Synura* sp.	Chrysophyta	16	5.70E+06	5.97E+08
9/8/2008	*Anabaena circinalis*	Cyanobacteria	1,632	5.82E+08	5.71E+10
9/8/2008	*Aphanizomenon* sp.	Cyanobacteria	1,196	4.26E+08	1.07E+10
9/8/2008	*Limnothrix* sp.[1]	Cyanobacteria	280	9.98E+07	9.40E+08
9/8/2008	*Microcystis flos-aquae*	Cyanobacteria	1,196	4.26E+08	6.03E+09
	Total		4,347	1.54E+09	7.55E+10
Kabetogama Lake at Ash River Landing near Ash River, Minn. (site A2, fig. 1, 482604092511801)					
9/10/2008	*Aulacoseira granulata*	Bacillariophyta	48	1.71E+07	8.13E+09
9/10/2008	*Aulacoseira* sp.	Bacillariophyta	3	6.00E+03	1.51E+06
9/10/2008	*Cocconeis placentula*	Bacillariophyta	4	1.43E+06	2.62E+08
9/10/2008	*Cyclostephanos dubius*	Bacillariophyta	2	7.13E+05	2.00E+00
9/10/2008	*Cymbella cistula*	Bacillariophyta	1	3.63E+04	4.53E+08
9/10/2008	*Epithemia adnata*	Bacillariophyta	2	4.00E+03	1.26E+06
9/10/2008	*Gomphonema acuminatum*	Bacillariophyta	2	7.26E+04	2.89E+07
9/10/2008	*Nitzschia* sp.	Bacillariophyta	8	2.91E+05	2.09E+07
9/10/2008	*Stephanodiscus niagarae*	Bacillariophyta	2	2.14E+06	2.24E+10
9/10/2008	*Surirella angusta*	Bacillariophyta	6	1.20E+04	9.95E+06
9/10/2008	*Chlamydomonas* sp.	Chlorophyta	1	3.63E+04	1.14E+07
9/10/2008	*Pyramimonas tetrarhynchus*	Chlorophyta	2	7.13E+05	2.69E+07

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm³/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^yy; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (µm³/L)
Kabetogama Lake at Ash River Landing near Ash River, Minn. (site A2, fig. 1, 482604092511801)—Continued					
9/10/2008	*Sphaerocystis schroeteri*	Chlorophyta	24	8.72E+05	5.70E+07
9/10/2008	*Anabaena circinalis*	Cyanobacteria	4,082	1.46E+09	1.43E+11
9/10/2008	*Aphanizomenon* sp.	Cyanobacteria	31,160	1.11E+10	7.85E+11
9/10/2008	*Limnothrix* sp.[1]	Cyanobacteria	146	5.20E+07	4.90E+08
9/10/2008	*Microcystis flos-aquae*	Cyanobacteria	1,660	5.92E+08	3.87E+10
9/10/2008	*Tapinothrix* sp.	Cyanobacteria	52,752	1.88E+10	1.85E+12
	Total		89,905	3.20E+10	2.84E+12
Kabetogama Lake, Sullivan Bay, NW near Ash River, Minn. (site A1, fig. 1, 482542092493701)					
9/1/2009	*Psammothidium sacculum*	Bacillariophyta	1	3.56E+04	3.56E+04
9/1/2009	*Achnanthidium exiguum*	Bacillariophyta	1	2.00E+02	2.00E+02
9/1/2009	*Asterionella formosa*	Bacillariophyta	11	3.92E+05	4.31E+06
9/1/2009	*Aulacoseira alpigena*	Bacillariophyta	165	5.88E+06	9.71E+08
9/1/2009	*Aulacoseira granulata*	Bacillariophyta	127	4.53E+06	5.75E+08
9/1/2009	*Aulacoseira japonica*	Bacillariophyta	57	2.03E+06	1.16E+08
9/1/2009	*Campylodiscus* sp.	Bacillariophyta	1	2.00E+02	2.00E+02
9/1/2009	*Diploneis parma*	Bacillariophyta	1	3.63E+03	3.63E+03
9/1/2009	*Fragilaria capucina*	Bacillariophyta	364	1.32E+06	4.81E+08
9/1/2009	*Gomphonema parvulum*	Bacillariophyta	1	3.63E+03	3.63E+03
9/1/2009	*Melosira varians*	Bacillariophyta	1	2.00E+02	2.00E+02
9/1/2009	*Meridion circulare*	Bacillariophyta	1	3.63E+03	3.63E+03
9/1/2009	*Navicula cryptocephala*	Bacillariophyta	1	2.00E+02	2.00E+02
9/1/2009	*Placoneis elginensis*	Bacillariophyta	1	2.00E+02	2.00E+02
9/1/2009	*Navicula schroeterii*	Bacillariophyta	1	3.63E+03	3.63E+03
9/1/2009	*Nitzschia acicularis*	Bacillariophyta	2	7.13E+04	1.43E+05
9/1/2009	*Nitzschia amphibia*	Bacillariophyta	22	7.84E+05	1.73E+07
9/1/2009	*Planothidium lanceolatum*	Bacillariophyta	1	3.63E+03	3.63E+03
9/1/2009	*Pseudostaurosira brevistriata*	Bacillariophyta	2	7.26E+03	1.45E+04
9/1/2009	*Rhoicosphenia curvata*	Bacillariophyta	1	2.00E+02	2.00E+02
9/1/2009	*Stephanocyclus meneghiniana*	Bacillariophyta	3	1.07E+05	3.21E+05
9/1/2009	*Stephanodiscus hantzschii*	Bacillariophyta	1	3.56E+04	3.56E+04
9/1/2009	*Actinastrum hantzschii*	Chlorophyta	8	2.91E+04	2.32E+05
9/1/2009	*Coelastrum sphaericum*	Chlorophyta	27	9.63E+05	2.60E+07
9/1/2009	*Dictyosphaerium pulchellum*	Chlorophyta	120	4.28E+06	5.13E+08
9/1/2009	*Pediastrum duplex*	Chlorophyta	16	3.20E+03	5.12E+04
9/1/2009	*Pyramimonas tetrarhynchus*	Chlorophyta	8	2.85E+05	2.28E+06
9/1/2009	*Scenedesmus abundans* var. *brevicauda*	Chlorophyta	4	1.45E+04	5.81E+04
9/1/2009	*Scenedesmus arcuatus*	Chlorophyta	4	8.00E+02	3.20E+03
9/1/2009	*Scenedesmus brasiliensis*	Chlorophyta	4	1.45E+04	5.81E+04
9/1/2009	*Scenedesmus dimorphus*	Chlorophyta	4	8.00E+02	3.20E+03

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; μm^3/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (μm^3/L)
Kabetogama Lake, Sullivan Bay, NW near Ash River, Minn. (site A1, fig. 1, 482542092493701)—Continued					
9/1/2009	*Scenedesmus quadricauda*	Chlorophyta	4	8.00E+02	3.20E+03
9/1/2009	*Sphaerocystis schroeteri*	Chlorophyta	8	1.60E+03	1.28E+04
9/1/2009	*Tetraedron* sp.	Chlorophyta	1	2.00E+02	2.00E+02
9/1/2009	*Tetraedron trigonum*	Chlorophyta	1	3.56E+04	3.56E+04
9/1/2009	*Dinobryon* sp.	Chrysophyta	27	9.81E+04	2.65E+06
9/1/2009	*Mallomonas* sp.	Chrysophyta	2	7.26E+03	1.45E+04
9/1/2009	*Cryptomonas* sp.	Cryptophyta	3	1.07E+05	3.21E+05
9/1/2009	*Rhodomonas minuta*	Cryptophyta	15	5.35E+05	8.02E+06
9/1/2009	*Anabaena circinalis*	Cyanobacteria	10	3.56E+05	3.56E+06
9/1/2009	*Anabaena planctonica*	Cyanobacteria	178	6.35E+06	1.13E+09
9/1/2009	*Anabaenopsis circularis*	Cyanobacteria	61	2.22E+05	1.35E+07
9/1/2009	*Aphanizomenon* sp.	Cyanobacteria	37	1.32E+06	4.88E+07
9/1/2009	*Chroococcus* sp.	Cyanobacteria	183	3.66E+04	6.70E+06
9/1/2009	*Euglena elastica*	Euglenophyta	1	2.00E+02	2.00E+02
9/1/2009	*Phacus pseudosworenkoi*	Euglenophyta	1	2.00E+02	2.00E+02
9/1/2009	*Phacus* sp.	Euglenophyta	1	2.00E+02	2.00E+02
9/1/2009	*Trachelomonas acanthostoma*	Euglenophyta	4	1.45E+04	5.81E+04
9/1/2009	*Trachelomonas pulcherrima* var. *minor*	Euglenophyta	1	3.56E+04	3.56E+04
9/1/2009	*Trachelomonas varians*	Euglenophyta	1	3.63E+03	3.63E+03
	Total		1,500	2.99E+07	3.92E+09
Kabetogama Lake at Cemetary Island, near Ray, Minn. (site K3, fig. 1, 483012093035001)					
9/1/2009	*Achnanthidium minutissimum*	Bacillariophyta	2	7.13E+04	1.43E+05
9/1/2009	*Asterionella formosa*	Bacillariophyta	17	6.06E+05	1.03E+07
9/1/2009	*Aulacoseira ambigua*	Bacillariophyta	41	1.46E+06	5.99E+07
9/1/2009	*Aulacoseira granulata*	Bacillariophyta	253	9.02E+06	2.28E+09
9/1/2009	*Cocconeis placentula*	Bacillariophyta	1	3.56E+04	3.56E+04
9/1/2009	*Cyclotella pseudostelligera*	Bacillariophyta	1	3.56E+04	3.56E+04
9/1/2009	*Gomphonema angustatum*	Bacillariophyta	1	2.00E+02	2.00E+02
9/1/2009	*Placoneis elginensis*	Bacillariophyta	1	2.00E+02	2.00E+02
9/1/2009	*Navicula radiosa*	Bacillariophyta	1	2.00E+02	2.00E+02
9/1/2009	*Nitzschia acicularis*	Bacillariophyta	3	1.07E+05	3.21E+05
9/1/2009	*Nitzschia amphibia*	Bacillariophyta	2	7.26E+03	1.45E+04
9/1/2009	*Nitzschia* sp.	Bacillariophyta	2	7.26E+03	1.45E+04
9/1/2009	*Rhoicosphenia curvata*	Bacillariophyta	1	2.00E+02	2.00E+02
9/1/2009	*Stephanocyclus meneghiniana*	Bacillariophyta	3	1.07E+05	3.21E+05
9/1/2009	*Stephanodiscus niagarae*	Bacillariophyta	2	7.13E+04	1.43E+05
9/1/2009	*Synedra* sp.	Bacillariophyta	1	2.00E+02	2.00E+02
9/1/2009	*Synedra tenera*	Bacillariophyta	3	1.07E+05	3.21E+05
9/1/2009	*Characium ambiguum*	Chlorophyta	4	8.00E+02	3.20E+03

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm³/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (µm³/L)
Kabetogama Lake at Cemetary Island, near Ray, Minn. (site K3, fig. 1, 483012093035001)—Continued					
9/1/2009	*Chlamydomonas* sp.	Chlorophyta	1	3.63E+03	3.63E+03
9/1/2009	*Closteriopsis* sp.	Chlorophyta	1	3.56E+04	3.56E+04
9/1/2009	*Coelastrum microporum*	Chlorophyta	14	2.80E+03	3.92E+04
9/1/2009	*Crucigenia quadrata*	Chlorophyta	4	1.45E+04	5.81E+04
9/1/2009	*Crucigenia tetrapedia*	Chlorophyta	4	1.43E+05	5.70E+05
9/1/2009	*Dictyosphaerium pulchellum*	Chlorophyta	59	2.14E+05	1.26E+07
9/1/2009	*Kirchneriella contorta*	Chlorophyta	8	2.85E+05	2.28E+06
9/1/2009	*Oocystis parva*	Chlorophyta	4	8.00E+02	3.20E+03
9/1/2009	*Pyramimonas tetrarhynchus*	Chlorophyta	2	7.13E+04	1.43E+05
9/1/2009	*Quadrigula* sp.	Chlorophyta	4	8.00E+02	3.20E+03
9/1/2009	*Scenedesmus bijuga*	Chlorophyta	4	8.00E+02	3.20E+03
9/1/2009	*Scenedesmus* sp.	Chlorophyta	4	1.43E+05	5.70E+05
9/1/2009	*Tetraedron constrictum*	Chlorophyta	1	2.00E+02	2.00E+02
9/1/2009	*Dinobryon* sp.	Chrysophyta	40	1.45E+05	5.81E+06
9/1/2009	*Mallomonas alpina*	Chrysophyta	2	7.26E+03	1.45E+04
9/1/2009	*Mallomonas pseudocoronata*	Chrysophyta	1	3.56E+04	3.56E+04
9/1/2009	*Rhodomonas minuta*	Cryptophyta	28	9.98E+05	2.79E+07
9/1/2009	*Anabaena circinalis*	Cyanobacteria	193	6.88E+06	1.33E+09
9/1/2009	*Anabaena planctonica*	Cyanobacteria	215	7.81E+05	1.68E+08
9/1/2009	*Anabaenopsis circularis*	Cyanobacteria	41	8.20E+03	3.36E+05
9/1/2009	*Aphanizomenon* sp.	Cyanobacteria	49	1.75E+06	8.56E+07
9/1/2009	*Aphanocapsa* sp.	Cyanobacteria	166	5.92E+06	9.82E+08
9/1/2009	*Cylindrospermopsis raciborskii*	Cyanobacteria	61	1.22E+04	7.44E+05
9/1/2009	*Leptolyngbya* sp.	Cyanobacteria	1,530	5.45E+07	8.35E+10
9/1/2009	*Microcystis aeruginosa*	Cyanobacteria	3,082	6.16E+05	1.90E+09
9/1/2009	*Raphidiopsis curvata*	Cyanobacteria	23	8.20E+05	1.89E+07
9/1/2009	*Phacus pseudosworenkoi*	Euglenophyta	1	2.00E+02	2.00E+02
9/1/2009	*Trachelomonas varians*	Euglenophyta	1	2.00E+02	2.00E+02
9/1/2009	*Trachelomonas volvocina*	Euglenophyta	1	3.56E+04	3.56E+04
9/1/2009	*Ceratium hirundinella*	Pyrrophyta	1	3.56E+04	3.56E+04
	Total		5,884	8.51E+07	9.03E+10
Kabetogama Lake, Mouth of Tom Cod Creek, near Ray, Minn. (site Q5, fig. 1, 482846093073001)					
9/1/2009	*Psammothidium sacculum*	Bacillariophyta	1	2.40E+03	2.40E+03
9/1/2009	*Aulacoseira granulata*	Bacillariophyta	25	6.01E+04	1.50E+06
9/1/2009	*Cocconeis placentula*	Bacillariophyta	8	1.92E+04	1.54E+05
9/1/2009	*Eunotia naegelii*	Bacillariophyta	1	2.00E+02	2.00E+02
9/1/2009	*Gomphonema olivaceum*	Bacillariophyta	2	4.81E+03	9.61E+03
9/1/2009	*Navicula cryptocephala*	Bacillariophyta	1	2.40E+03	2.40E+03
9/1/2009	*Navicula geoppertiana*	Bacillariophyta	1	2.40E+03	2.40E+03

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm^3/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (µm^3/L)
	Kabetogama Lake, Mouth of Tom Cod Creek, near Ray, Minn. (site Q5, fig. 1, 482846093073001)—Continued				
9/1/2009	*Navicula minuscula*	Bacillariophyta	2	4.81E+03	9.61E+03
9/1/2009	*Nitzschia amphibia*	Bacillariophyta	5	1.20E+04	6.01E+04
9/1/2009	*Nitzschia palea*	Bacillariophyta	11	2.64E+04	2.91E+05
9/1/2009	*Stephanocyclus meneghiniana*	Bacillariophyta	1	2.00E+02	2.00E+02
9/1/2009	*Synedra ulna*	Bacillariophyta	1	2.40E+03	2.40E+03
9/1/2009	*Closteriopsis* sp.	Chlorophyta	1	2.40E+03	2.40E+03
9/1/2009	*Pyramimonas tetrarhynchus*	Chlorophyta	123	2.96E+05	3.64E+07
9/1/2009	*Scenedesmus bijuga*	Chlorophyta	8	1.92E+04	1.54E+05
9/1/2009	*Tetraedron minimum*	Chlorophyta	7	1.68E+04	1.18E+05
9/1/2009	*Mallomonas alpina*	Chrysophyta	1	2.40E+03	2.40E+03
9/1/2009	*Mallomonas pseudocoronata*	Chrysophyta	3	7.21E+03	2.16E+04
9/1/2009	*Cryptomonas* sp.	Cryptophyta	2	4.81E+03	9.61E+03
9/1/2009	*Rhodomonas minuta*	Cryptophyta	214	5.14E+05	1.10E+08
9/1/2009	*Pseudanabaena* sp.	Cyanobacteria	23	5.53E+04	1.27E+06
9/1/2009	*Euglena polymorpha*	Euglenophyta	1	2.40E+03	2.40E+03
9/1/2009	*Trachelomonas hispida*	Euglenophyta	1	2.40E+03	2.40E+03
9/1/2009	*Trachelomonas volvocina*	Euglenophyta	1	3.63E+03	3.63E+03
	Total		444	1.06E+06	1.50E+08
	Kabetogama Lake at Ek Lake Trail near Ash River, Minn. (site A5, fig. 1, 482804092494701)				
9/8/2009	*Achnanthidium minutissimum*	Bacillariophyta	5	5.24E+04	2.62E+05
9/8/2009	*Asterionella formosa*	Bacillariophyta	11	2.20E+04	2.42E+05
9/8/2009	*Aulacoseira granulata*	Bacillariophyta	83	8.70E+05	7.22E+07
9/8/2009	*Cocconeis placentula*	Bacillariophyta	8	8.39E+04	6.71E+05
9/8/2009	*Cymbella* sp.	Bacillariophyta	1	2.00E+03	2.00E+03
9/8/2009	*Fragilaria crotonensis*	Bacillariophyta	4	4.19E+04	1.68E+05
9/8/2009	*Gomphonema gracile*	Bacillariophyta	2	2.10E+04	4.19E+04
9/8/2009	*Gomphonema olivaceum*	Bacillariophyta	1	2.00E+03	2.00E+03
9/8/2009	*Navicula radiosa*	Bacillariophyta	1	2.00E+03	2.00E+03
9/8/2009	*Nitzschia palea*	Bacillariophyta	2	4.00E+03	8.00E+03
9/8/2009	*Nitzschia* sp.	Bacillariophyta	3	6.00E+03	1.80E+04
9/8/2009	*Rhopalodia gibba*	Bacillariophyta	4	4.19E+04	1.68E+05
9/8/2009	*Botryococcus braunii*	Chlorophyta	581	6.09E+06	3.54E+09
9/8/2009	*Chlamydomonas globosa*	Chlorophyta	1	2.00E+03	2.00E+03
9/8/2009	*Coelastrum microporum*	Chlorophyta	42	4.40E+05	1.85E+07
9/8/2009	*Crucigenia tetrapedia*	Chlorophyta	17	1.78E+05	3.03E+06
9/8/2009	*Scenedesmus opoliensis*	Chlorophyta	9	9.44E+04	8.49E+05
9/8/2009	*Mallomonas alpina*	Chrysophyta	3	3.15E+04	9.44E+04
9/8/2009	*Rhodomonas minuta*	Cryptophyta	135	1.42E+06	1.91E+08
9/8/2009	*Anabaena circinalis*	Cyanobacteria	2,253	2.36E+07	5.32E+10

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm³/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^yy; sp., species]

Collection date	Genus	Division²	Quantity	Density (cells/L)	Biovolume (µm³/L)
Kabetogama Lake at Ek Lake Trail near Ash River, Minn. (site A5, fig. 1, 482804092494701)—Continued					
9/8/2009	*Anabaena planctonica*	Cyanobacteria	934	9.79E+06	9.15E+09
9/8/2009	*Anabaena* sp.	Cyanobacteria	2,531	2.65E+07	6.72E+10
9/8/2009	*Anabaena spiroides*	Cyanobacteria	143	5.19E+06	7.43E+08
9/8/2009	*Anabaenopsis circularis*	Cyanobacteria	681	7.14E+06	4.86E+09
9/8/2009	*Aphanizomenon* sp.	Cyanobacteria	1,495	1.57E+07	2.34E+10
9/8/2009	*Aphanothece stagnina*	Cyanobacteria	57	1.14E+05	6.50E+06
9/8/2009	*Cylindrospermopsis raciborskii*	Cyanobacteria	269	2.82E+06	7.59E+08
9/8/2009	*Gloeotrichia* sp.	Cyanobacteria	45,568	4.78E+08	2.18E+13
9/8/2009	*Oscillatoria* sp.	Cyanobacteria	1,343	1.41E+07	1.89E+10
9/8/2009	*Pseudanabaena* sp.	Cyanobacteria	704	7.38E+06	5.20E+09
9/8/2009	*Raphidiopsis curvata*	Cyanobacteria	7	1.40E+04	9.80E+04
9/8/2009	*Trachelomonas hispida*	Euglenophyta	5	5.24E+04	2.62E+05
9/8/2009	*Trachelomonas varians*	Euglenophyta	2	4.00E+03	8.00E+03
	Total		56,905	6.00E+08	2.20E+13
Kabetogama Lake at Ek's Bay near Ash River, Minn. (site A6, fig. 1, 482808092504901)					
9/8/2009	*Achnanthidium minutissimum*	Bacillariophyta	2	1.22E+05	2.44E+05
9/8/2009	*Amphora ovalis*	Bacillariophyta	2	4.00E+03	8.00E+03
9/8/2009	*Asterionella formosa*	Bacillariophyta	3	1.83E+05	5.50E+05
9/8/2009	*Aulacoseira ambigua*	Bacillariophyta	20	1.22E+06	2.44E+07
9/8/2009	*Aulacoseira granulata*	Bacillariophyta	47	2.87E+06	1.35E+08
9/8/2009	*Cocconeis placentula*	Bacillariophyta	488	2.98E+07	1.46E+10
9/8/2009	*Cymbella aspera*	Bacillariophyta	1	2.00E+03	2.00E+03
9/8/2009	*Cymbella* sp.	Bacillariophyta	1	3.63E+04	3.63E+04
9/8/2009	*Epithemia sorex*	Bacillariophyta	2	7.26E+04	1.45E+05
9/8/2009	*Epithemia* sp.	Bacillariophyta	1	3.63E+04	3.63E+04
9/8/2009	*Eunotia* sp.	Bacillariophyta	1	2.00E+03	2.00E+03
9/8/2009	*Gomphonema acuminatum*	Bacillariophyta	2	7.26E+04	1.45E+05
9/8/2009	*Gomphonema clevei*	Bacillariophyta	1	6.11E+04	6.11E+04
9/8/2009	*Gomphonema olivaceum*	Bacillariophyta	5	3.06E+05	1.53E+06
9/8/2009	*Navicula cryptocephala*	Bacillariophyta	2	7.26E+04	1.45E+05
9/8/2009	*Navicula radiosa*	Bacillariophyta	1	3.63E+04	3.63E+04
9/8/2009	*Nitzschia amphibia*	Bacillariophyta	1	2.00E+03	2.00E+03
9/8/2009	*Nitzschia palea*	Bacillariophyta	1	6.11E+04	6.11E+04
9/8/2009	*Nitzschia* sp.	Bacillariophyta	1	2.00E+03	2.00E+03
9/8/2009	*Nitzschia vermicularis*	Bacillariophyta	1	2.00E+03	2.00E+03
9/8/2009	*Pinnularia maior*	Bacillariophyta	1	2.00E+03	2.00E+03
9/8/2009	*Planothidium lanceolatum*	Bacillariophyta	2	1.22E+05	2.44E+05
9/8/2009	*Pseudostaurosira brevistriata*	Bacillariophyta	1	6.11E+04	6.11E+04
9/8/2009	*Sellaphora pupula*	Bacillariophyta	1	3.63E+04	3.63E+04

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm^3/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (µm^3/L)
	Kabetogama Lake at Ek's Bay near Ash River, Minn. (site A6, fig. 1, 482808092504901)—Continued				
9/8/2009	*Stauroneis anceps*	Bacillariophyta	1	6.11E+04	6.11E+04
9/8/2009	*Staurosira construens* var. *elliptica*	Bacillariophyta	55	3.36E+06	1.85E+08
9/8/2009	*Stephanocyclus meneghiniana*	Bacillariophyta	1	6.11E+04	6.11E+04
9/8/2009	*Stephanodiscus niagarae*	Bacillariophyta	7	4.28E+05	2.99E+06
9/8/2009	*Botryococcus braunii*	Chlorophyta	883	3.21E+07	2.83E+10
9/8/2009	*Cryptomonas* sp.	Cryptophyta	3	1.83E+05	5.50E+05
9/8/2009	*Anabaena circinalis*	Cyanobacteria	354	2.16E+07	7.66E+09
9/8/2009	*Anabaena planctonica*	Cyanobacteria	295	1.80E+07	5.32E+09
9/8/2009	*Anabaena* sp.	Cyanobacteria	13	7.94E+05	1.03E+07
9/8/2009	*Anabaena spiroides*	Cyanobacteria	84	1.68E+05	1.41E+07
9/8/2009	*Anabaenopsis circularis*	Cyanobacteria	15	9.17E+05	1.38E+07
9/8/2009	*Aphanizomenon* sp.	Cyanobacteria	213	7.74E+06	1.65E+09
9/8/2009	*Aphanothece stagnina*	Cyanobacteria	841	5.14E+07	4.32E+10
9/8/2009	*Leptolyngbya* sp.	Cyanobacteria	38	2.32E+06	8.82E+07
9/8/2009	*Microcystis aeruginosa*	Cyanobacteria	558	3.41E+07	1.90E+10
9/8/2009	*Oscillatoria* sp.	Cyanobacteria	2,280	1.39E+08	3.18E+11
9/8/2009	*Trachelomonas robusta*	Euglenophyta	1	6.11E+04	6.11E+04
9/8/2009	*Trachelomonas varians*	Euglenophyta	1	6.11E+04	6.11E+04
	Total		6,231	3.48E+08	4.38E+11
	Kabetogama Lake, Sullivan Bay, NW near Ash River, Minn. (site A1, fig. 1, 482542092493701)				
9/8/2009	*Psammothidium sacculum*	Bacillariophyta	5	9.72E+03	4.86E+04
9/8/2009	*Asterionella formosa*	Bacillariophyta	5	1.82E+04	9.08E+04
9/8/2009	*Aulacoseira alpigena*	Bacillariophyta	127	2.47E+05	3.14E+07
9/8/2009	*Aulacoseira granulata*	Bacillariophyta	8	1.56E+04	1.24E+05
9/8/2009	*Aulacoseira japonica*	Bacillariophyta	57	1.11E+05	6.32E+06
9/8/2009	*Cocconeis placentula*	Bacillariophyta	1	2.00E+02	2.00E+02
9/8/2009	*Diploneis parma*	Bacillariophyta	1	3.63E+03	3.63E+03
9/8/2009	*Eunotia praerupta*	Bacillariophyta	1	2.00E+02	2.00E+02
9/8/2009	*Gomphonema olivaceum*	Bacillariophyta	1	3.63E+03	3.63E+03
9/8/2009	*Navicula minusculoides*	Bacillariophyta	1	3.63E+03	3.63E+03
9/8/2009	*Navicula* sp.	Bacillariophyta	1	2.00E+02	2.00E+02
9/8/2009	*Navicula veneta*	Bacillariophyta	1	3.63E+03	3.63E+03
9/8/2009	*Nitzschia amphibia*	Bacillariophyta	1	3.63E+03	3.63E+03
9/8/2009	*Nitzschia* sp.	Bacillariophyta	2	3.89E+03	7.78E+03
9/8/2009	*Rhoicosphenia curvata*	Bacillariophyta	3	5.83E+03	1.75E+04
9/8/2009	*Staurosirella pinnata*	Bacillariophyta	3	6.00E+02	1.80E+03
9/8/2009	*Stephanocyclus meneghiniana*	Bacillariophyta	5	9.72E+03	4.86E+04
9/8/2009	*Characium* sp.	Chlorophyta	2	7.26E+03	1.45E+04
9/8/2009	*Dictyosphaerium pulchellum*	Chlorophyta	89	3.23E+05	2.88E+07

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm³/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^yy^; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (µm³/L)
Kabetogama Lake, Sullivan Bay, NW near Ash River, Minn. (site A1, fig. 1, 482542092493701)—Continued					
9/8/2009	*Kirchneriella lunaris* var. *irregularis*	Chlorophyta	5	1.82E+04	9.08E+04
9/8/2009	*Oocystis parva*	Chlorophyta	4	1.45E+04	5.81E+04
9/8/2009	*Pandorina morum*	Chlorophyta	25	5.00E+03	1.25E+05
9/8/2009	*Pyramimonas tetrarhynchus*	Chlorophyta	9	1.75E+04	1.58E+05
9/8/2009	*Dinobryon* sp.	Chrysophyta	32	6.22E+04	1.99E+06
9/8/2009	*Rhodomonas minuta*	Cryptophyta	81	1.58E+05	1.28E+07
9/8/2009	*Anabaena circinalis*	Cyanobacteria	1,298	2.52E+06	3.28E+09
9/8/2009	*Anabaena planctonica*	Cyanobacteria	882	1.72E+06	1.51E+09
9/8/2009	*Anabaena* sp.	Cyanobacteria	505	9.82E+05	4.96E+08
9/8/2009	*Anabaenopsis circularis*	Cyanobacteria	507	9.86E+05	5.00E+08
9/8/2009	*Aphanizomenon* sp.	Cyanobacteria	3,711	7.22E+06	2.68E+10
9/8/2009	*Aphanocapsa* sp.	Cyanobacteria	306	1.11E+06	3.40E+08
9/8/2009	*Aphanothece stagnina*	Cyanobacteria	386	7.72E+04	2.98E+07
9/8/2009	*Aphanothece* sp.	Cyanobacteria	49	1.78E+05	8.72E+06
9/8/2009	*Pseudanabaena* sp.	Cyanobacteria	51	9.92E+04	5.06E+06
9/8/2009	*Raphidiopsis curvata*	Cyanobacteria	6	2.18E+04	1.31E+05
9/8/2009	*Trachelomonas acanthostoma*	Euglenophyta	2	3.89E+03	7.78E+03
9/8/2009	*Trachelomonas pulcherrima*	Euglenophyta	13	2.53E+04	3.29E+05
9/8/2009	*Trachelomonas volvocina*	Euglenophyta	1	3.63E+03	3.63E+03
	Total		8,187	1.60E+07	3.30E+10
Kabetogama Lake west of Bald Rock Bay near Ray, Minn. (site A7, fig. 1, 483118093033601)					
9/10/2009	*Asterionella formosa*	Bacillariophyta	4	8.00E+03	3.20E+04
9/10/2009	*Aulacoseira granulata*	Bacillariophyta	55	1.37E+06	7.52E+07
9/10/2009	*Cocconeis placentula*	Bacillariophyta	4	9.95E+04	3.98E+05
9/10/2009	*Cyclotella pseudostelligera*	Bacillariophyta	6	1.49E+05	8.95E+05
9/10/2009	*Fragilaria capucina*	Bacillariophyta	2	4.00E+03	8.00E+03
9/10/2009	*Nitzschia palea*	Bacillariophyta	2	4.97E+04	9.95E+04
9/10/2009	*Stephanodiscus niagarae*	Bacillariophyta	7	1.74E+05	1.22E+06
9/10/2009	*Botryococcus braunii*	Chlorophyta	181	4.50E+06	8.15E+08
9/10/2009	*Chlamydomonas globosa*	Chlorophyta	1	3.63E+04	3.63E+04
9/10/2009	*Crucigenia tetrapedia*	Chlorophyta	9	2.24E+05	2.01E+06
9/10/2009	*Pyramimonas tetrarhynchus*	Chlorophyta	2	4.97E+04	9.95E+04
9/10/2009	*Rhodomonas minuta*	Cryptophyta	142	3.53E+06	5.02E+08
9/10/2009	*Anabaena circinalis*	Cyanobacteria	1,832	4.56E+07	8.35E+10
9/10/2009	*Anabaenopsis circularis*	Cyanobacteria	317	7.88E+06	2.50E+09
9/10/2009	*Aphanizomenon* sp.	Cyanobacteria	519	1.29E+07	6.70E+09
9/10/2009	*Aphanothece stagnina*	Cyanobacteria	2,241	5.57E+07	1.25E+11
9/10/2009	*Gloeotrichia* sp.	Cyanobacteria	52,780	1.06E+08	5.57E+12
9/10/2009	*Microcystis aeruginosa*	Cyanobacteria	28,696	7.14E+08	2.05E+13

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; μm^3/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (μm^3/L)
Kabetogama Lake west of Bald Rock Bay near Ray, Minn. (site A7, fig. 1, 483118093033601)—Continued					
9/10/2009	*Oscillatoria* sp.	Cyanobacteria	2,027	5.04E+07	1.02E+11
9/10/2009	*Pseudanabaena* sp.	Cyanobacteria	67	1.67E+06	1.12E+08
9/10/2009	*Raphidiopsis curvata*	Cyanobacteria	43	1.07E+06	4.60E+07
9/10/2009	*Ceratium hirundinella*	Pyrrophyta	1	3.63E+04	3.63E+04
9/10/2009	*Glenodinium quadridens*	Pyrrophyta	1	2.00E+03	2.00E+03
	Total		88,939	1.00E+09	2.64E+13
Kabetogama Lake at Bald Rock Bay near Ray, Minn. (site A8, fig. 1, 483146093032201)					
9/10/2009	*Psammothidium sacculum*	Bacillariophyta	6	1.05E+06	6.29E+06
9/10/2009	*Achnanthidium minutissimum*	Bacillariophyta	5	8.73E+05	4.37E+06
9/10/2009	*Asterionella formosa*	Bacillariophyta	2	1.60E+04	3.20E+04
9/10/2009	*Aulacoseira granulata*	Bacillariophyta	7	1.22E+06	8.56E+06
9/10/2009	*Cocconeis placentula*	Bacillariophyta	141	2.46E+07	3.47E+09
9/10/2009	*Craticula halophila*	Bacillariophyta	1	8.00E+03	8.00E+03
9/10/2009	*Cymbella* sp.	Bacillariophyta	1	8.00E+03	8.00E+03
9/10/2009	*Epithemia* sp.	Bacillariophyta	1	8.00E+03	8.00E+03
9/10/2009	*Fragilaria capucina*	Bacillariophyta	6	1.05E+06	6.29E+06
9/10/2009	*Gomphonema olivaceum*	Bacillariophyta	1	1.75E+05	1.75E+05
9/10/2009	*Martyana martyii*	Bacillariophyta	2	1.60E+04	3.20E+04
9/10/2009	*Navicula cryptocephala*	Bacillariophyta	2	3.49E+05	6.98E+05
9/10/2009	*Navicula radiosa*	Bacillariophyta	1	8.00E+03	8.00E+03
9/10/2009	*Nitzschia amphibia*	Bacillariophyta	12	2.10E+06	2.51E+07
9/10/2009	*Nitzschia inconspicua*	Bacillariophyta	15	2.62E+06	3.93E+07
9/10/2009	*Nitzschia palea*	Bacillariophyta	2	3.49E+05	6.98E+05
9/10/2009	*Nitzschia perminuta*	Bacillariophyta	3	5.24E+05	1.57E+06
9/10/2009	*Planothidium lanceolatum*	Bacillariophyta	15	2.62E+06	3.93E+07
9/10/2009	*Stauroneis wislouchii*	Bacillariophyta	9	1.57E+06	1.41E+07
9/10/2009	*Stephanodiscus niagarae*	Bacillariophyta	5	8.73E+05	4.37E+06
9/10/2009	*Botryococcus braunii*	Chlorophyta	1,756	3.07E+08	5.38E+11
9/10/2009	*Scenedesmus incrassatulus*	Chlorophyta	9	1.57E+06	1.41E+07
9/10/2009	*Anabaena circinalis*	Cyanobacteria	1,322	2.31E+08	3.05E+11
9/10/2009	*Anabaena planctonica*	Cyanobacteria	81	1.41E+07	1.15E+09
9/10/2009	*Anabaenopsis circularis*	Cyanobacteria	208	3.63E+07	7.55E+09
9/10/2009	*Aphanizomenon* sp.	Cyanobacteria	61	1.07E+07	6.50E+08
9/10/2009	*Aphanothece stagnina*	Cyanobacteria	2,161	3.77E+08	8.15E+11
9/10/2009	*Gloeotrichia* sp.	Cyanobacteria	10,868	1.90E+09	2.06E+13
9/10/2009	*Oscillatoria* sp.	Cyanobacteria	1,763	3.08E+08	5.43E+11
9/10/2009	*Pseudanabaena* sp.	Cyanobacteria	58	1.01E+07	5.87E+08
9/10/2009	*Trachelomonas pulcherrima*	Euglenophyta	1	8.00E+03	8.00E+03
	Total		18,525	3.23E+09	2.28E+13

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; μm^3/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (μm^3/L)
Kabetogama Lake at Ek's Bay near Ash River, Minn. (site A6, fig. 1, 482808092504901)					
9/10/2009	*Aulacoseira ambigua*	Bacillariophyta	9	1.31E+06	1.17E+07
9/10/2009	*Aulacoseira granulata*	Bacillariophyta	65	9.43E+06	6.13E+08
9/10/2009	*Cocconeis placentula*	Bacillariophyta	98	1.42E+07	1.39E+09
9/10/2009	*Cymbella cistula*	Bacillariophyta	1	8.00E+03	8.00E+03
9/10/2009	*Cymbella minuta*	Bacillariophyta	1	8.00E+03	8.00E+03
9/10/2009	*Cymbella* sp.	Bacillariophyta	1	1.45E+05	1.45E+05
9/10/2009	*Diploneis oblongella*	Bacillariophyta	2	2.90E+05	5.80E+05
9/10/2009	*Eunotia monodon* var. *bidens*	Bacillariophyta	1	8.00E+03	8.00E+03
9/10/2009	*Eunotia* sp.	Bacillariophyta	3	4.35E+05	1.31E+06
9/10/2009	*Gomphonema clevei*	Bacillariophyta	1	1.45E+05	1.45E+05
9/10/2009	*Gomphonema gracile*	Bacillariophyta	1	8.00E+03	8.00E+03
9/10/2009	*Gomphonema olivaceum*	Bacillariophyta	21	3.05E+06	6.40E+07
9/10/2009	*Gomphonema truncatum*	Bacillariophyta	1	1.45E+05	1.45E+05
9/10/2009	*Navicula capitatoradiata*	Bacillariophyta	1	8.00E+03	8.00E+03
9/10/2009	*Nitzschia amphibia*	Bacillariophyta	5	7.25E+05	3.63E+06
9/10/2009	*Stauroneis phoenicenteron*	Bacillariophyta	1	1.45E+05	1.45E+05
9/10/2009	*Stephanocyclus meneghiniana*	Bacillariophyta	2	2.90E+05	5.80E+05
9/10/2009	*Surirella angusta*	Bacillariophyta	2	2.90E+05	5.80E+05
9/10/2009	*Ankistrodesmus falcatus*	Chlorophyta	8	1.16E+06	9.28E+06
9/10/2009	*Botryococcus braunii*	Chlorophyta	2,116	3.07E+08	6.49E+11
9/10/2009	*Anabaena circinalis*	Cyanobacteria	6,654	9.65E+08	6.42E+12
9/10/2009	*Anabaena planctonica*	Cyanobacteria	1800	2.61E+08	4.70E+11
9/10/2009	*Anabaena* sp.	Cyanobacteria	542	7.86E+07	4.26E+10
9/10/2009	*Anabaena spiroides*	Cyanobacteria	278	2.22E+06	6.18E+08
9/10/2009	*Anabaenopsis circularis*	Cyanobacteria	286	4.15E+07	1.19E+10
9/10/2009	*Aphanothece stagnina*	Cyanobacteria	14,366	2.08E+09	2.99E+13
9/10/2009	*Microcystis aeruginosa*	Cyanobacteria	43,054	6.24E+09	2.69E+14
9/10/2009	*Oscillatoria* sp.	Cyanobacteria	6,636	9.62E+08	6.39E+12
9/10/2009	*Trachelomonas hispida*	Euglenophyta	2	2.90E+05	5.80E+05
9/10/2009	*Trachelomonas* sp.	Euglenophyta	2	2.90E+05	5.80E+05
9/10/2009	*Trachelomonas varians*	Euglenophyta	3	4.35E+05	1.31E+06
	Total		75,963	1.10E+10	3.13E+14
Kabetogama Lake at Ek Lake Trail near Ash River, Minn. (site A5, fig. 1, 482804092494701)					
9/10/2009	*Aulacoseira granulata*	Bacillariophyta	8	2.91E+07	2.32E+08
9/10/2009	*Cocconeis placentula*	Bacillariophyta	12	3.89E+07	4.67E+08
9/10/2009	*Epithemia sorex*	Bacillariophyta	2	7.26E+06	1.45E+07
9/10/2009	*Fragilaria nanana*	Bacillariophyta	3	9.72E+06	2.92E+07
9/10/2009	*Gomphonema clevei*	Bacillariophyta	3	9.72E+06	2.92E+07
9/10/2009	*Nitzschia amphibia*	Bacillariophyta	3	9.72E+06	2.92E+07

Appendix. Algal species composition, density, and biovolume for samples collected from Kabetogama Lake, 2008–09.—Continued

[cells/L, cells per liter; µm^3/L, cubic micrometers per liter; E notation, x.xxE + yy is x.xx times 10^{yy}; sp., species]

Collection date	Genus	Division[2]	Quantity	Density (cells/L)	Biovolume (µm^3/L)
Kabetogama Lake at Ek Lake Trail near Ash River, Minn. (site A5, fig. 1, 482804092494701)—Continued					
9/10/2009	*Nitzschia* sp.	Bacillariophyta	2	6.48E+06	1.30E+07
9/10/2009	*Synedra acus*	Bacillariophyta	2	6.48E+06	1.30E+07
9/10/2009	*Botryococcus braunii*	Chlorophyta	1,308	4.24E+09	5.54E+12
9/10/2009	*Pyramimonas tetrarhynchus*	Chlorophyta	9	2.92E+07	2.63E+08
9/10/2009	*Cryptomonas* sp.	Cryptophyta	1	2.00E+05	2.00E+05
9/10/2009	*Rhodomonas minuta*	Cryptophyta	141	4.57E+08	6.44E+10
9/10/2009	*Anabaena circinalis*	Cyanobacteria	5,593	1.81E+10	1.01E+14
9/10/2009	*Anabaena planctonica*	Cyanobacteria	225	7.29E+08	1.64E+11
9/10/2009	*Anabaena* sp.	Cyanobacteria	331	1.07E+09	3.55E+11
9/10/2009	*Anabaena spiroides*	Cyanobacteria	125	2.50E+07	3.13E+09
9/10/2009	*Anabaenopsis circularis*	Cyanobacteria	131	4.25E+08	5.56E+10
9/10/2009	*Aphanothece stagnina*	Cyanobacteria	2208	7.16E+09	1.58E+13
9/10/2009	*Gloeotrichia* sp.	Cyanobacteria	186,369	6.04E+11	1.13E+17
9/10/2009	*Microcystis* sp.	Cyanobacteria	438	1.59E+09	6.97E+11
9/10/2009	*Oscillatoria* sp.	Cyanobacteria	12,640	4.10E+10	5.18E+14
	Total		209,554	6.79E+11	1.13E+17

[1] Limnothrix occured in 2008 samples only. Several degraded filaments in the 2009 samples could not be verified as Limnothrix.

[2] Divisional names are reported according to nomenclature of Wehr and Sheath (2003) and Van den Hoek and others (1996).

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