NUTRIENTS AND PHYTOPLANKTON
IN SIX LAKES OF SOUTHWESTERN MANITOBA
WITH PARTICULAR REFERENCE TO SEASONAL ANOXIC CONDITIONS

by

VIJAI SRISUWANTACH

A thesis
submitted to the Faculty of Graduate Studies
in partial fulfillment of the requirements for the
degree of Master of Science

Department of Zoology
University of Manitoba
Winnipeg, Manitoba
Canada

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ABSTRACT

Physical and chemical characteristics together with phytoplankton parameters in six lakes of southwestern Manitoba were investigated from February 1976 to February 1977 with a special emphasis on relationships between dissolved oxygen, nutrients, and phytoplankton. These lakes varied in mean depth (1.5-3.4 m), average Secchi disc transparency during ice-free period (0.8-1.5 m), total ions in mid-summer (659-1691 mg/l), maximum winter ammonia nitrogen (331-669 μg/l), maximum winter soluble reactive phosphorus (8-159 μg/l), maximum summer chlorophyll-a content (12-260 μg/l), and maximum summer gross primary production (1.1-6.2 $gC/m^2/day$).

They were classified as non-stratified, shallow, eutrophic, moderately saline to saline lakes with Mg^{++}, $SO_4^{=}$, and HCO_3^- as predominant ions. Oxygen depletion in winter (winterkill) developed between February and March in lakes where the mean depth was 2.8 m or less. No winterkill was observed in a lake with the mean depth of 3.4 m. Oxygen depletion in summer (summerkill) occurred in a winterkill lake that contained maximum winter concentrations of 669 μg/l ammonia nitrogen (NH_3-N) and 159 μg/l soluble reactive phosphorus (SRP), and consequently developed a noxious bloom of Aphanizomenon flos-aquae with a maximum of 260 μg/l chlorophyll-a. The collapse of the bloom caused the dissolved oxygen to drop down to near zero (0.1 mg/l). The high phosphorus content of the lake appeared to be the cause of this bloom. A maximum winter concentration of 150 μg/l SRP or more was found to be the critical level for a high probability of the summerkill

occurrence. A high concentration of nutrients during the summerkill period was recorded. These nutrients did not lead to further *Aphanizomenon* blooms since weather conditions in early fall became less favorable for the growth of this alga. High winter concentrations of nutrients were observed in both winterkill and non-winterkill lakes. A direct relationship between winter nutrient concentration and summer algal standing crop was found in three lakes where the water was well mixed by wind action. This relationship was obscured in three other lakes by submerged macrophytes or nutrient accumulation in the bottom water during the summer months. Higher nutrient concentrations in the following winter in these lakes also appeared to be related with higher chlorophyll-a concentrations in the previous summer.

ACKNOWLEDGEMENTS

I am indebted to Drs. K. Patalas, J. Barica, F.J. Ward, and G.G.C. Robinson for critical comments on the manuscript. In addition, Drs. J. Barica, K. Patalas, and F.P. Healey contributed much in the way of useful discussions and suggestions during the course of the study and preparation of the manuscript. Dr. E.J. Fee advised for the computer aspects of primary production and D. Abrams helped with the regression analysis. H. Kling provided help in phytoplankton identifications; J. Gibson, M. Buckley, and G. Currey provided field assistance; R. Schade, J. Dentry, and G. Regeher provided assistance on the chemical analyses in central laboratory; M. Stainton provided the method and apparatus for analyzing dissolved organic carbon. I also thank J.G.I. Lark for the facilities at the Erickson camp, S. Zettler and L. Davies for reproducing the figures, A. Salki for drawing the hydrographic map of Lake 200 and Lake 019 and G.E. Porth for typing the manuscript.

Special thanks is given to Dr. G.H. Lawler, the Director-General of the Western Region, Fisheries and Marine Service, Department of Fisheries and Environment for enabling me to use the excellent facilities at the Freshwater Institute during this study.

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INTRODUCTION

Most of the Canadian prairie pothole lakes experience periodic seasonal oxygen depletion of varying duration and severity. These are commonly called winterkill or summerkill, depending on the time of occurrence. A cover of ice and snow extending continuously for several months in southwestern Manitoba lakes has a great impact on the aquatic environment. It limits the gaseous exchange (Greenbank 1945) and phytoplankton photosynthesis (Wright 1964). Respiration of organisms and chemical reduction processes under the ice cover make substantial demands on the limited oxygen supply. If oxygen demand exceeds the supply during this period, suffocation of aerobic organisms may occur. Winterkill is a common term used to describe this phenomenon (Greenbank 1945; Scidmore 1957; Moyle and Clothier 1959). During summer months, noxious blooms of blue-green algae may occur in lakes that contain high winter nutrient concentrations. The collapse of blooms and subsequent oxygen depletion due to bacterial decomposition of dead algae may bring about fish mortality, usually called summerkill (Mackenthun et al. 1945; Abeliovich 1969; Barica 1975b; Ayles et al. 1976).

These winter and summer oxygen depletion may be considered as the major factors governing the nutrient cycles in the lakes. The release of nutrients under anoxic conditions has been reported by many researchers (Mortimer 1941, 1942; Hutchinson 1957; Ahl 1966; Burns and Ross 1972; Schindler and Comita 1972; Barica 1974a). These investigations have been confirmed by the laboratory experiments of Grill and Richards (1964) and Foree and Barrow (1970).

It is known that nutrient concentrations can be used to determine the magnitude of algal populations. Many investigations have attempted to correlate the *in situ* phytoplankton development with nutrient concentrations. The best known is the relationship between spring total phosphorus and summer chlorophyll (Sakamoto 1966; Dillon and Rigler 1974). However, a significant correlation between winter maxima of ammonia nitrogen and summer maxima of chlorophyll-a was also reported by Barica (1975b). High concentrations of nutrients, especially nitrogen and phosphorus, are also considered to be an inducement for blue-green algal blooms (Sawyer 1947; Prescott 1960; Hammer 1964; Schindler *et al.* 1971; Renolds and Walsby 1975).

The winterkill and summerkill lakes of southwestern Manitoba received practically no study prior to 1963. Driver (1965) studied limnological aspects of six lakes in west central Manitoba. Between 1969 and 1974, a series of limnological investigations were carried out in southwestern Manitoba lakes. Geography and lake morphometry were reported by Sunde and Barica (1975). Nutrient cycling, effect of sediment mixing on water quality, predicting the summerkill risk, and geochemistry were studied by Barica (1974a, b and 1975a, b respectively). Phytoplankton successions and species distribution were reported by Kling (1975). The changes in physiological characteristics of *Aphanizomenon flos-aquae* during the course of some blooms were also studied by Healey and Hendzel (1976).

There are no studies comparing nutrient chemistry and phytoplankton communities in winterkill and non-winterkill lakes as well as no primary production data reported from southwestern Manitoba lakes. The purpose of this study is to determine the effect of oxygen depletion on nutrient concentrations which consequently relate to phytoplankton production by comparing the nutrients and phytoplankton in summerkill, winterkill, and non-winterkill lakes. This study also further documents changes in water quality of the Aquaculture Experimental Lakes of the Freshwater Institute.

DESCRIPTION OF THE STUDY AREA

The study area is located in central Canada at about 50° 30'N, 100° 10'W and 500 to 650 m above sea level. The area is characterized by morainal deposits resulting from a series of glaciations during the Pleistocene. Most of the area is cultivated with natural forest remaining on hillsides and lake shores (Sunde et al. 1970). The input of nutrients from rich prairie soils, agricultural fertilizers, and wastes from cattle farming are responsible for the high trophic state of the lakes in this area. More details of the description of the study area were reported by Sunde and Barica (1975).

Six lakes involved in this study (Lake 885, Lake 255, Lake 200, Lake 675, Lake 879, and Lake 019) were selected in the Aquaculture Experimental Lakes Area in the Erickson, Elphinstone, and Minnedosa district of southwestern Manitoba (Fig. 1). The selected lakes represented the variety of seasonal oxygen depletion. Two of them (Lake 885 and Lake 879) were known to undergo both winter and summerkill; in two others (Lake 255 and Lake 675) winterkill regularly occurred but no summerkill was expected; in two last lakes (Lake 200 and Lake 019) winterkill had never been observed. The hydrographic maps and sampling sites of these lakes are shown in Fig. 2a-2f. Some morphological characteristics of these lakes are also given in Table 1. The lakes studied have no permanent inflow or outflow. The main sources of water input are surface runoff, ground water inflow, and precipitation falling directly on the water surface. Water loss is mainly by ground seepage and evaporation.

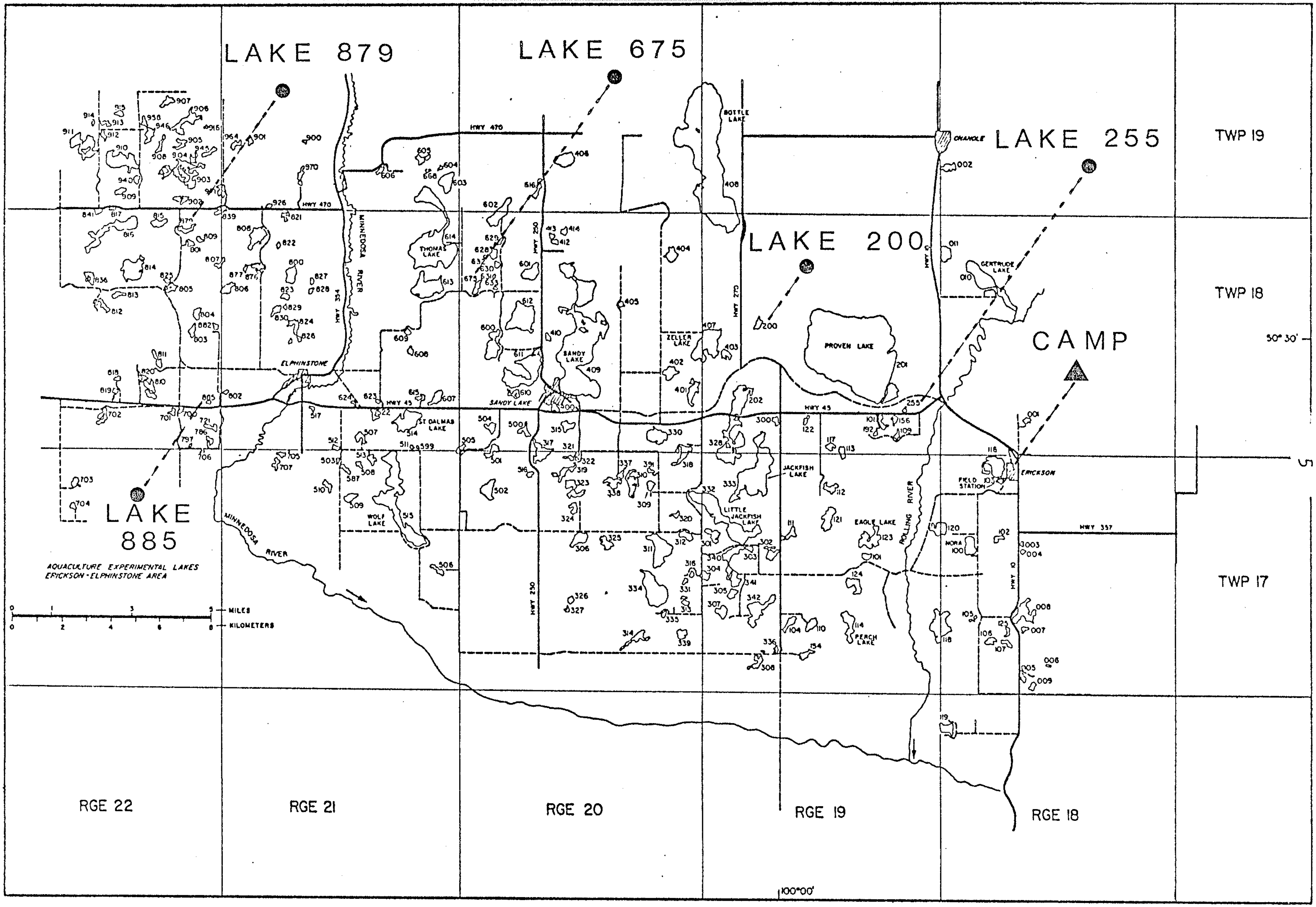


Figure 1. Map of the Aquaculture Experimental Lakes Area, southwestern Manitoba, showing locations of the lakes studied (●). Lake 019 is off this map, being about 30 km southwest of Erickson camp (▲).

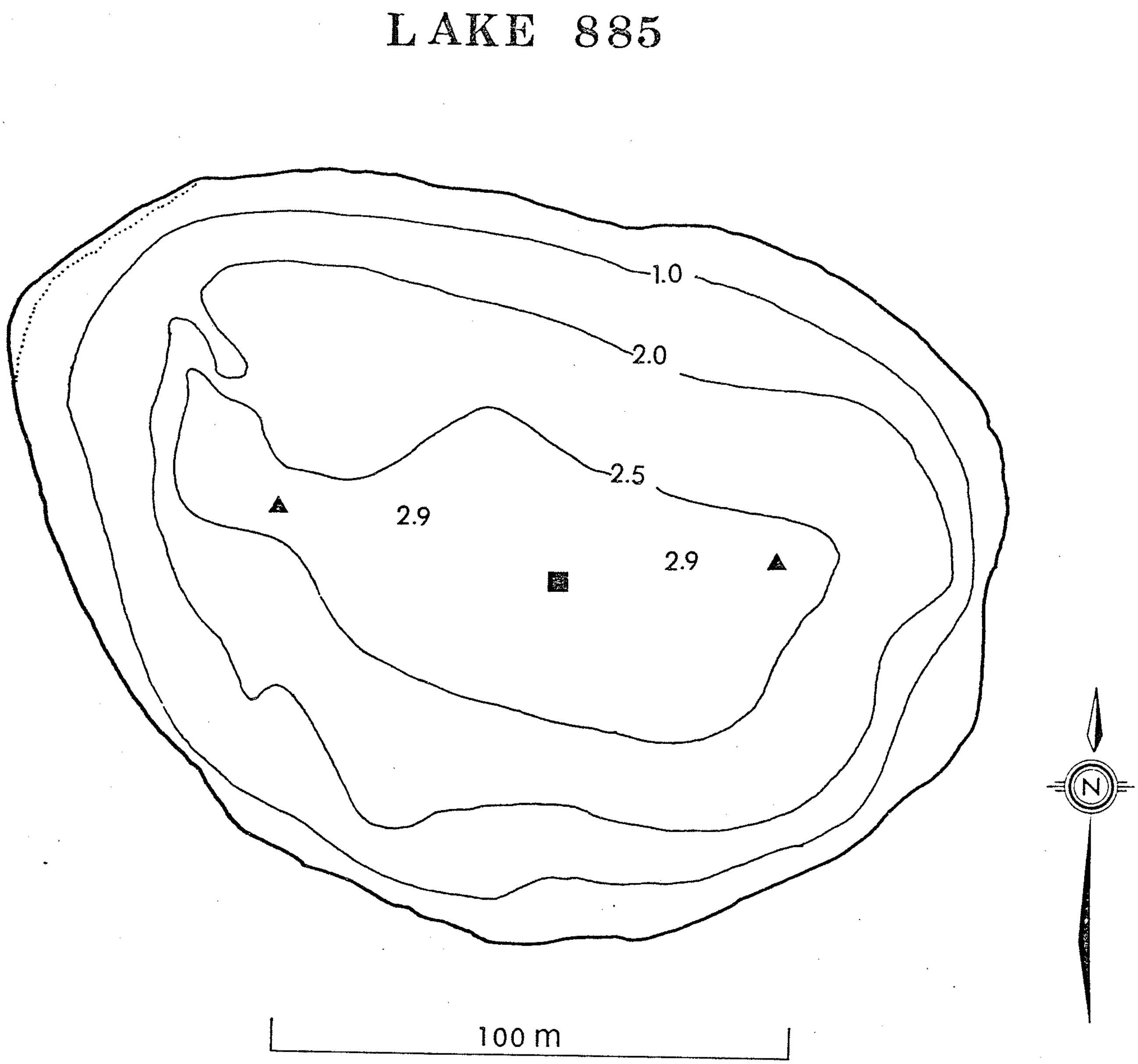


Figure 2a. Hydrographic map of Lake 885 (contours in meters).

..... Outline of emergent aquatic plants.

■ Collection site for physical, chemical, and phytoplankton samples.

▲ Collection site for phytoplankton samples only.

LAKE 255

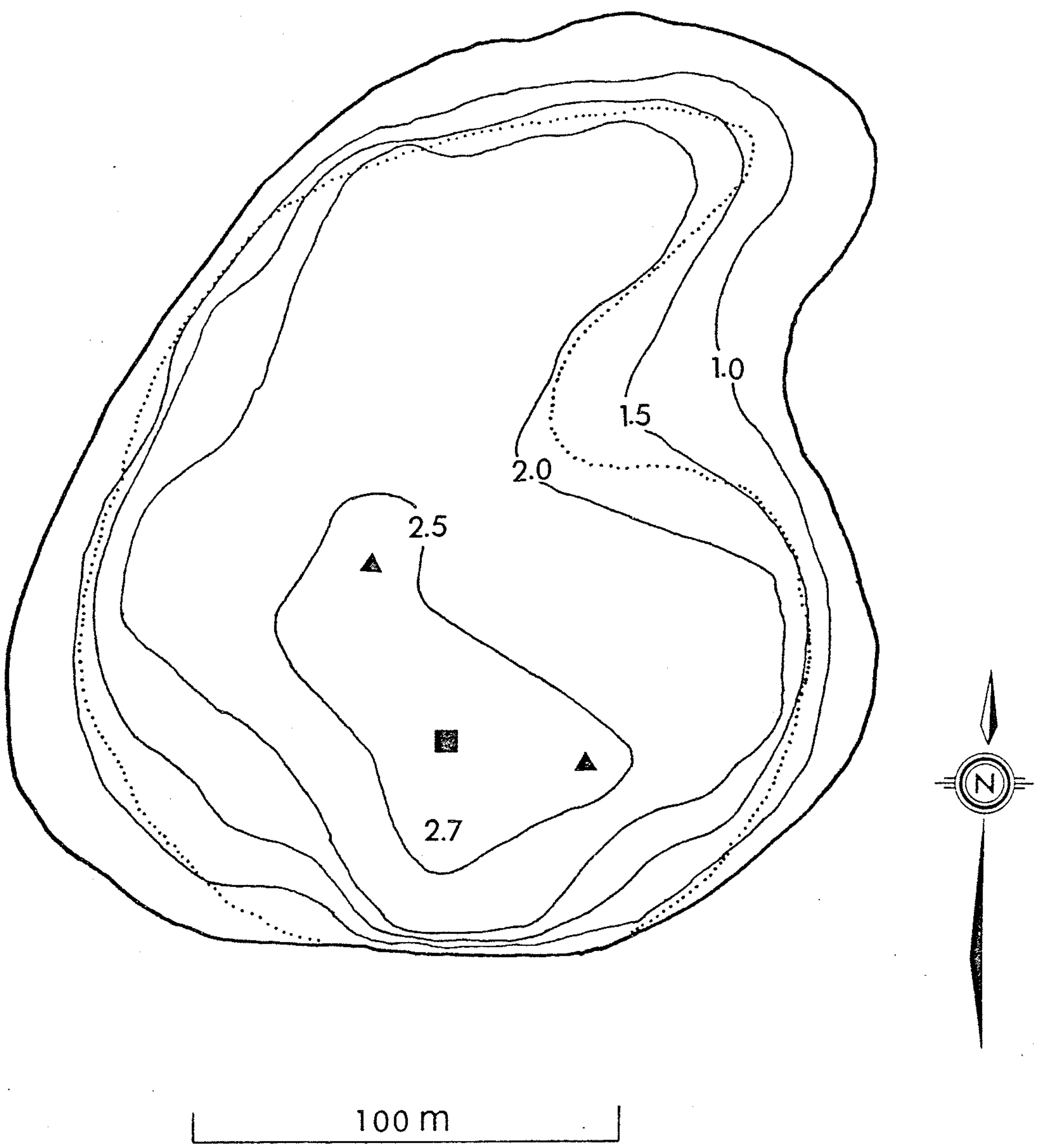


Fig. 2b. Hydrographic map of Lake 255 (contours in meters).

..... Outline of emergent aquatic plants.

■ Collection site for physical, chemical, and phytoplankton samples.

▲ Collection site for phytoplankton samples only.

LAKE 200

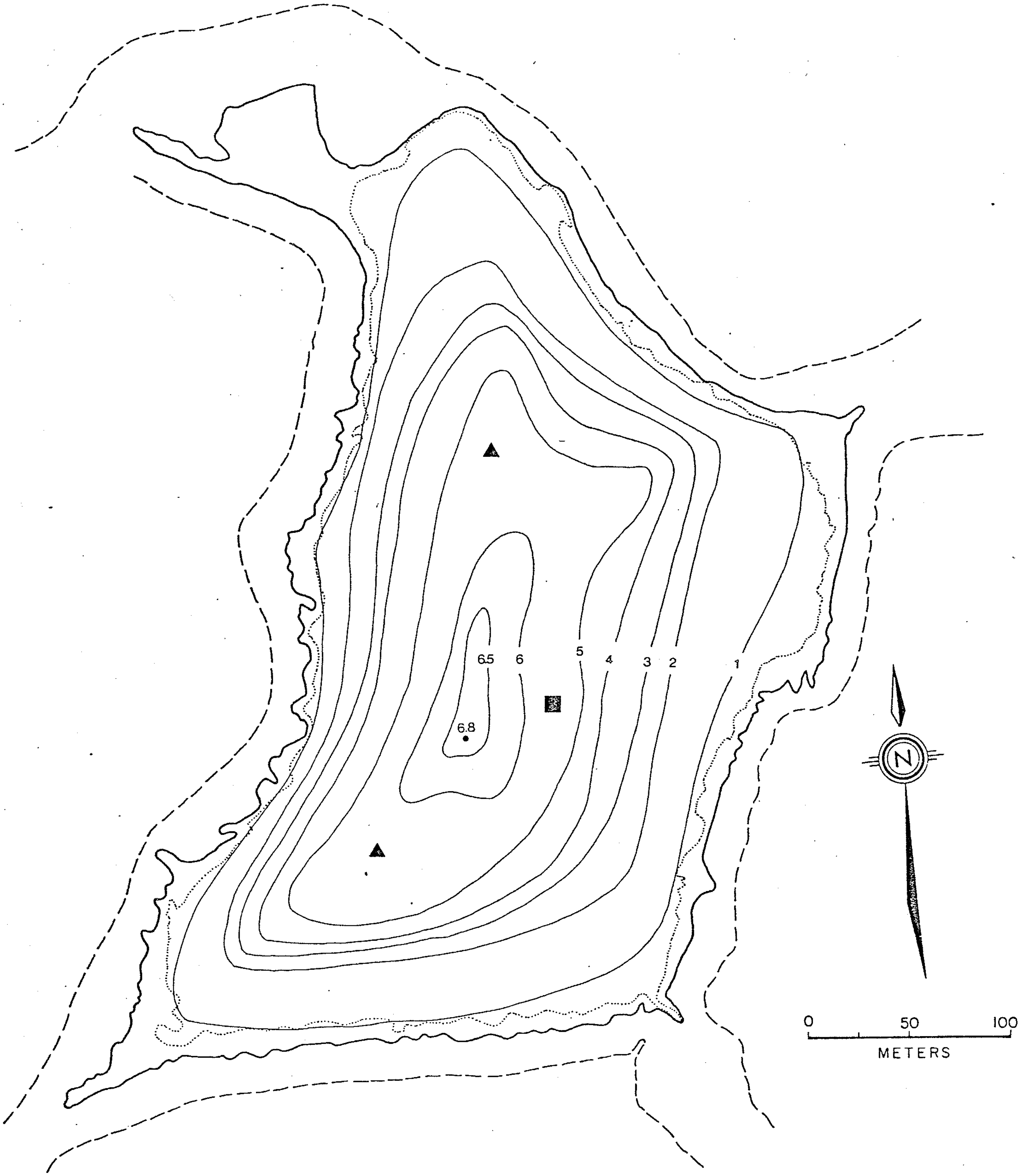


Figure 2c. Hydrographic map of Lake 200 (contours in meters).

..... Outline of emergent aquatic plants.

■ Collection site for physical, chemical, and phytoplankton samples.

▲ Collection site for phytoplankton samples only.

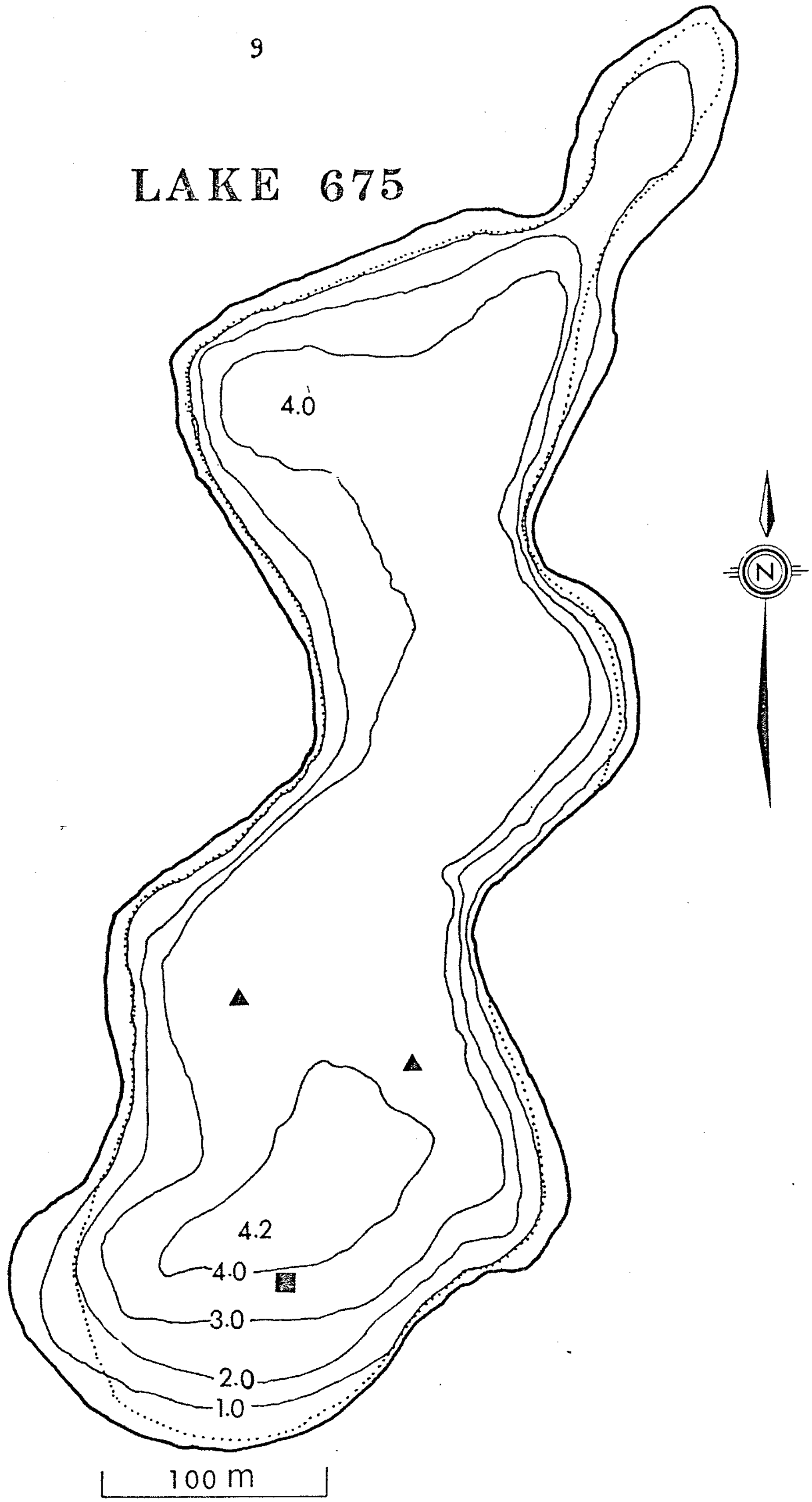


Figure 2d. Hydrographic map of Lake 675 (contours in meters).

..... Outline of emergent aquatic plants.

■ Collection site for physical, chemical, and phytoplankton samples.

▲ Collection site for phytoplankton samples only.

LAKE 879

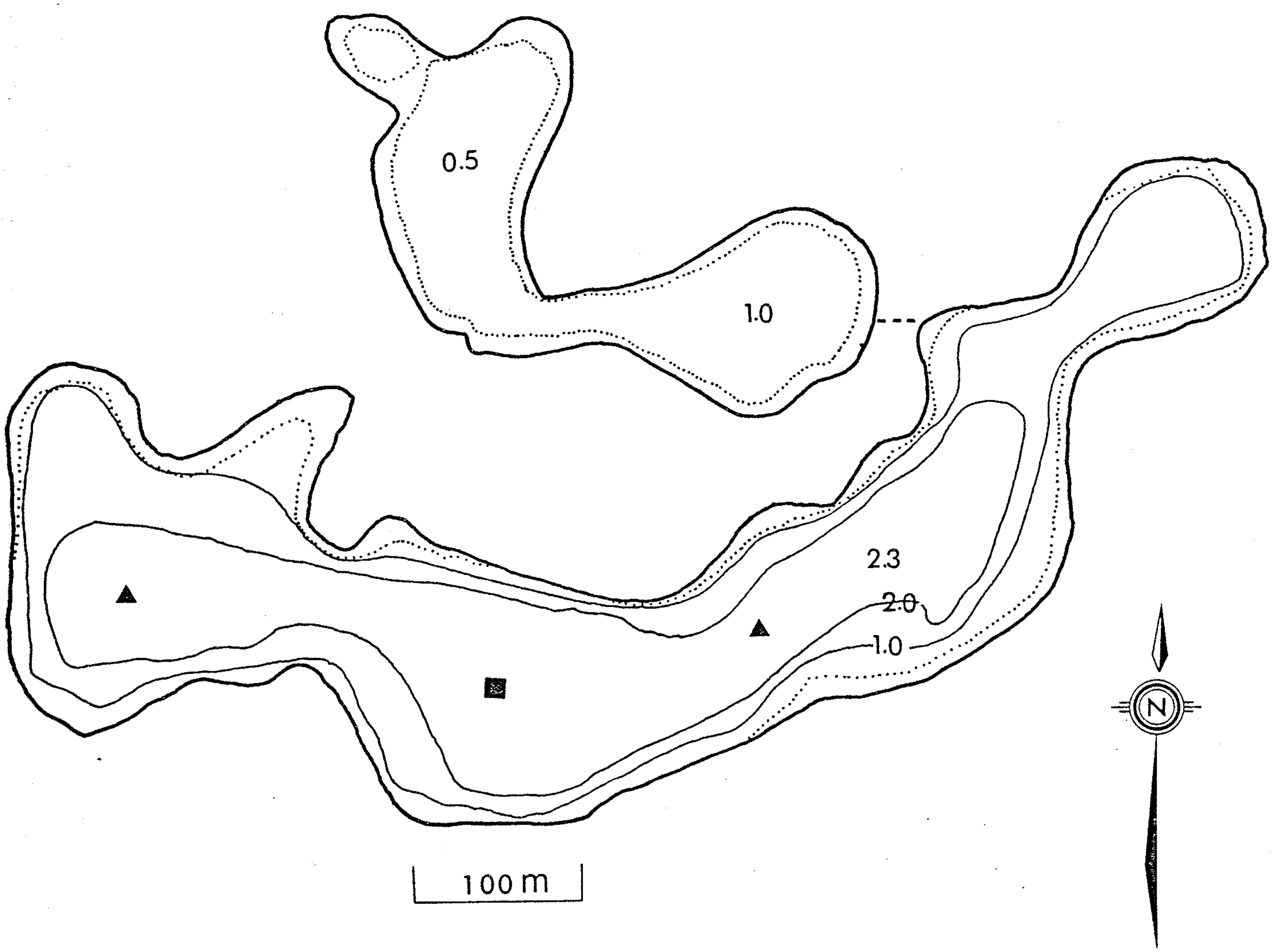


Figure 2e. Hydrographic map of Lake 879 (contours in meters).

..... Outline of emergent aquatic plants.

■ Collection site for physical, chemical, and phytoplankton samples.

▲ Collection site for phytoplankton samples only.

--- Intermittent connection between the shallow bay and the main basin (spring and early summer only).

LAKE 019

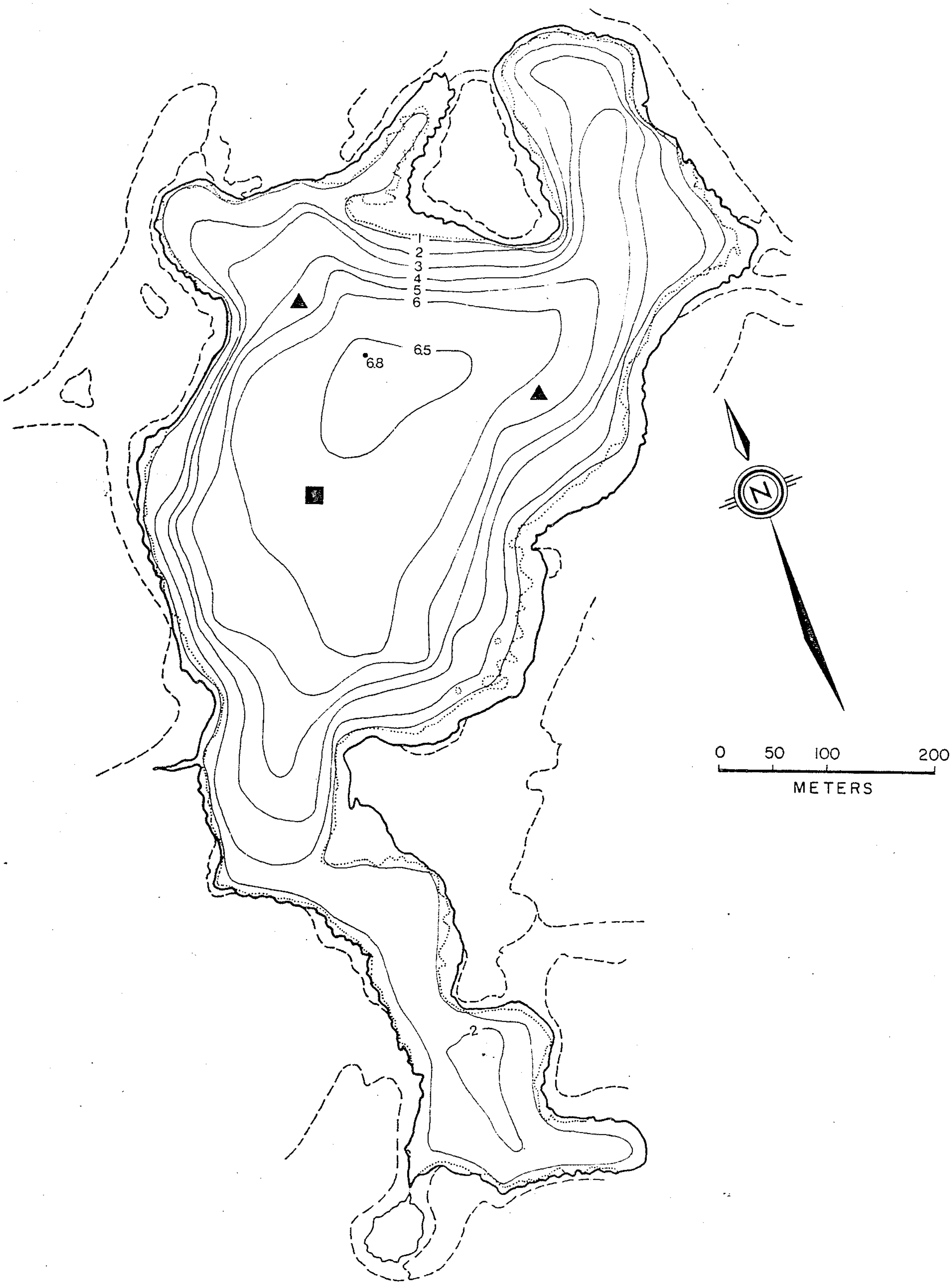


Figure 2f. Hydrographic map of Lake 019 (contours in meters).

..... Outline of emergent aquatic plants.

■ Collection site for physical, chemical and phytoplankton samples.

▲ Collection site for phytoplankton samples only.

Table 1. Morphometric data for six lakes of southwestern Manitoba.

Lake	Surface area (km^2)	Maximum depth (m)	Mean depth (m)	Volume (m^3)	Water level fluctuations* (m)
885	0.024	3.0	1.9	45,600	0.41
255	0.032	2.7	1.7	54,400	0.41
200	0.095	6.8	2.8	266,000	0.43
675	0.097	4.2	2.6	252,200	0.37
879	0.126	2.4	1.5	189,000	0.24
019	0.287	6.8	3.4	975,800	0.55

* During the study period.

METHODS

Sampling procedures

The selected lakes were sampled from February 1976 until February 1977. Sampling rate was monthly during winter, biweekly in spring and fall, weekly during summer and twice a week during the summerkill period. All samples were taken between 9:00 a.m. and 12:00 noon. The lakes were sampled at or close to the site of their maximum depth (Zm) for physical and chemical measurements at the depths (except as otherwise stated) of 0, 1, 2 meters and bottom in Lake 885, Lake 255, Lake 675 and Lake 879; 0, 1, 3 meters and bottom in Lake 200; and 0, 1, 3, 5 meters and bottom in Lake 019. Bottom samples for each lake were taken at about 0.1 m above the bottom.

Physical measurements

Estimates of light penetration were made in two ways. Routinely, Secchi visibility was measured with a 25 cm diameter Secchi disc. From July to October, a Whitney submersible photometer (cadmium sulphide cell) was also used to measure per cent light transmittance. One hundred per cent transmittance was taken at 0.05 meters under the lake surface. Total solar radiation was recorded by means of a Belfort pyrheliometer mounted on a tower at Erickson camp, within 10 to 30 km of all study lakes.

Temperature was measured *in situ* with a YSI tele-thermometer (accuracy to about 0.2°C).

Chemical analysis

Water samples were collected by Kemmerer bottles. Water samples were partially processed for pH, dissolved oxygen, inorganic carbon, ammonia nitrogen, and soluble reactive phosphorus in the field laboratory within 2 to 3 hours of sampling. Samples for dissolved organic carbon, nitrate nitrogen, total dissolved nitrogen, total dissolved phosphorus, major ions, and specific conductance were preserved and analyzed in the Freshwater Institute (FWI) in Winnipeg.

pH, $CO_3^=$, and HCO_3^- were determined potentiometrically on unfiltered samples using a Radiometer Model 4 pH-meter and titration with 0.1 N HCl (from pH exceeding 8.3 to pH 8.3 for $CO_3^=$, and from pH 8.3 to 4.5 for HCO_3^-). Free CO_2 was determined by titration on unfiltered samples with 0.1 N NaOH (from pH less than 8.3 to pH 8.3). The sum of carbon content in $CO_3^=$, HCO_3^-, and CO_2 was expressed as dissolved inorganic carbon (DIC).

Dissolved oxygen was determined by the azide modification of the Winkler method (American Public Health Association 1976).

The remaining chemical analyses of water were done by standard FWI methods (Stainton et al. 1977).

Portions of water samples were filtered through Whatman GF/C filters and filtrate was analyzed for dissolved organic carbon (DOC) by photocombustion with short ultraviolet light and the resultant CO_2 was measured by specific conductance.

Part of the filtrate was used for determining ammonia nitrogen (NH_3-N) and soluble reactive phosphorus (SRP) on a spectrophotometer (Spectronic 88, Bausch and Lomb) using the phenol-hypochlorite and acid molybdate-ascorbic acid methods respectively. Nitrate nitrogen (NO_3-N) was determined on the basis of reducing nitrate to nitrite. The resulting nitrite was measured with an automated colorimetric method.

The remaining filtrate was irradiated with ultraviolet light for analyzing total dissolved nitrogen (TDN) and total dissolved phosphorus (TDP). Concentrations of dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP) were obtained by subtracting the inorganic forms from TDN and TDP.

Samples for major ions and specific conductance were taken twice (February 1976 and August 1976) during the study period from the surface and bottom of each lake. Analyses for Ca^{++}, Mg^{++}, Na^{+}, Fe^{+++}, and Mn^{++} were done by atomic absorption spectrophotometry on filtered, acidified samples. K^{+} was analyzed by atomic emission spectrophotometry on the same samples. $SO_4^{=}$ and Cl^{-} were determined by an ion exchange method. The sum of all determined cations and anions was expressed as total ion concentration (TI). Conductivity was measured at 25°C using YSI conductivity meter calibrated against 0.001 and 0.0001 N KCl standard solution.

Phytoplankton study

Sampling for estimating chlorophyll-a and major phytoplankton taxa was conducted from February 1976 to February 1977. Samples for measuring primary production were taken from June 1976 to October 1976. The frequency of sampling was as mentioned before. Integrated samples from 0-2 m for measurement of primary production, chlorophyll-a, and phytoplankton taxa were collected using a 1.6 inch diameter and 2.2 m long PVC tube at the site of maximum lake depth during the ice covered period and at three sites in each lake during the ice-free period. Water samples were transferred to a 4-liter polyethylene bottle. Upon arrival at the field laboratory, the samples were processed as quickly as possible under conditions of reduced light. The 4-liter sample bottle was shaken to homogenize the sample. The primary production sample was transferred to twelve 60 ml Pyrex reagent bottles using a siphon. Two hundred ml for chlorophyll-a and 50 ml for phytoplankton counts were also collected from the same sample.

Primary production was measured using the light and dark bottle oxygen method of Gaarder and Gran (1927). Samples in 60 ml reagent bottles were incubated in the laboratory using the method of Fee (1973) as modified by Shearer and Fee (1974). Of the twelve 60 ml bottle samples, two bottles were immediately analyzed for the initial dissolved oxygen concentration and eight were used as light bottles at different intensities. Two light bottles were placed in each of the four incubation chambers with known light intensity as measured by a quantum meter (Lambda Instr. Co., model LI-185). The remaining two were used for dark bottles and were wrapped in aluminum foil and black PVC tape. These two bottles were placed in a light tight, cool, box. Samples were incubated for 6 hours. The incubation temperature was maintained within 2°C of the _in situ_ temperature by addition of ice when necessary. The dark bottles were changed from 60 ml to 300 ml and their incubation times extended from 6 to 24 hours after the first week of experiment, since the smaller volume was insufficient to provide accurate respiration data. The dissolved oxygen was measured by a modified Winkler method. Additions of 0.5 ml each of manganese sulphate, alkaline iodide azide, and sulphuric acid were made to 50 ml samples. A 2 ml microburette reading to the nearest 0.002 ml was used to titrate samples with N/10 $Na_2S_2O_3$. The precision of this method at 13.1 mg O_2/l was ± 0.15 mg O_2/l (M. Stainton, personal communication). The readings of two replicate samples were averaged. Oxygen increase in the light bottle was interpreted as a measure of net photosynthesis, oxygen decrease in the dark bottle as dark respiration, and the sum of these changes as gross photosynthesis. The value of 1.0 was assumed for photosynthetic quotient and respiration quotient. The carbon values were obtained from the oxygen values by multiplying with 0.375 (Strickland 1960). The numerical model of Fee (1977) was used to calculate daily areal production rates (mg C/m^2/day).

Filters for chlorophyll-a analysis (uncorrected for phreophytins) were frozen and stored in the dark. The filters were ground in a 90% acetone solution and the fluorescence of the extract was measured on a Turner Model III Fluorometer (Stainton et al. 1977).

Phytoplankton samples were immediately preserved on collection with Lugol's solution (Kling and Holmgren 1972). Phytoplankton counts were obtained with an inverted microscope using the Utermöhl technique described by Margalef in Vollenweider (1971). The cell numbers were converted to total phytoplankton volume by approximation to geometrical shapes (Vollenweider 1971). The cell volume was then converted to per cent composition for each taxonomic group.

RESULTS

Presentation of the data

The physical and chemical data obtained from samples taken at individual depth intervals of six lakes are given in the Appendices. These data were averaged from the surface to 2 m in shallow lakes (Lake 885, Lake 255, Lake 675, and Lake 879) and from the surface to 3 m in deeper lakes (Lake 200 and Lake 019) and presented separately in the Figures. Phytoplankton parameters from the integrated samples (0-2 m) are also presented graphically. The lakes in the Figures are arranged according to the increasing surface area. The annual or seasonal mean values were calculated using the monthly averages.

Ice thickness, snow cover, and light penetration

The study lakes were covered with ice from late October until late April (Fig. 3). The ice reached a maximum thickness in March 1976, ranging from 0.44 m in Lake 019 to about 0.86 m in Lake 675. The average depth of snow cover in mid-winter (February-March) ranged from 0.25 m (Lake 019) to 0.28 m (Lake 200, Lake 675, and Lake 879). Maximum snow depth was recorded in February 1976, ranging from 0.30 m (Lake 885) to about 0.35 m (Lake 200).

Secchi disc transparency in most of these lakes was relatively low during spring, high in early summer and decreased again during mid summer and fall (Fig. 3). The exceptions to these are Lake 885 and Lake 255. The Secchi disc reading in Lake 885 was relatively high in late summer after the summer algal bloom collapse, while in Lake 255 the Secchi disc

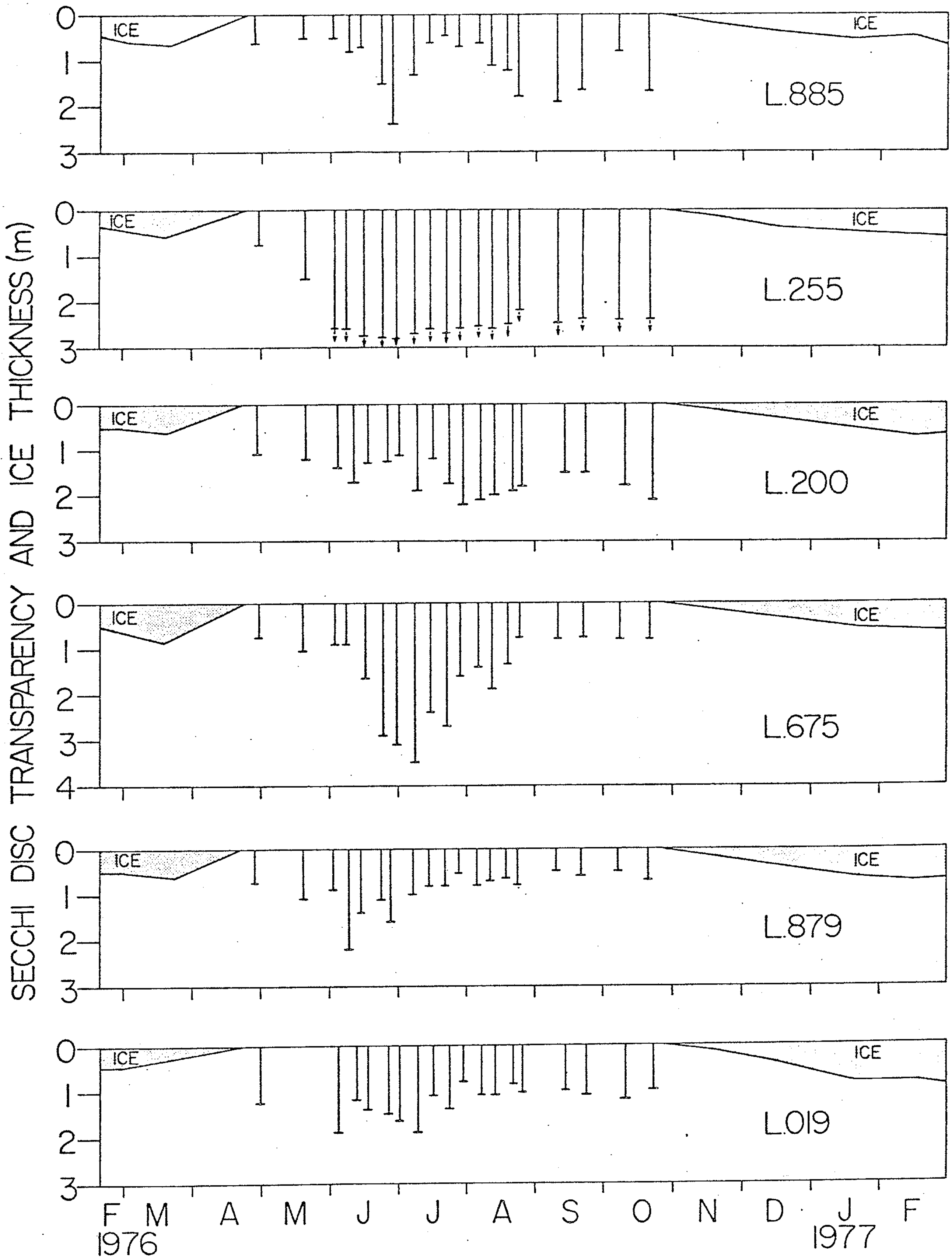


Figure 3. Ice thickness and Secchi disc transparency in six lakes of south-western Manitoba, February 1976 to February 1977. Secchi disc reading in Lake 255 reaches the bottom most of the ice-free period.

reading reached the bottom (2.5 m) most of the ice-free period. The mean transparency during the ice-free period ranged from 0.8 m (Lake 879) to 1.5 m (Lake 200), excluding Lake 255. The greatest difference between the minimum and maximum values of Secchi disc transparency was 2.8 m (0.7-3.5 m) in Lake 675, while the least difference was 1.1 m (0.8-1.9 m) in Lake 019 and Lake 200 (1.1-2.2 m).

The approximate 1% light transmittance was frequently reached between 2 and 3 m in these lakes except Lake 255, where approximately 10% light transmittance was recorded at the bottom throughout the monitoring period (Appendix 1). The average extinction coefficient (k) in summer (July-August) ranged from 1.2 in Lake 675 to 2.9 in Lake 885. Lake 255, where the Secchi disc reading always reached the bottom, had an extinction coefficient of about 0.8. Good agreement between Secchi disc measurements and extinction coefficients was observed (Fig. 4). This indicates that Secchi disc reciprocals can be used for estimation of the extinction coefficient within a single lake. A similar result was reported by Graham (1966).

Water temperature

All of the study lakes developed inverse temperature gradients during winter (Fig. 5). The mean difference between surface and bottom temperature during this period ranged from 2.0°C in Lake 200 to 3.1°C in Lake 019. Average winter temperature (December-March) for the upper 0-2 or 0-3 m layer ranged from 1.2°C in Lake 675 to 1.9°C in Lake 255. Lakes were homothermic just before the ice break-up. The warming trend tended to be a very rapid rising to 8-10°C (upper 2 or 3 m layer) within

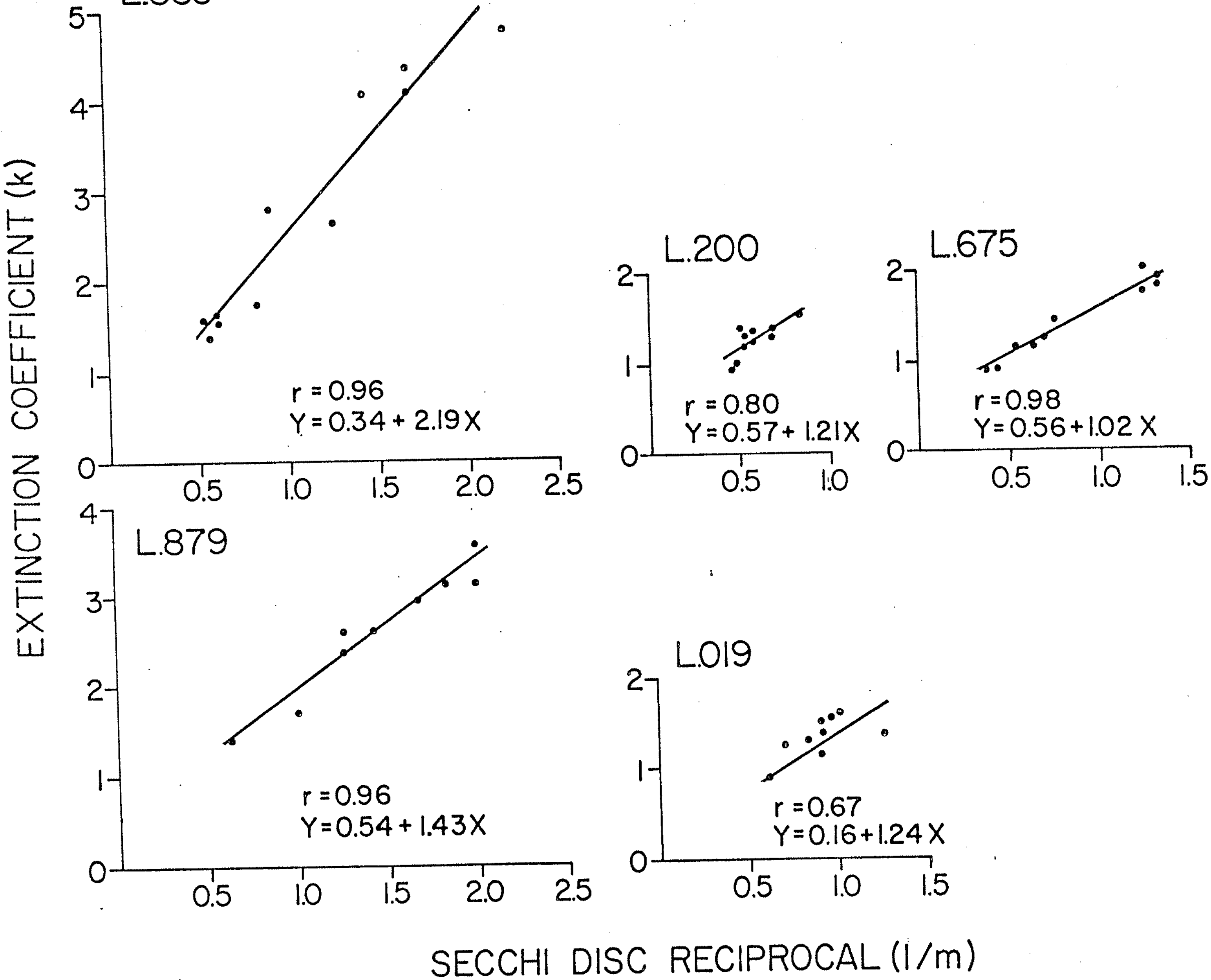


Figure 4. Relationship between Secchi disc reciprocals and extinction coefficients in lakes studied (Lake 255 was excluded because Secchi disc reading always reached the bottom), July to October 1976. All significant at 1% level except Lake 019 at 5%.

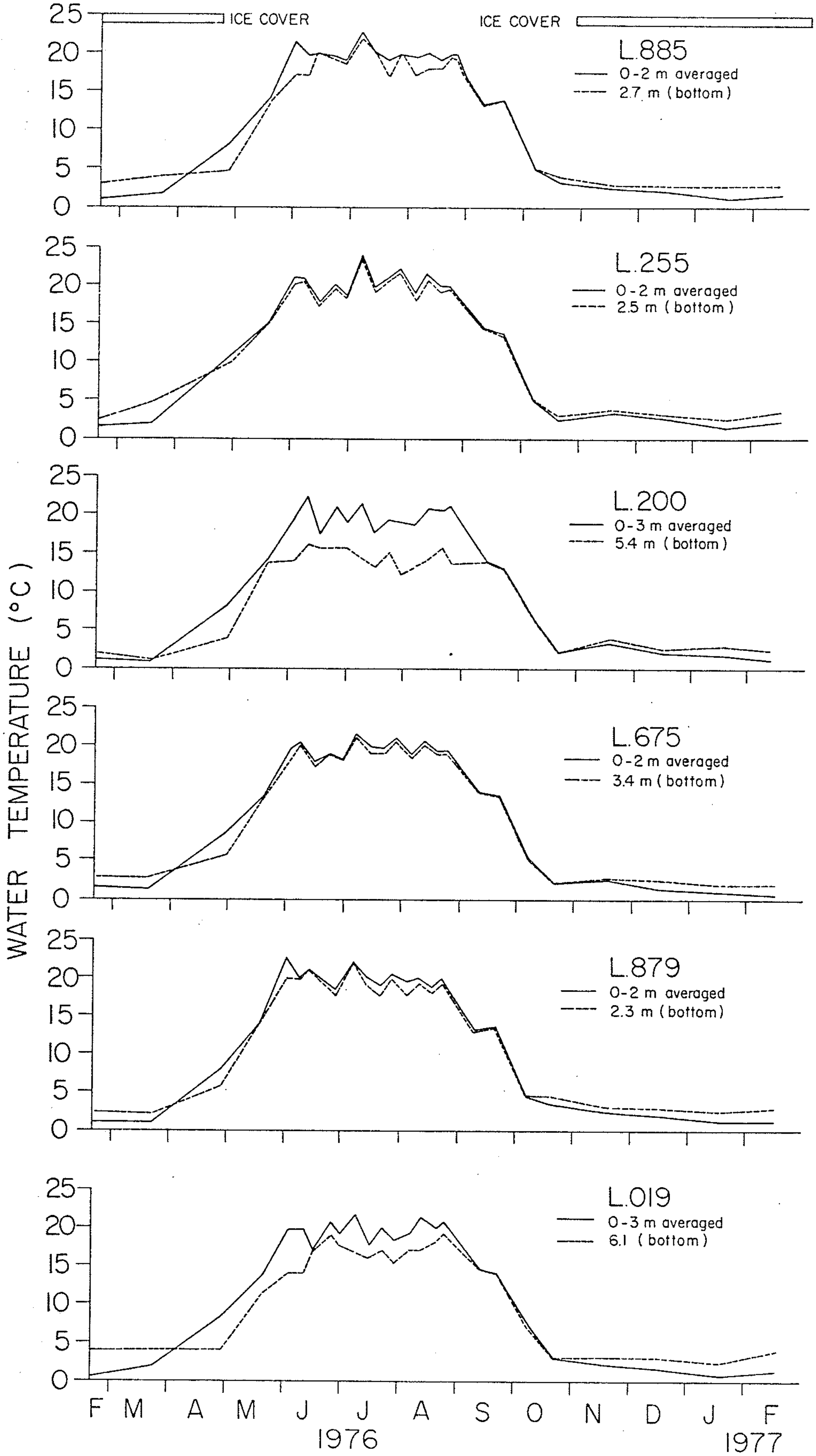


Figure 5. Water temperatures (0-2 m or 0-3 m layer and the bottom) in six lakes of southwestern Manitoba, February 1976 to February 1977.

a week after the lakes were free of ice in late April. Thermal stratification was found at this time; it was, however, destroyed by wind action throughout the ice-free period except for Lake 200 and Lake 019 which showed a thermal stratification in the summer. The summer fluctuation patterns of water temperature in the upper layers were similar for all six lakes. The mean temperature for the upper layer during the summer months (June-August) ranged from 19.6°C in Lake 019 to 20.4°C in Lake 255. The mean difference between surface and bottom temperature during this period in four of the lakes studied was less than 1.7°C, but Lake 019 and Lake 200 where the mean differences were as much as 3.2°C and 5.7°C respectively. However, the thermal stratification in these two lakes was not clear and only partially developed. The epilimnion in these lakes extended down to about 3 m, from where the metalimnion continued down to the bottom. Lake 200 and Lake 019 were homothermic once again in mid-September. By late September the temperature throughout the lake dropped to about 14°C and to about 6°C by early October in all six lakes.

Dissolved oxygen and per cent saturation

In 5 of the lakes, low dissolved oxygen (DO) concentrations (<1.0 mg/l) were observed during February and March (Fig. 6). Only Lake 019 showed a high concentration of DO in the upper layer. The mean DO of the upper layer in Lake 019 in this period was 5 mg/l (37% saturation) while the bottom water was under anoxic conditions. DO in the upper 2 or 3 m was high in all six lakes immediately after ice disappearance. The maximum values in this time ranged from 9 mg/l (90% saturation) in Lake 255 to 16 mg/l (141% saturation) in Lake 885. DO concentration in the

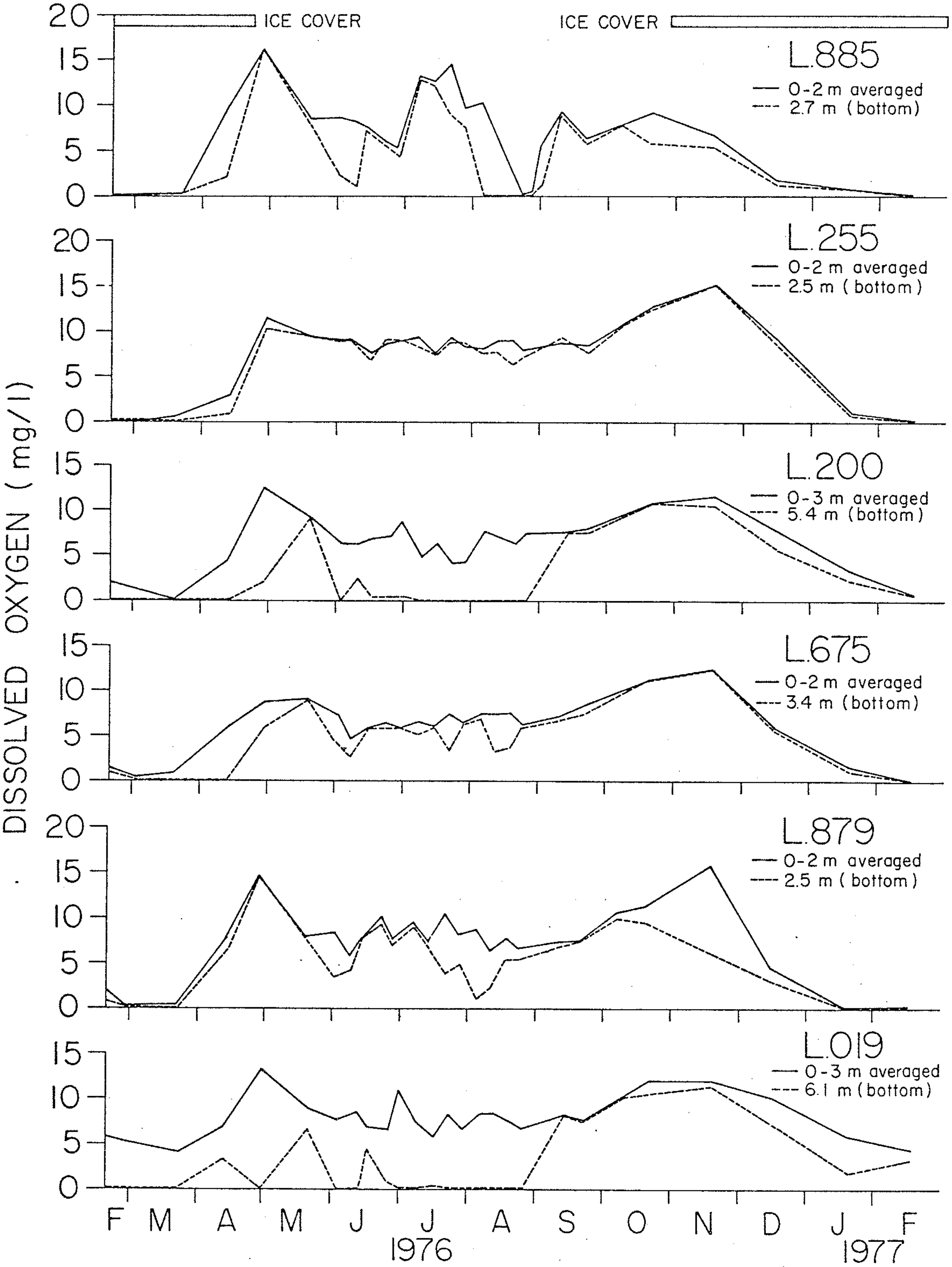


Figure 6. Dissolved oxygen (0-2 m or 0-3 m layer and the bottom) in six lakes of southwestern Manitoba, February 1976 to February 1977.

upper layer during the summer months remained high except for Lake 885 which showed oxygen depletion in late August (summerkill period). The greatest range of DO in summer was found in Lake 885 (0.1-14 mg/l or 1-160% saturation) while the smallest range was 7-9 mg/l or 84-111% saturation in Lake 255. Vertical stratification of DO in the summer was found in Lake 200 and Lake 019, both of which showed a marked decrease in DO with increased depth. During the fall circulation the DO tended to increase and reached a maximum in mid November, ranging from 9 mg/l (71% saturation) in Lake 885 to 16 mg/l (119% saturation) in Lake 879.

Hydrogen ion concentration

Hydrogen ion concentration varied seasonally within and between lakes (Fig. 7). Lowest pH values occurring during the winter, were probably caused by bacterial CO_2 production. Minimum winter values ranged from 7.1 (Lake 675) to 8.0 (Lake 885). Highest values occurred during summer months, and were probably caused by the uptake of CO_2 by phytoplankton, and ranged from 8.6 (Lake 200) to 9.4 (Lake 885). However, during August 21-26 (summerkill period) there was a significant drop of pH by 0.9 units in Lake 885. This was probably caused by the production of CO_2 by bacteria, combined with the cessation of algal consumption of CO_2. A drop in pH was recorded for all lakes in late November as uptake of CO_2 by algae slowed. The greatest variation of pH during the ice-free period was 1.1 units in Lake 885 (pH 8.3-9.4). The smallest variation was 0.5 units in Lake 255 (pH 8.3-8.8), Lake 200 (pH 8.1-8.6), and Lake 675 (pH 8.2-8.7). The annual average pH ranged from 8.1 (Lake 200) to 8.5 (Lake 885). the high pH values (never below 7) and the stability of pH

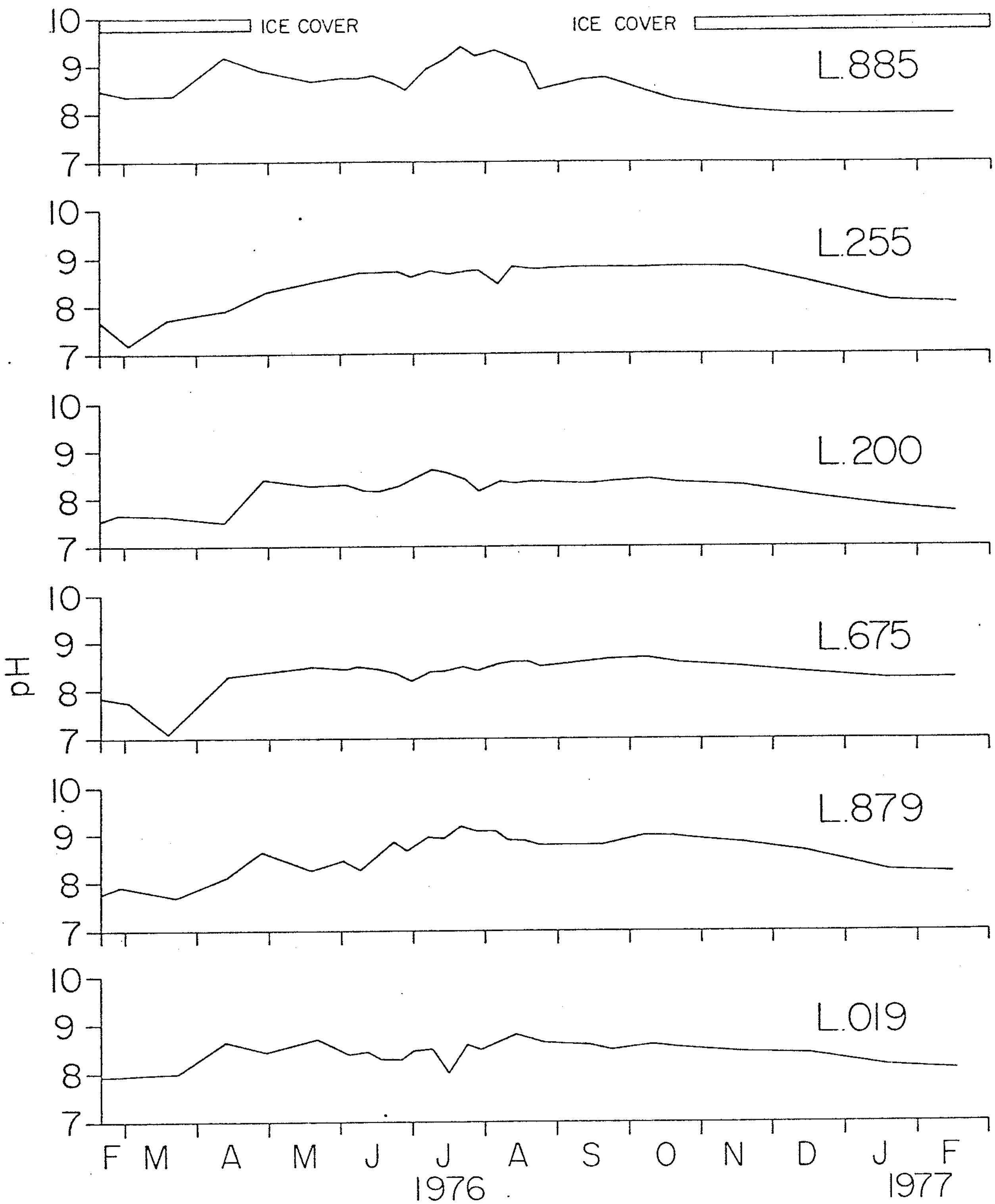


Figure 7. pH values (1 m) in six lakes of southwestern Manitoba, February 1976 to February 1977.

throughout the year in these lakes is probably due to their high content of HCO_3^- (yearly average 268 mg/l - 444 mg/l) which acts as a strong buffer.

Specific conductance and major ions

In all study lakes in both winter and summer, the surface and bottom values for specific conductance and concentration of individual major ions were similar (Appendix 8). Specific conductance and major ions were higher in winter than in summer presumably as a result of the freezing out effect and the consequent reduction of the lake volume. These values decreased in summer, and were probably caused by the input of water from ice and snow melt and spring runoff as well as biological processes of precipitation of some salts. Based on summer values (Table 2), specific conductance in study lakes ranged from 795 (Lake 879) to 1945 (Lake 675) µmhos/cm and the total ions (TI) ranged from 659 (Lake 879) to 1691 (Lake 675) mg/l. Values for specific conductance and TI do not differ very much; therefore, for all practical purposes, the value of specific conductance might be used in place of TI concentration because specific conductance is a measure of major ion concentration (Rodhe 1949). The relationship between specific conductance and TI ($r = 0.99$, $df = 78$, $P < 0.01$) was reported by Barica (1975b).

The order of concentration of major cations as per cent milliequivalents is $Mg^{++} > Ca^{++} > Na^{+} > K^{+}$ for most of the study lakes except Lake 885, where the order is $Mg^{++} > Na^{+} > Ca^{++} > K^{+}$. The order of major anions is $SO_4^{=} > HCO_3^{-} + CO_3^{=} > Cl^{-}$, except for Lake 019 where the order is $HCO_3^{-} + CO_3^{=} > SO_4^{=} > Cl^{-}$.

Table 2. Specific conductance and concentration and relative proportions* of major ions in six lakes of southwestern Manitoba, during August 10 to 12, 1976. Surface and bottom samples are averaged.

Lake	Specific Cond. (µmhos/cm)	Units	Cations				Anions				Total Ions
			Na^+	K^+	Mg^{++}	Ca^{++}	Cl^-	$SO_4^=$	HCO_3^-	$CO_3^=$	
885	1360	mg/l	93	36	113	28	44	412	294	53	1073
		%	25.6	5.8	59.6	9.0	7.3	52.4	29.3	11.0	
255	885	mg/l	13	19	83	57	48	242	232	14	708
		%	5.6	4.7	63.5	26.2	12.3	47.2	35.8	4.7	
200	1330	mg/l	11	19	113	102	23	498	234	0	1000
		%	3.2	3.2	60.4	33.1	4.0	70.3	25.7	0.0	
675	1945	mg/l	69	36	181	104	19	880	386	16	1691
		%	12.5	3.7	62.0	21.7	1.9	71.5	24.6	1.9	
879	795	mg/l	18	20	72	55	25	213	220	36	659
		%	8.1	5.0	59.6	27.3	7.1	44.4	36.4	12.1	
019	860	mg/l	26	27	75	57	32	161	270	38	686
		%	10.2	6.5	57.4	25.9	9.1	33.3	44.3	13.1	

* Values are given as equivalent percentage of total cations or total anions respectively.

Carbon

The maximum values of DIC were found in winter (Fig. 8), ranging from 72 mg/l (Lake 200) to 142 mg/l (Lake 885). There was a sharp decrease of DIC in April for all six lakes when runoff from rain and melted snow ran under the ice. Schindler and Comita (1972) noted a similar decrease in carbonate alkalinity values in mid April. DIC concentrations remained low during the summer months. The average summer values ranged from 49 mg/l (Lake 200 and Lake 879) to 75 mg/l (Lake 885 and Lake 675). There was a gradual increase in DIC from November to February.

DOC concentrations showed a similar pattern of seasonal distribution but fluctuations were less pronounced (Fig. 8). The maximum values were found in the winter, ranging from 25 mg/l (Lake 200 and Lake 019) to 40 mg/l (Lake 675). The concentration decreased in summer ranging from 15 mg/l (Lake 019) to 24 mg/l (Lake 675). The yearly average values ranged from 17 mg/l (Lake 019) to 27 mg/l (Lake 675), approximately 3-4 times less than DIC concentrations.

Nitrogen

Two peaks of NO_3-N were found in the study lakes (Fig. 9). One occurred in early spring (April) just before the ice disappeared, and ranged from 26 μg/l (Lake 885) to 510 μg/l (Lake 879). DO at this time ranged from 3 mg/l (Lake 255) to 10 mg/l (Lake 885). These high concentrations of NO_3-N were probably due to oxidation of NH_3-N to NO_3-N (nitrification) as well as the input of NO_3-N from surface runoff. Ahl (1966) also observed an increase of NO_3-N at or near the end of the ice

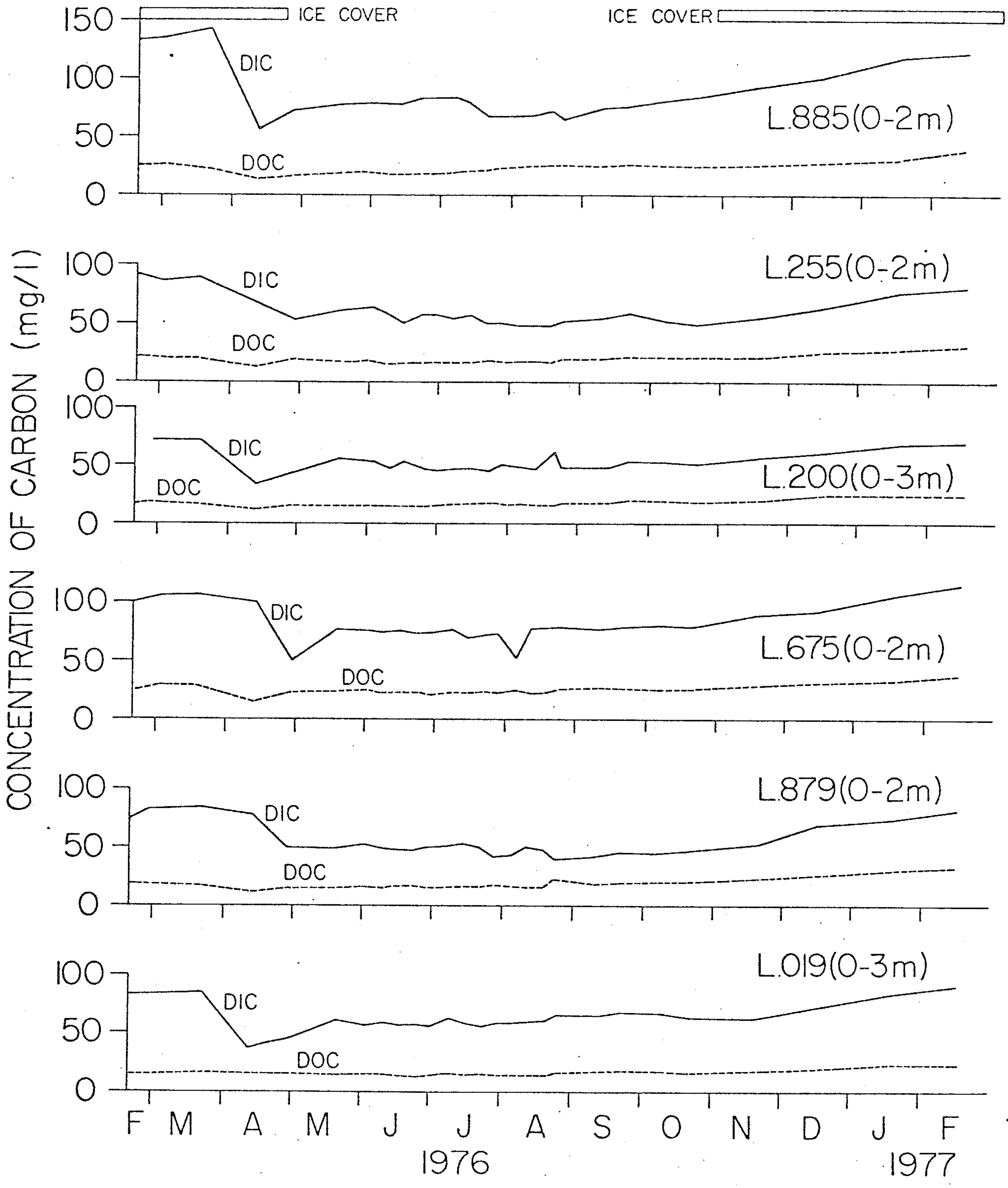


Figure 8. Dissolved inorganic carbon (1 m) and dissolved organic carbon (0-2 m or 0-3 m) in six lakes of southwestern Manitoba, February 1976 to February 1977.

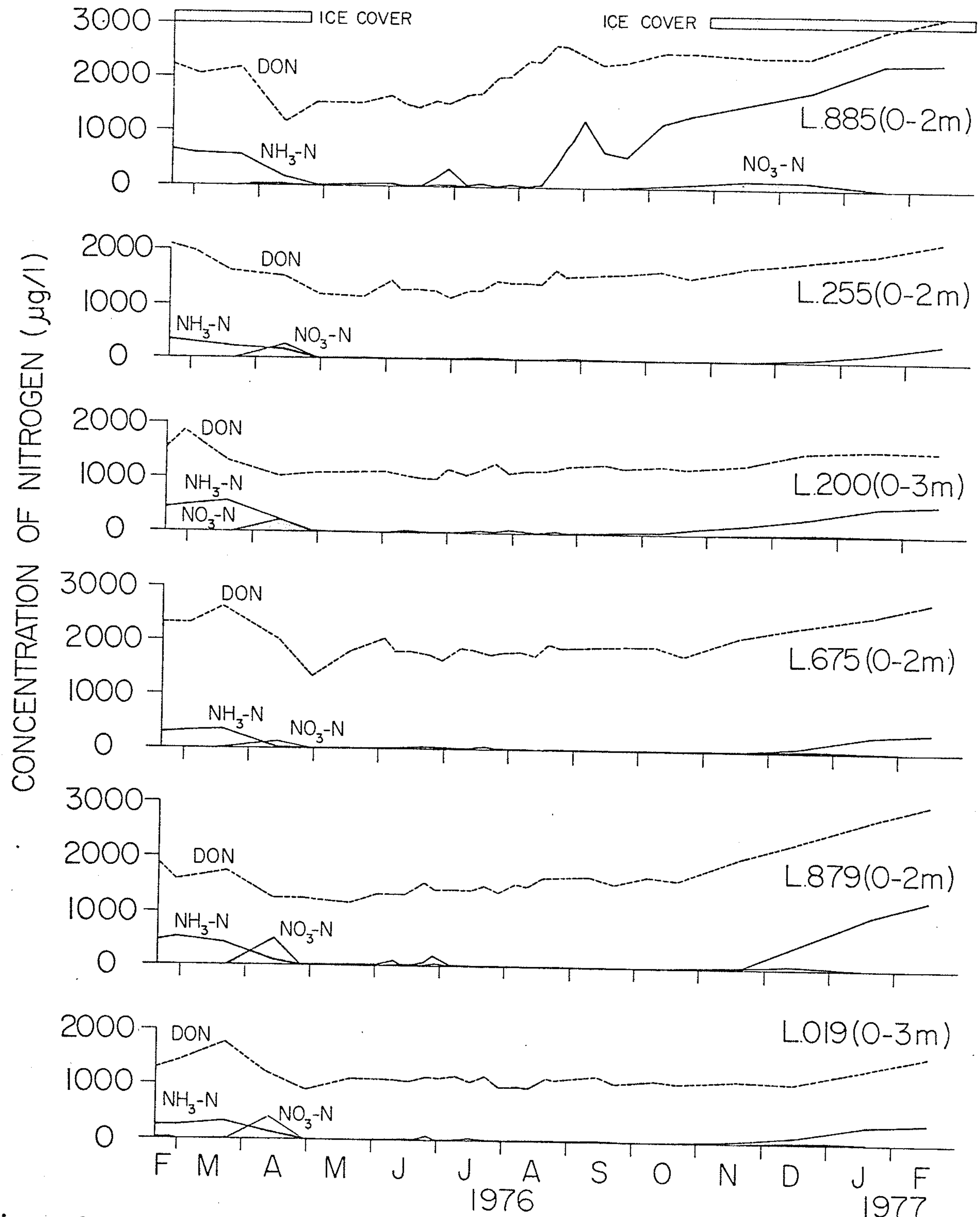


Figure 9. Nitrate nitrogen, ammonia nitrogen, and dissolved organic nitrogen (0-2 m or 0-3 m) in six lakes of southwestern Manitoba, February 1976 to February 1977.

break-up. Another peak of NO_3-N occurred in early winter (November-December), at the time of an increasing NH_3-N concentration, and ranged from 10 µg/l (Lake 019) to 147 µg/l (Lake 885). DO in this period ranged from 4 mg/l (Lake 879) to 10 mg/l (Lake 019). It can be assumed that this NO_3-N peak was caused by gradual nitrification of NH_3-N also. The NO_3-N concentrations were relatively low during the summer months (June to August) for all six lakes presumably due to utilization of NO_3-N by phytoplankton. The average values during the summer months ranged from below the limit of detectability (<5 µg/l) in Lake 255 to 12 µg/l in Lake 879.

NH_3-N was present in greater concentrations than was NO_3-N (Fig. 9). High concentration of NH_3-N were found during the ice cover period in the winters of both 1976 and 1977. Maximum NH_3-N in winter (February-March) 1976 ranged from 331 µg/l (Lake 255 and Lake 019) to 669 µg/l (Lake 885) and maximum in February 1977 ranged from 334 µg/l (Lake 255) to 2340 µg/l (Lake 885). During the ice-free period NH_3-N concentrations were relatively low for most of the study lakes except Lake 885. The average summer NH_3-N concentrations ranged from 12 µg/l (Lake 200) to 41 µg/l (Lake 879) while NH_3-N in Lake 885 increased rapidly under low oxygen conditions from 42 µg/l on August 10, to 388 µg/l on August 17, and 1205 µg/l on August 31, and remaining high thereafter until winter. Evidence from numerous studies which were reviewed by Brezonik (1972) and Horne and Goldman (1972) indicated that nitrogen fixation could contribute substantial amounts to the nitrogen input to the lakes. The increase in NH_3-N concentration in this lake is probably due to the nitrogen fixation by <u>Aphanizomenon</u> which presumably took place on a large scale during the period of bloom.

DON was the most abundant component of dissolved nitrogen in these lakes but its seasonal fluctuations were not as great as those of NH_3-N (Fig. 9). DON concentrations tended to increase in winter and remained at uniformly low levels during the ice-free period for most of the study lakes except Lake 885, which showed a noticeable peak during the summerkill period. The yearly mean concentrations of DON during the study period ranged from 1213 μg/l (Lake 019) to 2145 μg/l (Lake 885).

Phosphorus

SRP concentrations were high during the ice-cover period (Fig. 10). The maxima in winter (February-March) 1976 ranged from 8 μg/l (Lake 019) to 159 μg/l (Lake 885). The maxima in winter (February) 1977 ranged from 2 μg/l (Lake 019) to 222 μg/l (Lake 879). The SRP concentrations were relatively low during the ice-free period for most of the study lakes. Lakes 885 and 879 were exceptions and showed an increase in SRP after each algal bloom collapse. The mean values of SRP during the summer months never exceeded 3 μg/l for most of the study lakes while the mean values in Lake 885 and Lake 879 were 31 μg/l and 15 μg/l respectively.

The vertical gradient of NH_3-N and SRP during ice-cover period in Lake 019 (Fig. 11) was much higher than that in the other lakes (Appendices 10-14 and 16-20). High concentrations of NH_3-N and SRP were observed near the anoxic bottom of stratified lakes (Lake 200 and Lake 019) in summer (Fig. 12 and Fig. 13). In well circulated lakes (Lake 885, Lake 255, Lake 675, and Lake 879), these nutrients were low throughout the water column (Appendices 10-14 and 16-20).

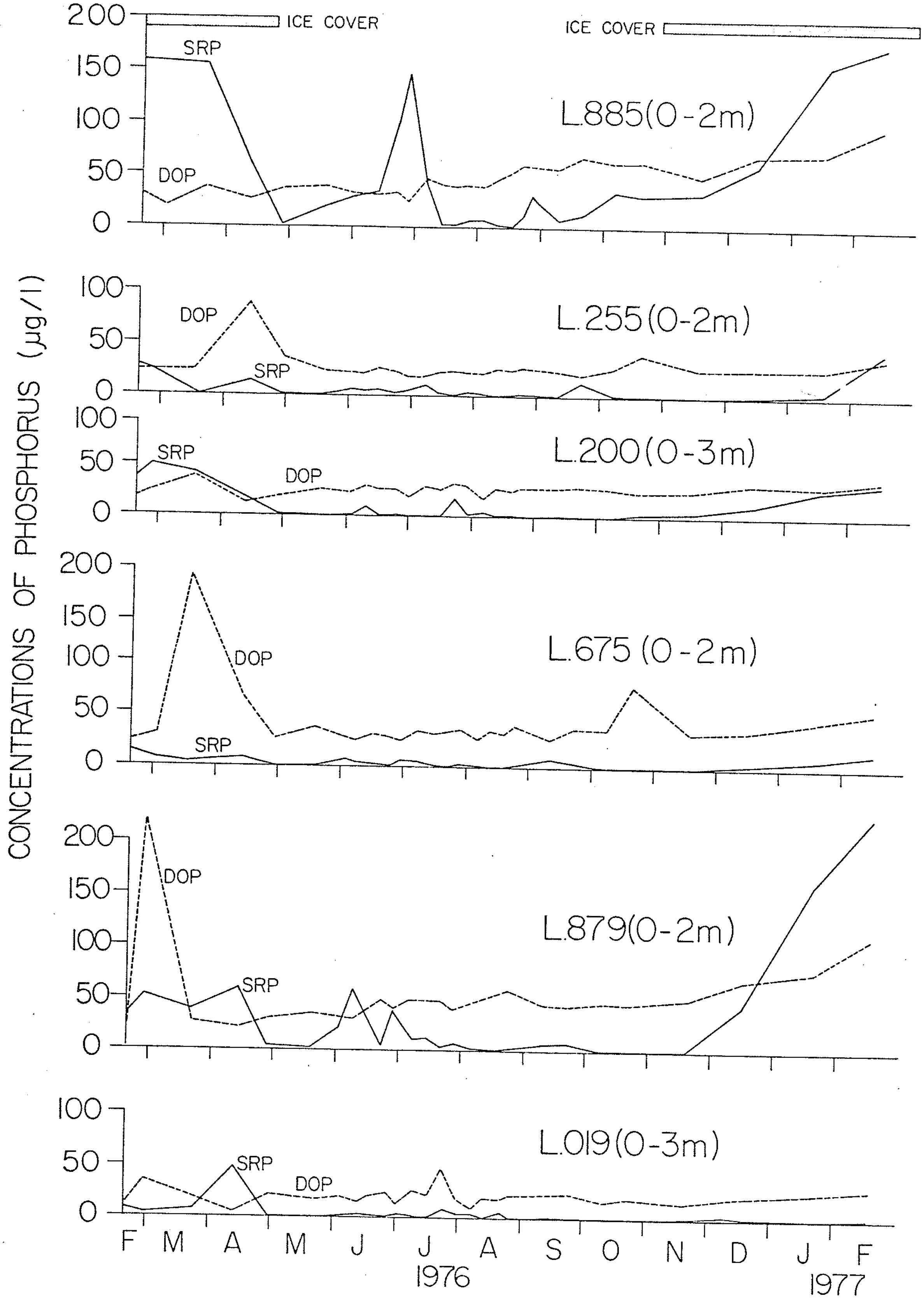


Figure 10. Soluble reactive phosphorus and dissolved organic phosphorus (0-2 m or 0-3 m) in six lakes of southwestern Manitoba, February 1976 to February 1977.

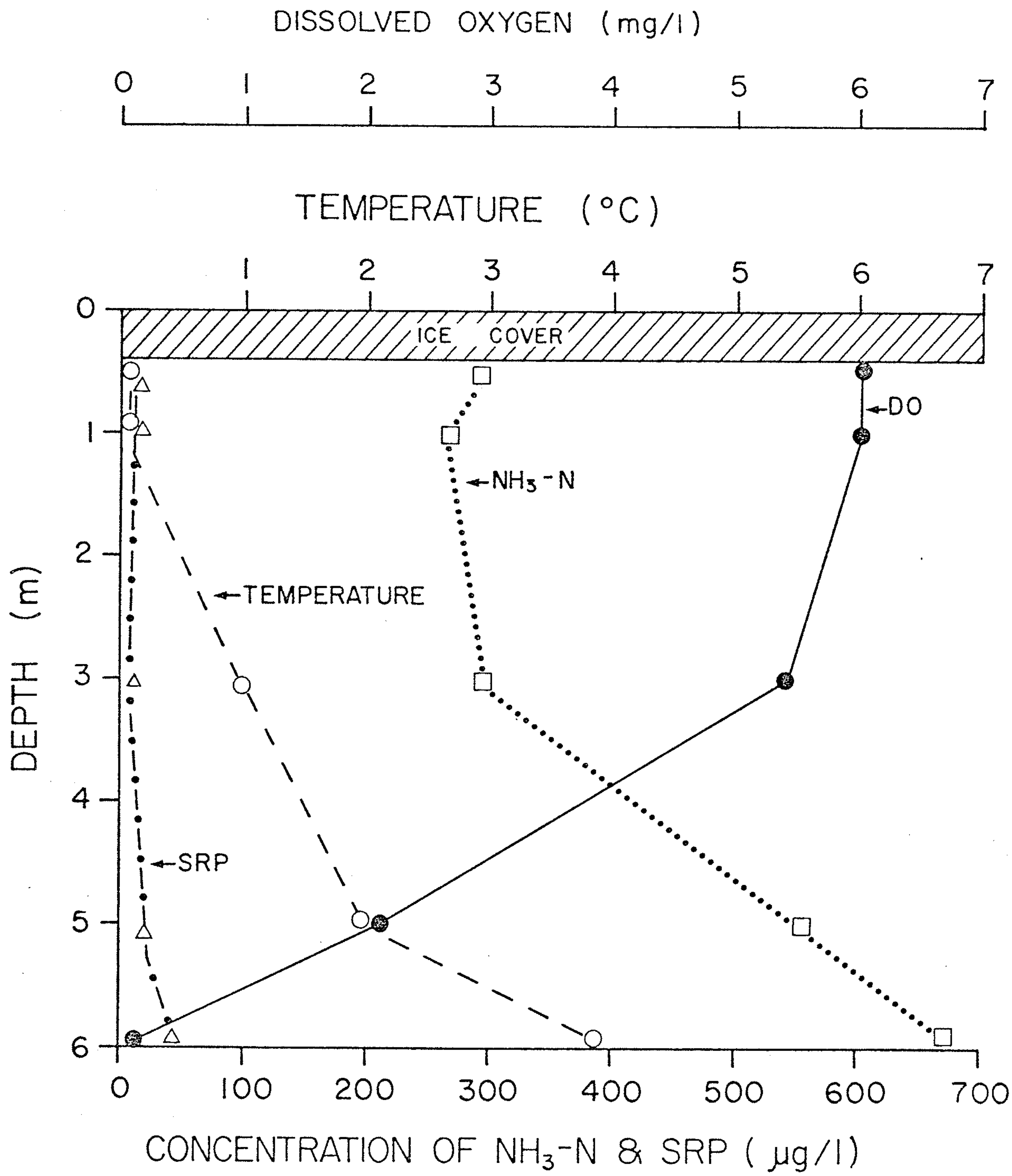


Figure 11. Vertical distribution of water temperature, dissolved oxygen (DO), ammonia nitrogen (NH_3-N), and soluble reactive phosphorus (SRP) in Lake 019, February 20, 1976.

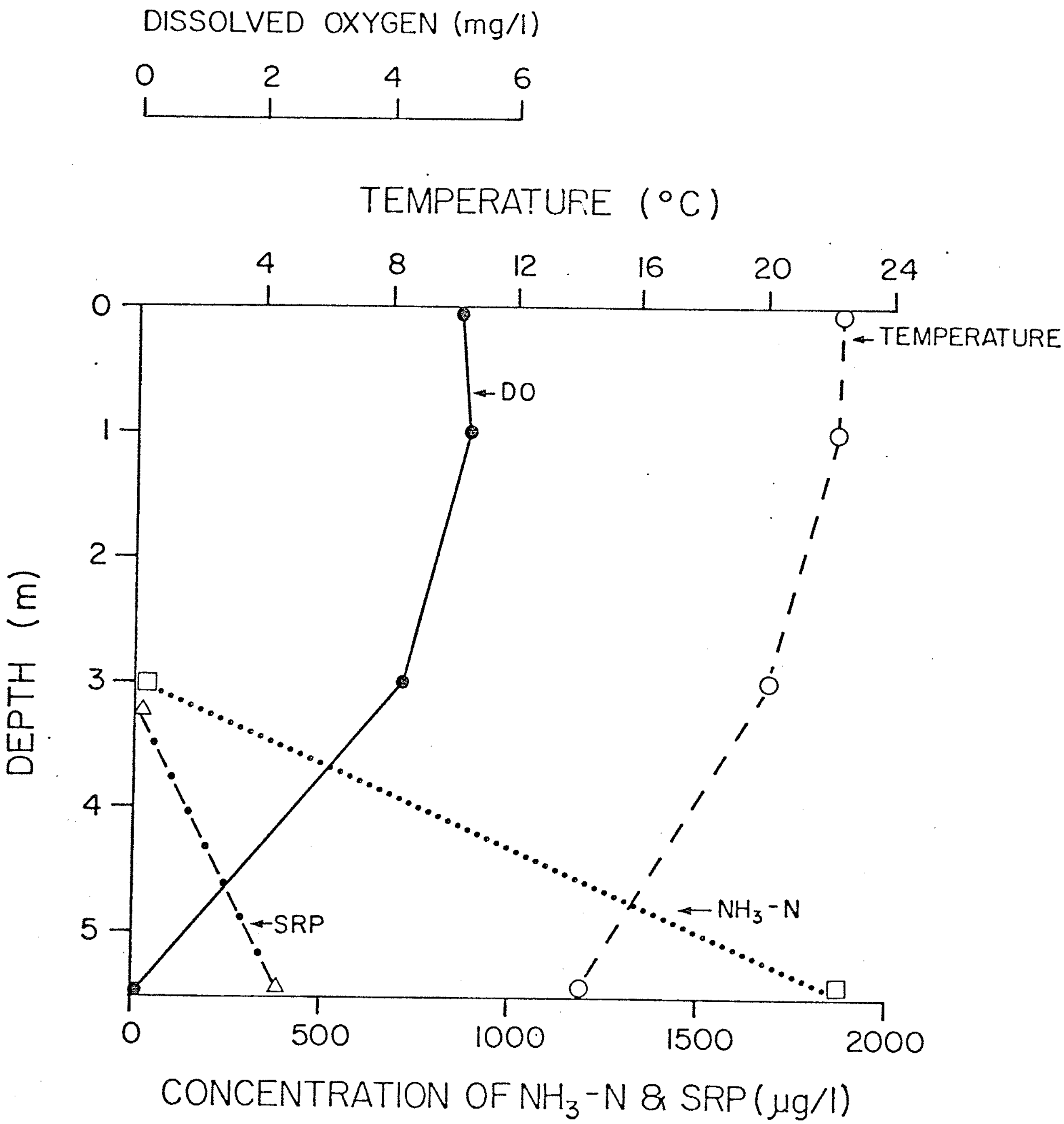


Figure 12. Vertical distribution of water temperature, dissolved oxygen (DO), ammonia nitrogen (NH_3-N), and soluble reactive phosphorus (SRP) in Lake 200, July 8, 1976. NH_3-N and SRP were undetectable in upper 3 m.

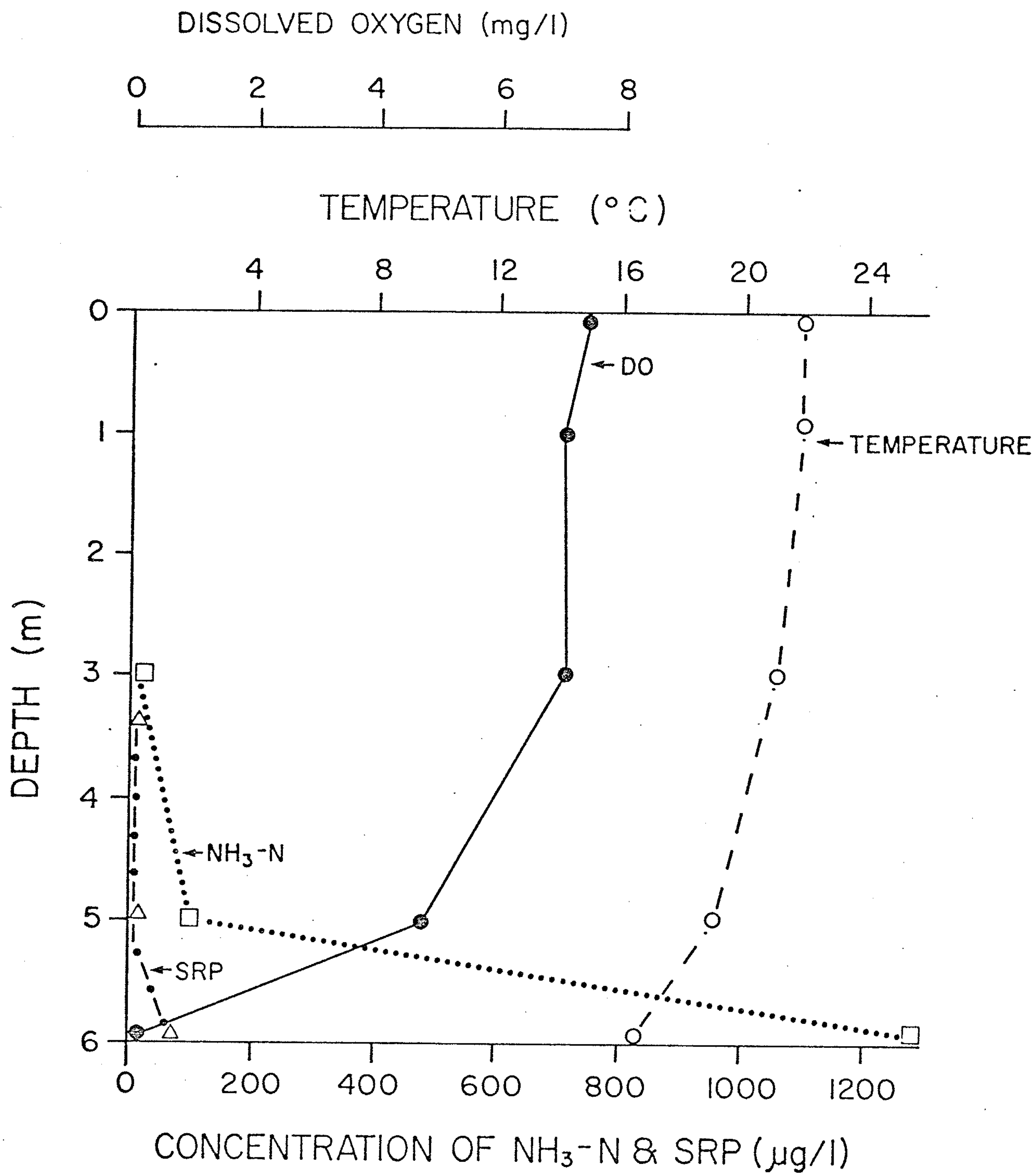


Figure 13. Vertical distribution of water temperature, dissolved oxygen (DO), ammonia nitrogen (NH_3-N), and soluble reactive phosphorus (SRP) in Lake 019, July 8, 1976. NH_3-N and SRP were undetectable in upper 3 m.

The concentrations of DOP were also high during the ice-cover period (Fig. 10). The average values during winter 1976 ranged from 22 µg/l in Lake 019 to 90 µg/l in Lake 879. DOP concentrations tended to decrease during the ice-free period. The mean values during June to August ranged from 21 µg/l (Lake 019) to 44 µg/l (Lake 879).

The increase in concentration of both DON and DOP during ice-cover period indicated that they were produced by decomposing algae (Watt and Hayes 1963; Grill and Richards 1964) and also the freezeout effect. These organic nitrogen and phosphorus compounds tended to decrease during the ice-free period but the concentrations remained high suggesting that they were also excreted by algae (Kuenzler 1970; Fogg 1971).

Phytoplankton

The chlorophyll-a concentrations during the ice-cover period in mid-winter were low for most of the lakes studied (Fig. 14) and ranged from 6 to 26 µg/l. However Lake 675 and Lake 879 showed some algal growth under the ice in mid-winter with a chlorophyll-a concentration about 39 µg/l (March 18, 1976) and 54 µg/l (February 19, 1976) respectively. The chlorophyll-a concentrations in Lake 255, Lake 200, Lake 675 and Lake 019 were low throughout the year. The yearly average ranged from 7 µg/l (Lake 255) to 22 µg/l (Lake 019). In contrast to this the largest peaks during the ice-free period were found in Lake 885 (260 µg/l) and Lake 879 (124 µg/l). However, chlorophyll-a in Lake 879 was relatively high throughout the year with a yearly average of 45 µg/l while in Lake 885 in spite of the highest summer peak the average was 39 µg/l. During the bloom period in Lake 885, the increase of chlorophyll-a concentration

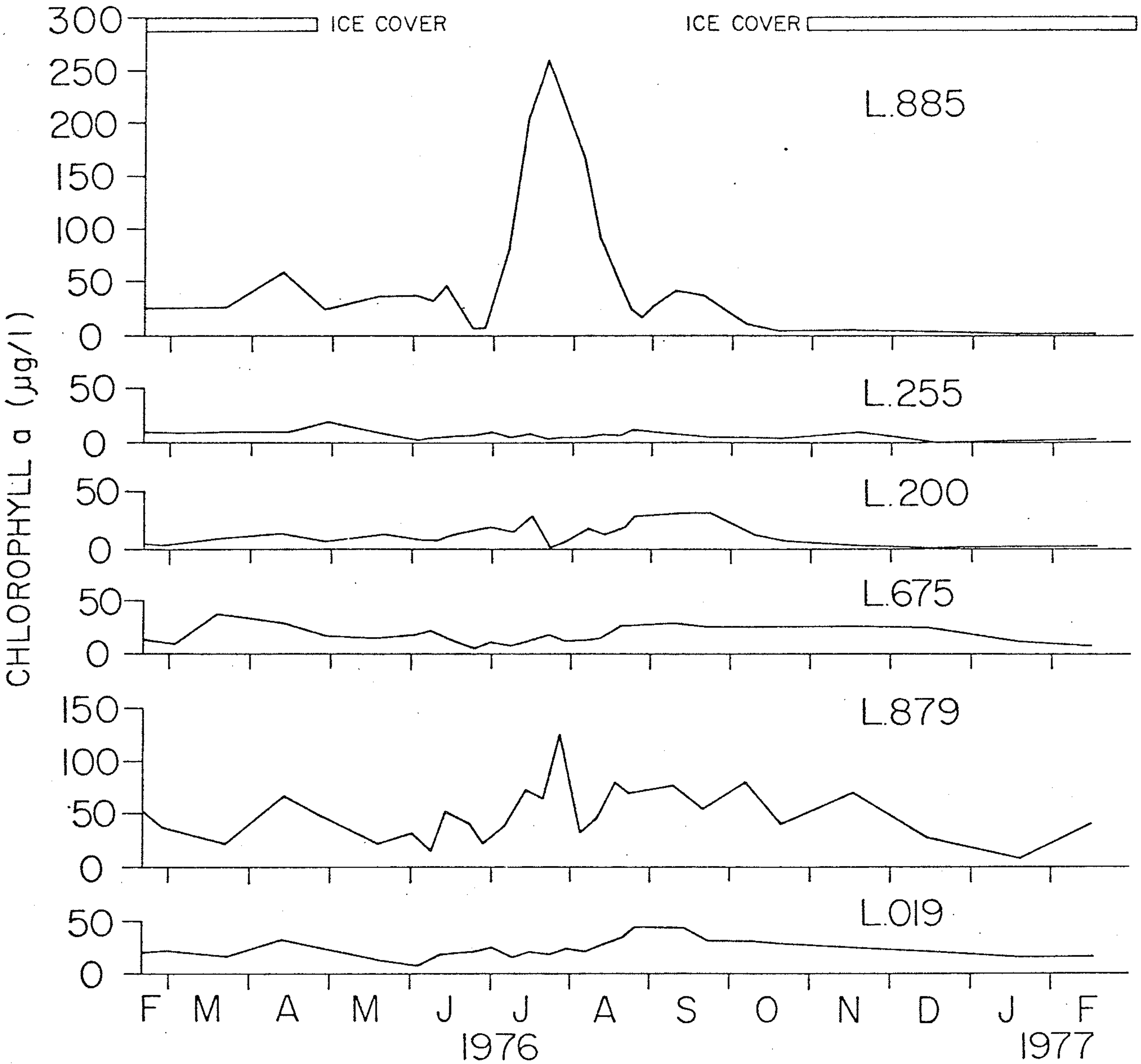


Figure 14. Chlorophyll-a concentrations from integrated samples over 0-2 m in six lakes of southwestern Manitoba, February 1976 to February 1977.

was found to coincide with the decrease of HCO_3^- and a rise in pH (Table 3).

Most of the study lakes showed several pronounced production peaks during the measuring period except for Lake 255 in which no pronounced peak was observed over the growth season (Fig. 15a and 15b). Maximum gross primary production was found during July and August. The mean gross production rates in summer (June-August) ranged from 0.6 g C/m^2/day (Lake 255) to 3.2 g C/m^2/day (Lake 885). The gross production rates gradually decreased in late September in all lakes studied, which coincided with the start of the drop of water temperatures. Negative net production was observed when the rate of respiration was higher than the oxygen production rate. The net production rates in these lakes were low in relation to gross values (Table 4). The average net production in summer ranged from 23% (Lake 200) to 55% (Lake 879) of the gross production. Vinberg (1960) also found a low net production (23% of gross production) in eutrophic Lake Beloye, U.S.S.R. The low net production in lakes studied was probably due to high respiration by non-algal organisms (i.e. bacteria, zooplankton). Pratt and Berkson (1959) studied the sources of error in light and dark oxygen method and reported that bacterial respiration was responsible for 42% to 62% of the total respiration. The total respiration in this study contributed to 45% of the gross production in Lake 879 and to 77% in Lake 200 (Table 4). Therefore the net production in this study is underestimated as it was not possible to separate the respiration of bacteria and other organisms from that of the phytoplankton.

The relationship between gross primary production and chlorophyll-a

Table 3. Chlorophyll-a (μg/l) - HCO_3^- (mg/l) - pH relationships in Lake 885.

Date	Chlorophyll-a	HCO_3^-	pH
June 27	7	415	8.5
July 6	78	384	8.9
July 13	204	336	9.1
July 20	260 (maximum)	275	9.4

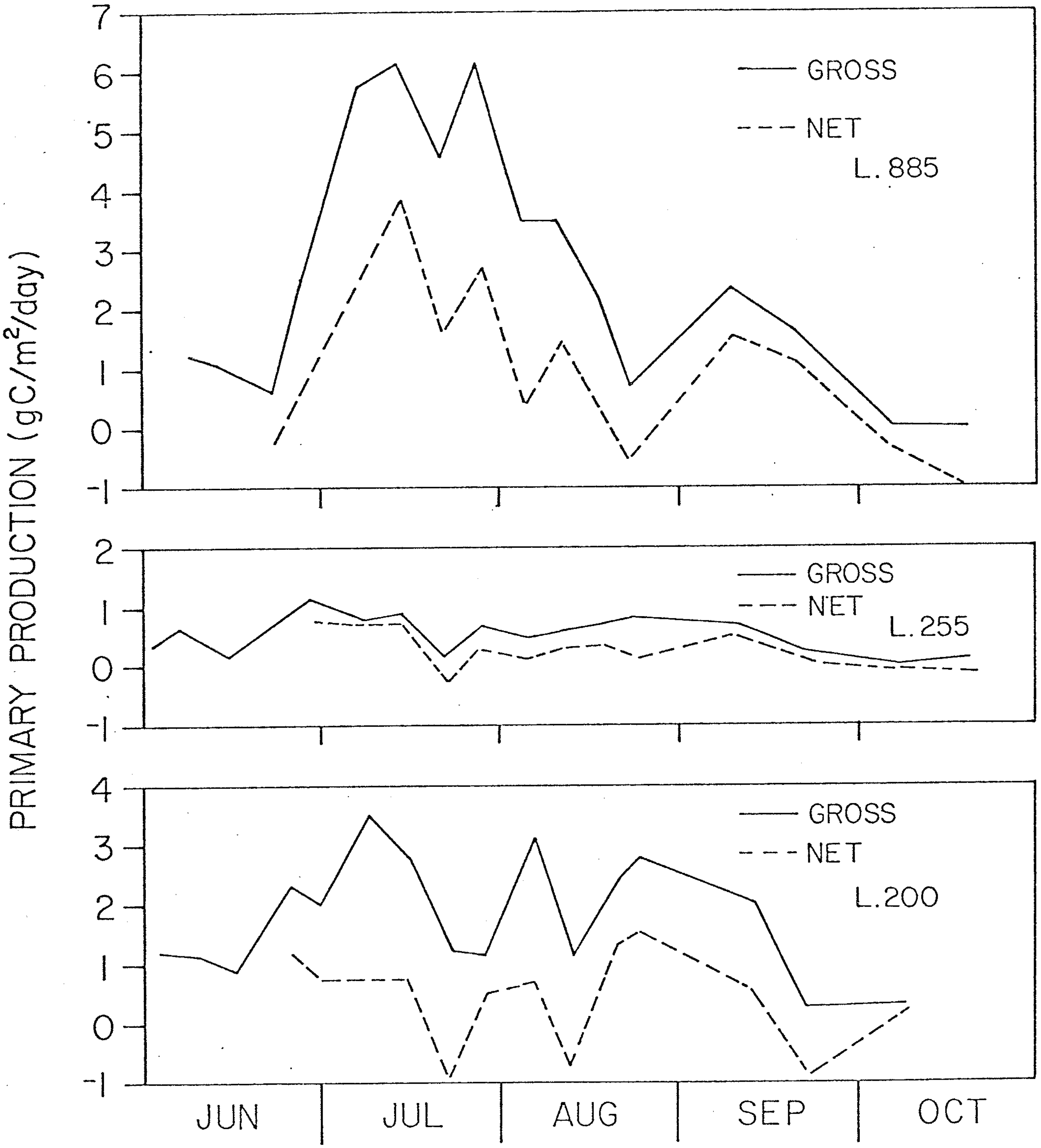


Figure 15a. Daily integrated values of gross and net primary production in Lake 885, Lake 255, and Lake 200 of southwestern Manitoba, June to October 1976.

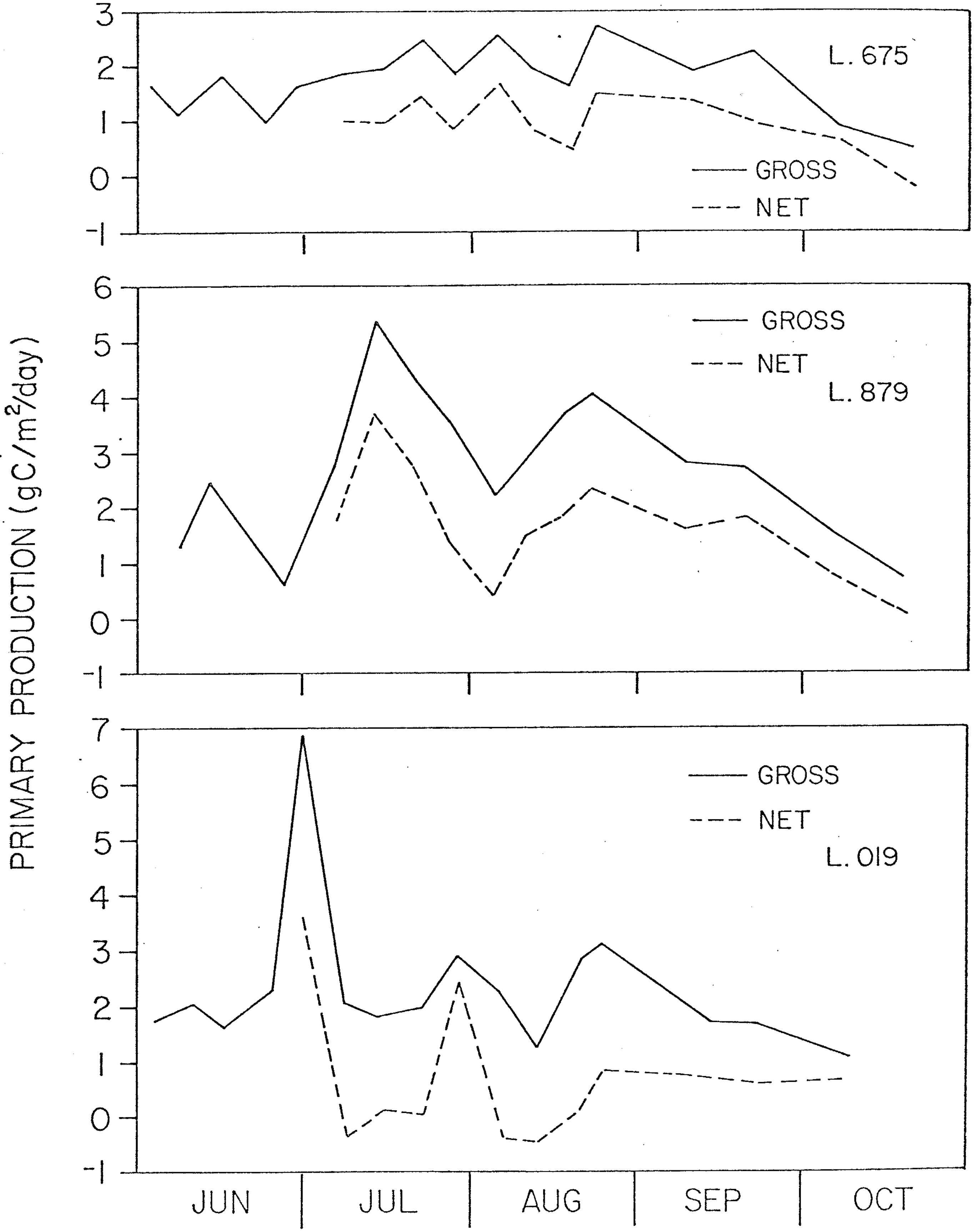


Figure 15b. Daily integrated values of gross and net primary production in Lake 675, Lake 879, and Lake 019 of southwestern Manitoba, June to October 1976.

Table 4. Mean values (July-August 1976) of gross primary production, net primary production, and respiration in mg C/m^2/day of lakes studied.

Lake	885	255	200	675	879	019
Gross primary production (G.P.)	3863	631	2136	2105	3652	2810
Net primary production	1478	281	485	1087	1996	667
% of G.P.	38	45	23	52	55	24
Respiration	2385	350	1651	1018	1656	2143
% of G.P.	62	55	77	48	45	76

in these lakes is shown in Fig. 16. The correlation coefficients range from 0.59 (Lake 675) to 0.97 (Lake 885) which are similar to those reported by Glooschenko et al. (1974) for Lake Erie (0.52) and Lake Ontario (0.91). The lower values of r in Lake 675 and Lake 255 are in part a function of lower range of both primary production and chlorophyll-a. However, it can be seen from this figure that the linearity of this relationship is not quite perfect. It looks more like a curvilinear relationship when the scatter points are considered. The most likely explanation is that the rate of photosynthesis depends not only on the chlorophyll-a concentration but also on many other factors (i.e. water temperature, changes in species composition). The effect of light on primary production was not a factor in this case since a constant light intensity was applied throughout the study period.

Production per unit chlorophyll-a or assimilation numbers (mg C/mg chlorophyll-a per hour) were high in summer and decreased in fall (Table 5). The average summer values ranged from 4.0 (Lake 885) to 6.3 (Lake 675). These values are similar to those reported by Manning and Juday (1941) for lakes in northeastern Wisconsin (1.2 to 5.1).

Summer chlorophyll-a content was related to winter nutrient concentration (Fig. 17). The correlation coefficients were significant ($r = 0.77$, $df = 5$, $P < 0.10$ for NH_3-N and $r = 0.93$, $df = 5$, $P < 0.01$ for SRP). Nutrient concentration in the following winter was also related to summer chlorophyll-a content (Fig. 18). The correlation coefficients were significant ($r = 0.99$, $df = 5$, $P < 0.01$ for NH_3-N and $r = 0.78$, $df = 5$, $P < 0.10$ for SRP). Since the maximum gross primary production in this study did not occur at the same time as the maximum chlorophyll-a

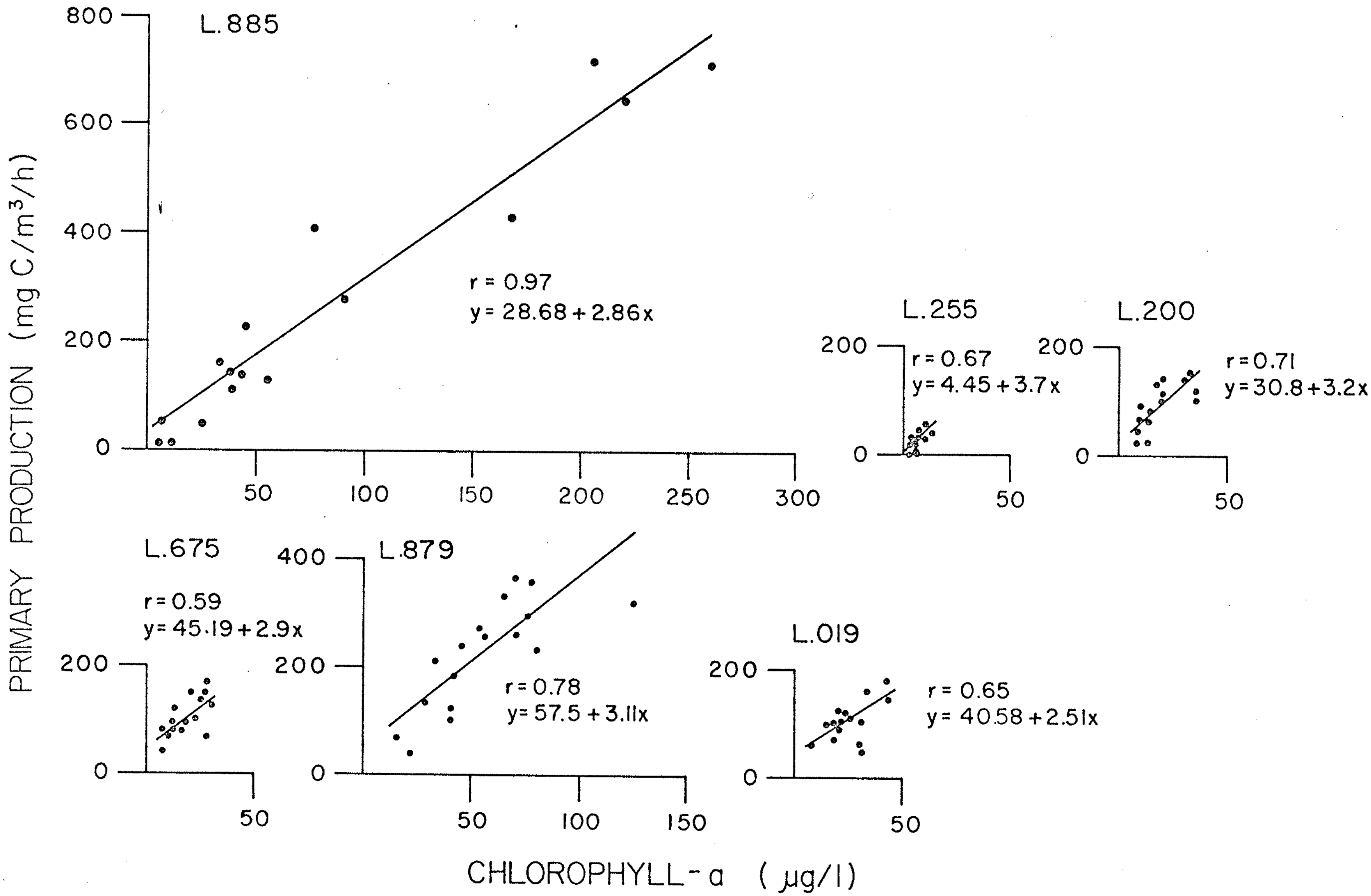


Figure 16. Gross primary production - chlorophyll-a relationships in six lakes of southwestern Manitoba. All significant at 1% level except Lake 675 at 5%.

Table 5. Assimilation numbers (mg C/mg chlorophyll-a per hour) for six lakes of southwestern Manitoba, June to October 1976.

Date	mg C/mg chlorophyll-a per hour					
	L. 885	L. 255	L. 200	L. 675	L. 879	L. 019
June 1-3	3.9	13.2	9.3	7.8	4.2	8.5
8-10	4.8	9.4	6.6	4.4	4.7	5.7
13-16	5.1	2.0	5.5	5.1	5.2	4.5
22-25	9.4	5.3	7.2	5.4	3.0	4.3
27-30	-	5.2	5.4	5.8	1.8	5.2
July 6-8	5.2	12.9	7.8	8.5	4.6	6.6
13-15	3.5	4.6	4.6	6.3	5.2	4.3
20-22	2.7	3.5	-	5.1	5.2	4.0
26-28	2.9	6.6	5.4	6.3	2.6	5.6
Aug. 4-6	2.6	3.6	5.5	9.3	6.2	4.3
10-12	3.1	5.3	4.5	5.8	5.2	4.2
17-20	2.3	5.7	4.8	5.4	4.6	4.8
22-24	1.9	3.4	4.7	6.0	5.3	4.3
Sept. 9-13	3.3	4.1	3.4	4.5	3.8	3.3
20-22	3.0	3.4	3.0	5.3	4.7	3.3
Oct. 6-9	1.1	0.7	1.4	2.6	2.9	1.8
19-21	1.3	4.3	1.9	2.5	2.4	2.0
Mean	3.2	4.9	4.5	5.2	4.1	4.1

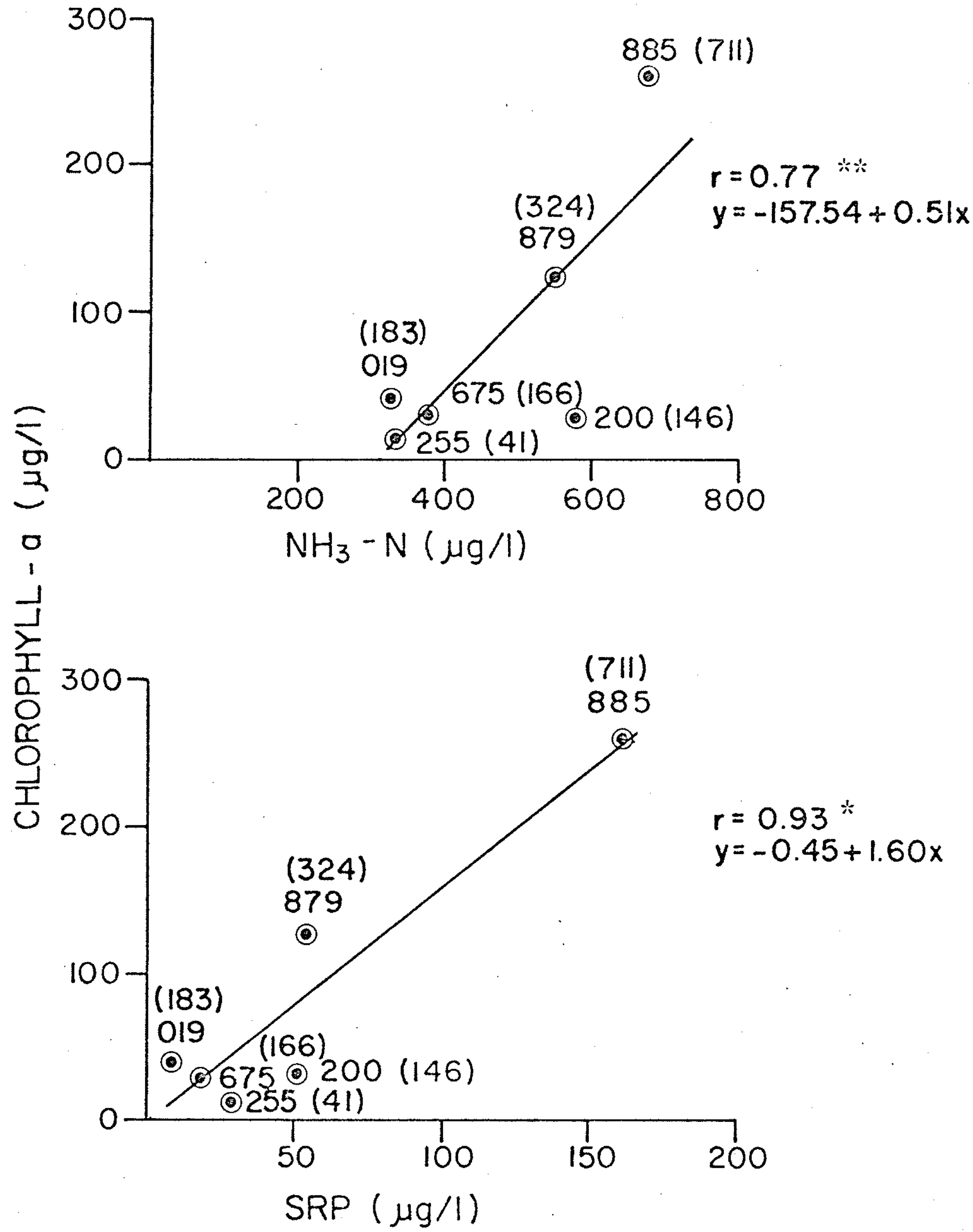
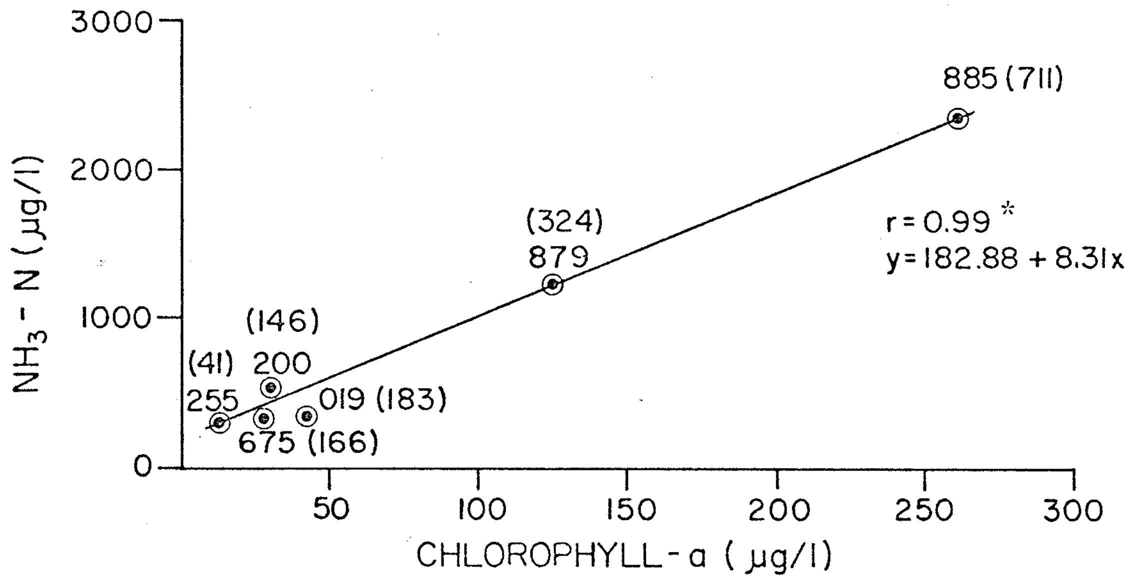


Figure 17. Correlation between winter (1976) maxima of ammonia nitrogen (NH_3-N) and soluble reactive phosphorus (SRP) and summer (1976) maxima of chlorophyll-a concentration in six lakes of southwestern Manitoba.

Number beside each point is lake identification. Gross primary production ($mgC/m^3/hr$) at time of maximum chlorophyll-a is given in the bracket.

* Significant at 1% level.
** Significant at 10% level.



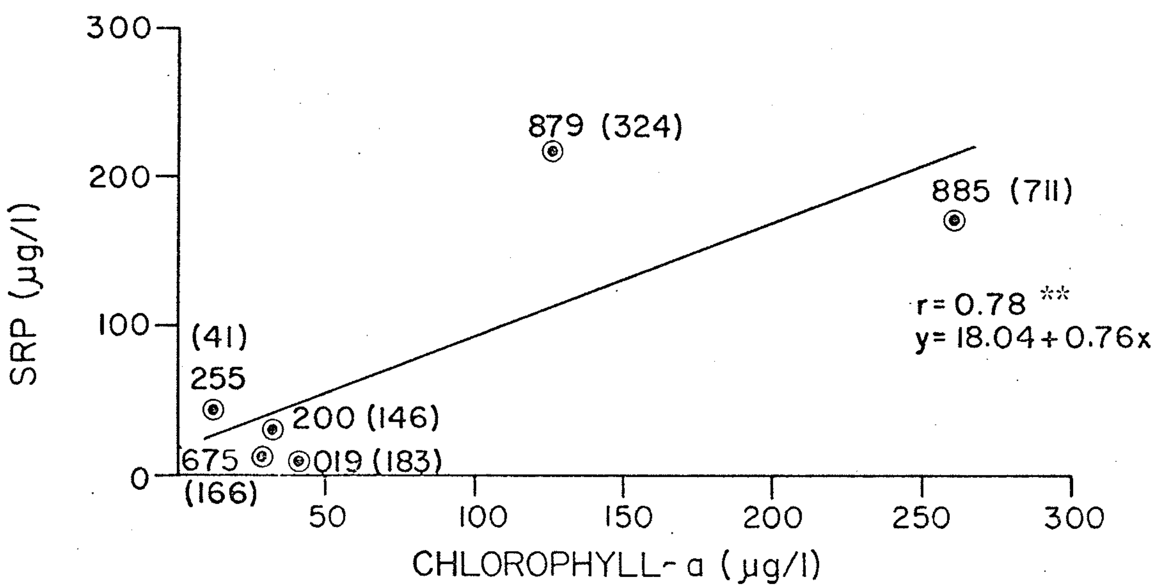


Figure 18. Correlation between summer (1976) maxima of chlorophyll-a concentration and winter (1977) maxima of ammonia nitrogen (NH_3-N) and soluble reactive phosphorus (SRP) in six lakes of southwestern Manitoba.

Number beside each point is lake identification. Gross primary production (mg C/m^3/hr) at time of maximum chlorophyll-a is given in the bracket.

* Significant at 1% level.
** Significant at 10% level.

concentration, the production in mg $C/m^3/hr$ at the time of maximum chlorophyll-a is given in brackets in the figure. The relationship between N:P ratio and chlorophyll-a content in lakes studied is given in Table 6.

The seasonal distribution of major groups composing the phytoplankton in the study lakes varied within and between lakes (Fig. 19a and 19b).

In Lake 885, cryptomonads and green algae were abundant during winter and spring respectively. Both decreased during summer months and were replaced by blue-green algae throughout the summer. This period was dominated by a nearly pure culture of Aphanizomenon flos-aquae. It composed about 96-100% of the total biomass from July to September. Cryptomonads were once again dominant in October comprising 81% of the biomass. From November to February, green algae were dominant but occurred in low standing crop (averaged 3 µg/l chlorophyll-a).

The winter phytoplankton in Lake 255 was composed mainly of Euglenophyta and green algae in late winter. The spring phytoplankton was dominated by cryptomonads. In June dinoflagellates were most abundant (94% biomass). After the dinoflagellate pulse, blue-green algae increased to form 65% of the biomass in summer. This population declined in fall with a change in dominance to cryptomonads during the ice-cover period.

The phytoplankton composition in Lake 200 showed more diversity than that in Lake 885 and Lake 255. Blue-green algae contributed most during the ice-free period but at a lower standing crop than in Lake 885. Diatoms and chrysomonads were dominant in spring, green algae and blue-green algae in mid-summer, dinoflagellates and blue-green algae in late summer

Table 6. The relationship between winter ammonia nitrogen (NH_3-N): soluble reactive phosphorus (SRP) ratio and summer algal standing crop in six lakes of southwestern Manitoba.

Lake	Maximum winter concentration			Maximum summer chlorophyll-a (µg/l)
	NH_3-N (µg/l)	SRP (µg/l)	NH_3-N:SRP	
885	669	159	4:1	260
255	332	28	12:1	12
200	579	50	12:1	31
675	374	14	27:1	28
879	549	53	10:1	124
019	331	8	41:1	42

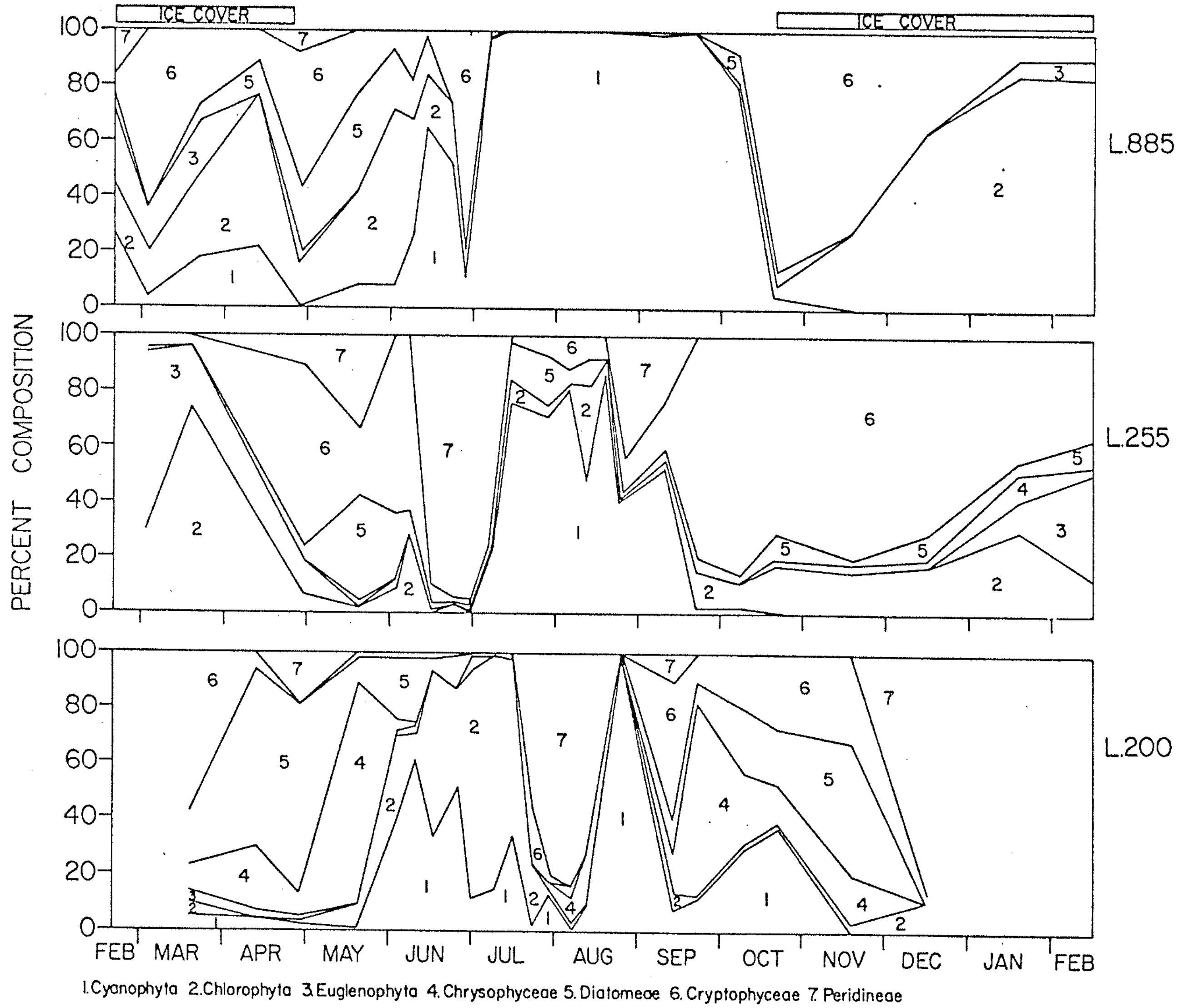
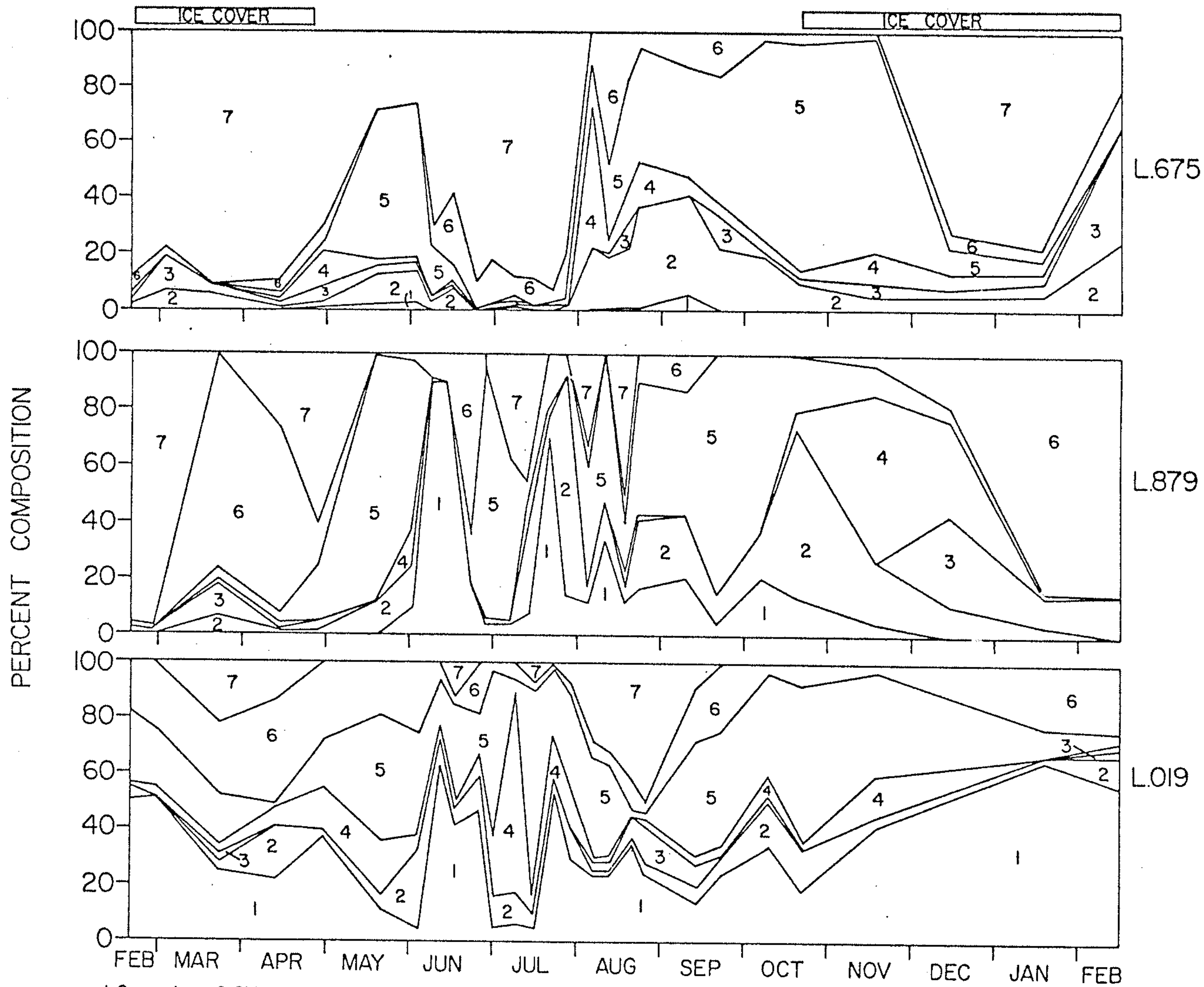


Figure 19a. Seasonal distribution of the major groups of phytoplankton in Lake 885, Lake 255, and Lake 200 of southwestern Manitoba, February 1976 to February 1977.



1. Cyanophyta 2. Chlorophyta 3. Euglenophyta 4. Chrysophyceae 5. Diatomeae 6. Cryptophyceae 7. Peridineae

Figure 19b. Seasonal distribution of the major groups of phytoplankton in Lake 675, Lake 879, and Lake 019 of southwestern Manitoba, February 1976 to February 1977.

and cryptomonads and chrysomonads were abundant in fall.

In Lake 675, dinoflagellates were abundant during late winter (86% biomass) and early summer (81% biomass). Dinoflagellates were scarce during mid-summer and fall and were replaced by diatoms. In winter 1977, dinoflagellates were once again dominant.

The winter phytoplankton in Lake 879 was composed mainly of dinoflagellates and cryptomonads. Diatoms were abundant during spring (87% biomass). The summer phytoplankton showed more diversity with diatoms and blue-green algae the most important constituents. However, green algae were dominant in late July composing 77% of the biomass (124 µg/l chlorophyll-a). The fall phytoplankton was dominated by diatoms, green algae, and chrysomonads. Cryptomonads were once again dominant in winter 1977.

The phytoplankton composition of Lake 019 showed more diversity throughout the year than did that of the other lakes. Blue-green algae and diatoms were the most important constituents and composed 31% and 28% of the yearly average biomass respectively.

Based on the yearly average per cent composition, Lake 885 and Lake 019 are basically blue-green algal lakes (Table 7). Lake 200 and Lake 879 are diatom lakes. Lake 255 and Lake 675 are cryptomonad and dinoflagellate lakes respectively.

Table 7. Mean values of percentage group composition of phytoplankton in six lakes of southwestern Manitoba, February 1976 to February 1977.

Lake	Cyanophyta	Chlorophyta	Euglenophyta	Chrysomonadinae	Diatomeae	Cryptomonadinae	Dinophycinae
885	35.9	26.5	4.2	0.0	6.5	25.2	1.7
255	13.8	15.1	6.1	1.7	8.1	41.7	13.5
200	15.5	12.0	0.7	18.9	19.2	15.7	18.0
675	0.9	9.2	3.4	5.0	26.2	6.7	48.6
879	10.3	13.1	5.0	8.4	26.8	21.0	15.4
019	32.1	6.5	1.4	8.3	28.4	16.1	7.2

DISCUSSION

Trophic state of the lakes studied

Various morphometric and limnological characteristics can be used to classify the trophic state of lakes. Rawson (1955, 1961) emphasized in various publications the importance of mean depth in the productivity of lake. Sakamoto (1966) suggested that among various characteristics of lakes affecting the production of phytoplankton, the morphometry of lakes, especially their depth, is the most important. He also found that shallow lakes were more productive than the deeper ones. The lakes studied are shallow with mean depth range from 1.5 m to 3.4 m (Table 1) and can be classified as productive.

The seasonal average of Secchi disc transparency also provides a useful physical variable in lake classification (Rawson 1961). Dobson et al. (1974) classified eutrophic lakes as having a yearly average Secchi disc transparency less than 3 m. The average Secchi disc readings during the ice-free period in these lakes range from 0.8 m to 1.5 m except for Lake 255 where the Secchi disc readings always reach to the bottom.

Most of the lakes studied (except Lake 200 and Lake 019) have a bottom temperature similar to that of the surface and exhibit continuous circulation except under the ice cover (Fig. 5). This type of lake can be classified as a third order temperate lake (Welch 1952) or a thermally unstratified lake (Hutchinson 1957). The temperature conditions of Lake 200 and Lake 019 (Fig. 5) are similar to that of Lake Östbysjön described by Ahl (1966) where no real hypolimnion was formed. The epilimnion of these lakes extends down to about 3 m where it changes into a metalimnion continuing down to the bottom (Fig. 12 and Fig. 13).

Major ions have been used to classify the level of salinity of the lakes. Barica (1975b) in accordance with Rawson and Moore (1944) defined the lakes as moderately saline with total ionic (TI) level below 1000 mg/l or saline with TI level more than 1000 mg/l. The TI concentrations in the lakes studied ranged from 659 to 1691 mg/l (Table 2). Therefore, the salinity of these lakes is moderately saline to saline according to Barica (1975b). The dominance of Mg^{++} and $SO_4^{=}$ is obvious for all six lakes although the HCO_3^{-} concentration in Lake 019 is higher than that of $SO_4^{=}$ (Table 2). Rawson and Moore (1944) also found the predominance of HCO_3^{-} and $SO_4^{=}$ as a typical feature of prairie and parkland lakes in Saskatchewan. According to Filatov's system which was modified by Barica (1975b), the lakes studied are classified as intermediate $SO_4^{=}$ - HCO_3^{-}, Mg^{++} type except Lake 019, which is an intermediate HCO_3^{-} - $SO_4^{=}$, Mg^{++} type.

The concept of nutrient loading was developed by Vollenweider (1968) to classify the lake trophic states. There are no nutrient loading data available to classify the trophic state of these lakes because their sources are diffuse. However, algal blooms can be expected from winter concentrations of inorganic nitrogen exceeding 300 μg/l and inorganic phosphorus exceeding 10 μg/l (Sawyer 1947). Maximum concentrations of inorganic nitrogen about 640 μg/l and soluble reactive phosphorus (SRP) about 23 μg/l were found in eutrophic western Lake Erie (Dobson et al. 1974). The maximum winter (1976) concentration of ammonia nitrogen (NH_3-N) and SRP in the lakes studied ranged from 331 to 669 μg/l and

8 μg/l to 159 μg/l, respectively (Fig. 9 and Fig. 10). Comparison with nutrient concentrations presented by Dobson _et al._ (1974) indicates that these lakes are eutrophic.

The classification of lake trophic status based on the chlorophyll-a concentrations has been proposed by many limnologists. Vollenweider (1968) stated that highly productive lakes contained chlorophyll-a concentrations greater than 30 μg/l. Sakamoto (1966) indicated that eutrophic lakes contained chlorophyll-a concentrations from 5-140 μg/l. Dobson _et al._ (1974) have also attempted to classify lake trophic status on the basis of average chlorophyll-a concentrations. They considered that lakes having average chlorophyll-a levels during the ice-free period of more than 8.8 μg/l were eutrophic. The average chlorophyll-a during the ice-free period in the lakes studied ranged from 9 μg/l to 63 μg/l.

A classification of lake types on the basis of primary production has been also attempted. Vinberg (1960) summarized the data from lakes of the Moskovsky and Kalininsky provinces in U.S.S.R. and concluded that the gross primary production in mid-summer of highly eutrophic lakes was between 2.8 and 3.7 g C/m^2/day. Rodhe (1969) restricted the term "natural eutrophic" to lakes having a range of primary production between 0.3 and 1.0 g C/m^2/day and "polluted eutrophic" between 1.5 and 3.0 g C/m^2/day. The average summer gross primary production in our lakes is from 1.9 to 3.2 g C/m^2/day, which is in the range of highly eutrophic lakes according to Vinberg, or in the range of polluted eutrophic lakes according to Rodhe. An exception is Lake 255 (0.6 g C/m^2/day), which can be classified as natural eutrophic (Rodhe 1969). It is noticeable that the algal production in Lake 255 is low. This is probably due to competition between phytoplankton and submerged macrophytes, which developed dense growths in this lake. The maximum daily primary production of the lakes studied (2.7-6.9 g C/m^2, excluding Lake 255) is close to that of highly eutrophic western Lake Erie (4.8 g C/m^2) as described by Glooschenko et al. (1974).

The relationship of primary production to chlorophyll-a or assimilation number can be used to interpret the nutrient status of the lakes and is consequently related to the trophic state. Curl and Small (1965) measured primary production of marine phytoplankton communities using the ^{14}C method and reported on the basis of their experiments and the work of others that assimilation numbers between 1 and 3 indicated very low nutrient supply and between 5 and 10 nutrient-rich waters. Glooschenko et al. (1974) reported that mean assimilation number from April to December 1970 in Lake Erie was 1.9 (range 0.8-3.8). Based on the assimilation number presented by Curl and Small, this value would mean a low nutrient supply in Lake Erie. Glooschenko et al. (1974) explained that the low assimilation numbers in Lake Erie might be due to inherent differences between marine and freshwater phytoplankton communities. However, they felt that mean assimilation above 2 indicate nutrient enrichment in their studies. The average assimilation numbers (June-October) in our lakes (3.2-5.2) indicated nutrient enrichment in comparison to Lake Erie. However, the higher assimilation numbers in our lakes than that of Lake Erie might be due to the different methods in measuring primary production. If the oxygen method is supposed to measure gross photosynthesis and the ^{14}C method approximately net photosynthesis, the assimilation number according to the oxygen method should exceed those found by the ^{14}C method. I feel, however, that there is no general correlation between assimilation number and trophic state. In oligotrophic lakes generally nannoplankton are the major components of phytoplankton. We could have a high assimilation number in an oligotrophic lake where the algal biomass was being controlled by grazing. On the other hand, a low assimilation number might be found in an eutrophic lake where larger forms of phytoplankton are dominant. These algae are not liable to grazing, therefore, the turnover of the algal standing crop in the oligotrophic lake will be more rapid than in the eutrophic one. In our lakes, the lowest summer mean assimilation number (4.0) was found in Lake 885 where the nutrient supply was high and the bloom dominated by Aphanizomenon. On the contrary, the highest summer mean assimilation number (6.3) was found in low nutrient supply lake (Lake 675) where dinoflagellates were dominant. This indicates that assimilation number does not depend upon nutrient supply alone but also depends upon the species composition as well as physiological state of the algae.

The dominance of the algal population by blue-green algae is also an indication of the degree of eutrophication (Teiling 1955; Rawson 1956). Blue-green algae were found in summer in all six lakes (Fig. 19a and 19b) but they dominated only in three lakes (Lake 885, Lake 255, Lake 200) and composed a variable percentage of the standing crop. There is no relationship between winter nutrient concentration and composition of phytoplankton in the following summer. For example, Lake 885 (high winter nutrients) and Lake 255 (low winter nutrients) were dominated by blue-green algae in summer. This indicates that the availability of winter nutrients may be responsible for the magnitude of algal production but its role in determining succession is less obvious.

On the basis of selected morphometric, physical, chemical, and biological characteristics, the lakes studied can be classified as non-stratified, shallow, eutrophic, moderately saline to saline lakes with Mg^{++}, $SO_4^{=}$, and HCO_3^{-} comprising the most of major ions.

Dissolved oxygen-nutrients-phytoplankton relationships

Causes of winter and summer oxygen depletion

The minimum DO concentration at which fish can live is not easily determined because of differences in resistance to DO deficiency in different species. Ayles *et al.* (1976) quoted Merkens and Downing (1957) that a 100 min. LC 50 of DO at 1.8 mg/l was found for rainbow trout acclimated to 15.2°C. Doudoroff and Shumway (1970) reviewed the DO requirements of freshwater fishes and reported that the lethal levels of DO for carp (*Cyprinus carpio*), age 2 years, at 5-8°C were only 0.3-0.8 mg/l.

Based on the above-mentioned reports, it was assumed that winterkill or summerkill might occur when the oxygen concentration in the whole water column drops below 1.0 mg/l.

On the basis of oxygen depletion in winter and summer (Fig. 6), Lake 019 is a non-winterkill lake and the rest winterkill. Among the winterkill lakes, Lake 885 is also a summerkill lake.

Oxygen demand exceeds supply beneath the ice causing complete oxygen depletion (Greenbank 1945). The decomposition of organic matter produced during the ice-free period by bacteria and resultant consumption of oxygen plus the respiration of organisms under the ice appear to be the major demands on the oxygen supply. The formation of ice and snow cover usually affects the gaseous exchange and reduces the amount of light penetration which further limits photosynthetic oxygen production. Greenbank (1945) and Nickum (1970) reported that oxygen depletion in winter was associated with snow cover. Wright (1964) found that an accumulation of 0.29 m of snow on the ice reduced light penetration to

0.2% of incident light. This caused a decline in phytoplankton abundance. However, the presence or absence of snow on the ice in six lakes of northern Michigan had little effect on the fluctuations and decline of oxygen (Patriarche and Merna 1970). The thickness of snow cover in this study was similar in all six lakes and close to that observed by Wright (1964) and yet no winterkill occurred in Lake 019. Therefore, snow depth is probably not the principal factor affecting oxygen regimes beneath the ice. Patriarche and Merna (1970) suggested that phytoplankton pulses under ice in non-winterkill lakes might have a greater influence on the oxygen regime than the presence or absence of snow. In this study, no algal pulses in mid-winter were observed in the non-winterkill lake but they occurred in some winterkill lakes (Fig. 14). This shows that oxygen produced by the algal pulse in winter does not increase the net concentration of oxygen since the overall oxygen uptake is much higher. Therefore, the possibility of a phytoplankton pulse having a significant effect on the oxygen regime in winter is unlikely. Winterkill lakes may be associated with high salinity under ice since the solubility of oxygen decreases with increasing salinity (Reid 1965). The total ions of winterkill lakes in mid winter ranged from 990 to 2003 mg/l while the non-winterkill lake was about 892 mg/l. However, salinity itself may not be sufficient to cause the winter oxygen depletion. There is a possibility that the depth of the lake can differentiate a non-winterkill lake from a winterkill lake because the shallow lakes have less storage capacity for the oxygen under high oxygen consumption conditions. Nickum (1970) reviewed limnological conditions in South Dakota lakes and reported that winterkill was rarely observed in lakes greater than 5 m in maximum depth. In this study, no winterkill was found in a lake (Lake 019) with a maximum depth (Zm) of 6.8 m. Most winterkills were found in lakes with Zm less than 4.2 m, except Lake 200 with Zm about 6.8 m. However, the mean depth of Lake 200 (2.8 m) is less than Lake 019 (3.4 m).

The basic cause of summer oxygen depletion is the collapse of heavy blooms of blue-green algae and the subsequent high oxygen uptake by bacterial populations which break down the algal material. The genera which most commonly form blooms are Anabaena, Aphanizomenon, Gloeotrichia, and Microcystis (Reynolds and Walsby 1975). Mackenthun et al. (1945) reported that the primary cause of the fish mortality in Yahara River, Wisconsin was the depletion of dissolved oxygen which was caused by decomposition of excess growth of Aphanizomenon flos-aquae. This species is also found to be most commonly responsible for heavy blooms in southwestern Manitoba lakes (Barica 1975a). In Lake 885 this noxious bloom started about July 6 (Fig. 14) and reached its maximum on July 20 (260 µg/l chlorophyll-a). Phytoplankton in this period consisted almost entirely of Aphanizomenon (Fig. 19a). The dominance of a single species in this blue-green algal bloom may be due to the extra-cellular byproducts by which one species can inhibit the growth of another (Prescott 1960; Vance 1965). Murphy et al. (1976) recently reported that blue-green algae excrete a hydroxamate chelator which is effective in suppressing other algae. Since ammonia nitrogen was undetectable during the main bloom period, the ability of Aphanizomenon to fix nitrogen probably permits it to grow when concentrations of ammonia nitrogen are sufficiently low to limit the development of other algae. Aphanizomenon which contributed up to 99-100% of biomass, began to die off rapidly after it reached the maximum bloom. The chlorophyll-a concentration (Fig. 14), dropped from 260 μg/l to 24 μg/l within one month and gross primary production (Fig. 15a) from 4.6 g C/m^2/day to 0.8 g C/m^2/day. This bloom collapse and subsequent decomposition of dead cells caused DO to drop to near zero (0.1 mg/l or 1.1% saturation) throughout the whole water column (Fig. 6). What caused the actual collapse of the heavy bloom is not yet known. The exhaustion of nutrients may be associated with the bloom collapse. Healey and Hendzel (1976) suggested that phosphorus deficiency seem to play an important part in setting the conditions for a collapse but it was not the factor that triggered the collapse. The phosphorus concentration (SRP) in Lake 885 (Fig. 10) was low to undetectable during the bloom period (one week prior to and at the time of maximum bloom) which indicated phosphorus shortage. Excretion of self-inhibiting substances (Prescott 1960; Vance 1965), or attacking and lysing of algal cells by viruses and bacteria (Shilo 1971) may also be involved in the bloom collapse.

Limiting nutrients and the role of phosphorus in controlling noxious bloom

It is known that several nutrients are required for the growth of algae but few are likely to act as limiting factors. Carbon in either dissolved inorganic (DIC) or dissolved organic form (DOC) causes little or no increase in standing crop (Schindler *et al.* 1971). DIC is unlikely to limit algal production because algae can utilize HCO_3^- either directly or through equilibrium with CO_2 (King 1970; Schindler 1971). Goldman *et al.* (1972) suggested that when free CO_2 content was insufficient to meet the demand of algae, HCO_3^- ion could continually supply CO_2 for algal utilization through a readjustment of the CO_2-HCO_3^--$CO_3^=$ equilibrium. This process results in a rise of pH, as demonstrated in Table 3 (for Lake 885). Dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP) were present in high concentrations even when ammonia nitrogen (NH_3-N) and soluble reactive phosphorus (SRP) were undetectable, indicating that not all dissolved organic compounds were utilized directly by phytoplankton (Schindler 1971). The comparison of the nutrient chemistry (Fig. 8-10) indicates that NH_3-N and SRP are perhaps more critical in determining phytoplankton production than other nutrients because both NH_3-N and SRP concentrations were low during the summer months. However, NO_3-N concentration was also low in summer, but there was no relationship found between the spring maximum concentration of NO_3-N and the summer algal standing crop in this study.

Most limnologists have assumed that phosphorus is the most limiting nutrient in determining the size of algal blooms. The ability of blue-green algae to fix atmospheric nitrogen and the ability to use CO_2 from HCO_3^- through the equilibrium make phosphorus the most probable controlling nutrient. Hammer (1964) found that Aphanizomenon blooms developed in lakes with high phosphate concentrations. Prescott (1968) reported that a minimum of 30 μg/l orthophosphate was critical for blue-green algae. Since Aphanizomenon was found in both Lake 885 and Lake 879 but the noxious bloom occurred only in Lake 885, this bloom may have been due to higher winter SRP concentration (159 μg/l) than that of Lake 879 (53 μg/l). It might have been also directly caused by the high concentration of SRP (146 μg/l) found prior to the noxious bloom. In Lake 879 this pre-bloom concentration reached only 57 μg/l. The lower

SRP concentration of Lake 879 in both winter and pre-bloom might have not been enough to cause a noxious bloom. On the basis of the above, it might be expected that the high SRP concentration of Lake 885 (175 μg/l) and Lake 879 (222 μg/l) in winter 1977 (Fig. 10) would bring about noxious blooms in both lakes in the following summer. In fact, summerkills (total in Lake 885 and at least partial in Lake 879) did occur in both lakes in summer 1977 (J. Barica, personal communication). From this point of view, it can be arbitrarily assumed that summerkill would occur in a lake which contains maximum winter concentrations of SRP exceeding 150 μg/l.

Nutrients and phytoplankton after a noxious bloom collapse

High concentrations of nutrients (937 μg/l NH_3-N and 22 μg/l SRP) were observed during summerkill period in Lake 885 (Fig. 9 and Fig. 10). However, these available nutrients did not support further blooms of phytoplankton. The algal pulse in early fall was 42 μg/l chlorophyll-a and *Aphanizomenon* composed of 80% of biomass. Phosphorus appeared to become limiting in this time. Hammer (1964) reported from observations in Saskatchewan lakes that *Aphanizomenon* blooms occasionally persisted into late fall when temperatures were low. He also found that growth of this blue-green algae sharply increased above 20°C. The water temperature in Lake 885 in early fall was about 14°C as compared to that at maximum bloom period of about 20°C (Fig. 5). It is possible that the weather conditions in this period became less favorable for the growth of this blue-green alga.

Relationship between winter nutrient concentration and summer algal standing crop

Mortimer's (1941, 1942) and Hutchinson's (1957) theories of nutrient regeneration under anoxic conditions have been widely accepted. However, oxic regeneration of nutrient has also been reported. Vollenweider (1968) suggested that denitrification by bacteria seemed not to require anaerobic conditions but might also occur in layers where oxygen was plentiful. Burns and Ross (1972) found that during oxic degradation of organic materials approximately 45% of the nitrogen and 25% of the phosphorus contained in the organic material was returned to the water in soluble form. Bloesch et al. (1977) calculated the decomposition of algae under oxic condition in epilimnion and found that 77-79% of the total phytoplankton was decomposed in the epilimnion before it could sink into the hypolimnion. Nevertheless, the anoxic regeneration of nutrients seems to be higher than oxic regeneration. Otsuki and Hanya (1972) found relatively higher concentrations of dissolved organic matter in anaerobic decomposition than in aerobic decomposition. Burns and Ross (1972) reported that the anoxic regeneration rate of phosphorus was 11 times greater than the oxic rate. High winter concentrations of NH_3-N (286-616 μg/l) and SRP (8-157 μg/l) were observed in all winterkill lakes (Lake 885, Lake 255, Lake 200, Lake 675, and Lake 879). This indicates regeneration of nutrients at low oxygen levels (0.0-0.9 mg/l). However, high concentrations of NH_3-N (298 μg/l) and SRP (6 μg/l) were also found at high oxygen levels (5 mg/l DO or 37% saturation) in the upper 3 m of the non-winterkill lake. It appears that the decomposition of organic matter and consequent release of nutrients occur even at relatively high oxygen concentrations. No data are available for comparison between oxic and anoxic regeneration of nutrients in this study. However, substantially higher concentrations of NH_3-N (792 μg/l) and SRP (58 μg/l) near the anoxic bottom in the non-winterkill lake (Lake 019) than that of the upper 3 m oxic layer suggests that anoxic regeneration of nutrient was higher than oxic regeneration. This high nutrient concentration near the bottom is also a result of gradual settling of particulate organic matter.

The relationship between nutrient concentrations and algal standing crop has been reported by many researchers. Sakamoto (1966) found a linear relation between chlorophyll content and the total nitrogen or total phosphorus content in many Japanese lakes. Dillon and Rigler (1974) demonstrated a high level of success in predicting summer chlorophyll concentrations from spring total phosphorus. Barica (1975b) found a significant correlation between winter maxima of NH_3-N and summer maxima of chlorophyll-a concentration in southwestern Manitoba lakes. In this study, the summer maxima of chlorophyll-a were plotted against winter maxima of NH_3-N and SRP (Fig. 17). From this correlation, it appears that higher winter nutrient concentrations will yield the higher algal standing crop and production in the following summer. However, SRP appears to be more significant in relating with algal standing crop than NH_3-N. This can be seen more clearly from the N:P ratio (Table 6) since the ionic ratio indicates which ion is likely to be limiting algal production (Schindler _et al_. 1971). Flett (1976) calculated the N:P ratio from dissolved inorganic nitrogen:total dissolved phosphorus. Haertel (1976) calculated from dissolved inorganic nitrogen: orthophosphate. Since NH_3-N and SRP were high in winter and are known to be readily available to algae, N:P ratio in lakes studied was calculated from NH_3-N:SRP. It can be seen from Table 6 that the highest algal standing crop occur in Laek 885 where the winter N:P ratio is lowest. This low ratio is also related to the summer dominance of Aphanizomenon because a low N:P ratio favors nitrogen fixing blue-green algae over other algae that cannot compete with blue-greens at low nitrogen concentrations because they are unable to fix atmospheric nitrogen. Schindler (1977) concluded from his nutrient enrichment experiments that the bloom shifted from green algae to blue-green algae when the N:P ratio by weight changed from about 14:1 to 5:1.

Summer algal standing crop and production cannot be explained only by winter nutrient concentrations because population changes in nature depend on many other factors (Hasler 1964). Hasler and Jones (1949) have demonstrated that algae are inhibited by the presence of aquatic macrophytes in small test ponds. The low standing crop and production in Lake 255 was probably caused by the extensive growth of submerged macrophytes. The accumulation of nutrient in the bottom water of stratified lakes during the summer months also limits algal growth. Sakamoto (1966) suggested that phytoplankton production in a lake depends on the concentration of nutrients as well as their recycling. Haertel (1976) assumed that the correlation between nutrient levels and wind stress was the result of wave action recirculating nutrients released at the sediment surface. High winter nutrient concentrations in Lake 200 (as high as in Lake 879) yielded low summer algal standing crop and production (Fig. 17). This is probably caused by the fact that Lake 200 is located in a sheltered basin and is deep enough to prevent direct stirring of bottom sediments by waves, and this may in turn limit transport of nutrients from the bottom into the upper layer. Most of the nutrients in this lake were accumulated in the bottom (under anoxic condition) during the summer months (Fig. 12). As mentioned before, the nutrients were accumulated near the anoxic bottom during the winter in Lake 019 (Fig. 11), but only the upper 3 m layer was considered. The initial winter nutrient supply is therefore under-estimated and should be higher than that presented in Fig. 17. However, summer algal standing crop and production in this lake was still lower than expected. This was caused by the accumulation of nutrients near the bottom (Fig. 13) as in Lake 200. The higher standing crop and production in Lake 885 and Lake 879 than other lakes are related to the higher winter nutrient supply and the re-distribution of nutrient liberated throughout the whole lake by wind action during the summer. The low standing crop and production in Lake 675 appears to be caused by low initial winter nutrient supply. The effect of submerged macrophytes was probably less pronounced here than in Lake 255 and the lake water was also well circulated. It should be pointed out here from Fig. 17 that the relationship between winter nutrient concentration and summer algal standing crop as well as primary production will be more pronounced if all lakes studied had similar environmental factors (i.e. no dense growth of submerged macrophytes and no accumulation of nutrient in the bottom water during the summer months).

Since the algal standing crop and production as well as the accumulation of organic material during growing season in Lake 885 and Lake 879 are higher than the rest of the lakes studied, it could be expected that the concentration of nutrients in the following winter (1977) in these two lakes would be greater. To demonstrate this expectation, the nutrient concentrations in winter (1977) were plotted against maximum chlorophyll-a from the previous summer (Fig. 18). It can be seen from this correlation that the higher winter nutrient concentrations seem to agree with higher summer chlorophyll-a in the previous summer.

It can be concluded that both winter and summer oxygen depletion played an important role in governing the nutrient cycles in these lakes. The winter ammonia nitrogen and soluble reactive phosphorus can be used to determine the magnitude of the summer algal standing crop and primary production.

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APPENDIX

Appendix 1. Per cent light transmittance (%) in six selected lakes. July 1976 to October 1976.

Lake 885

Date	Depth (m) 0.05	0.25	0.5	1.0	1.5	2.0	2.7 (bottom)
Jul 6	100	80	60	14.0	7.0	1.6	0.6
13	100	60	24	2.6	0.3	0.1	0.03
20	100	60	14	0.4	0.04	0.02	0.02
26	100	66	28	3.6	0.5	0.1	0.02
Aug 4	100	56	22	2.4	0.1	0.04	0.02
10	100	80	50	14.0	2.4	0.7	0.1
17	100	70	48	20.0	7.8	3.4	0.5
22	100	80	60	28.0	14.0	7.0	2.4
Sep 9	100	82	60	24.0	10.0	5.6	2.2
20	100	-	-	46.0	20.0	7.4	1.8
Oct 6	100	64	36	10.0	1.6	0.8	0.3

Lake 255

Date	Depth (m) 0.05	0.25	0.5	1.0	1.5	2.0	2.5 (bottom)
Jul 7	100	94	78	56	20	16	16
14	100	90	78	60	44	26	18
21	100	84	76	58	40	24	16
27	100	88	76	58	36	22	8
Aug 5	100	86	72	48	30	18	10
11	100	82	68	44	36	20	10
18	100	92	73	52	30	24	14
23	100	92	74	40	24	15	7
Sep 10	100	82	78	50	32	18	4
21	100	90	74	50	34	22	12
Oct 7	100	70	64	46	32	20	14

Appendix 1. (cont.)

Lake 200

Date	Depth (m)								
	0.05	0.25	0.5	1.0	1.5	2.0	3.0	4.0	5.4 (bottom)
Jul 8	100	85	54	32	18	14	10	1.2	0.02
15	100	80	54	34	14	7	1	0.2	0.01
22	100	76	58	26	10	4	2	0.5	0.08
28	100	84	70	36	26	16	6	2.3	0.01
Aug 6	100	84	62	38	20	12	5	2.0	0.01
12	100	90	62	30	14	7	3	0.4	0.01
20	100	82	60	34	16	9	3	0.9	0.01
24	100	82	60	26	14	7	2	0.5	0.01
Sep 13	100	-	-	44	20	10	2	0.8	0.04
22	100	80	48	24	7	6	2	0.5	0.04
Oct 9	100	-	-	52	28	14	4	1.0	0.40

Lake 675

Date	Depth (m)						
	0.05	0.25	0.5	1.0	1.5	2.0	3.4 (bottom)
Jul 7	100	86	68	60	28	20	7.8
14	100	90	84	56	34	18	2.4
21	100	84	68	42	24	18	2.9
27	100	88	72	36	24	12	2.4
Aug 5	100	84	65	30	16	10	1.6
11	100	90	62	40	18	12	2.2
18	100	82	56	14	10	7	0.8
23	100	82	45	20	8	3	0.2
Sep 10	100	74	40	12	6	2	0.2
21	100	78	46	20	8	3	0.1
Oct 7	100	80	40	12	7	3	0.5

Appendix 1. (cont.)

Lake 879							
Date	Depth (m)						
	0.05	0.25	0.5	1.0	1.5	2.0	2.3 (bottom)
Jul 6	100	88	70	16	7	6.0	0.6
13	100	-	80	24	8	2.0	1.0
20	100	74	54	10	3	1.4	0.6
26	100	64	36	8	2	0.3	0.1
Aug 4	100	70	42	10	3	0.8	0.3
10	100	68	41	10	2	0.7	0.3
17	100	68	34	8	2	0.8	0.2
22	100	64	36	9	3	0.6	0.3
Sep 9	100	84	76	5	1	0.3	0.1
20	100	-	64	15	3	0.6	0.4
Oct 6	100	60	28	4	1	0.3	0.2

Lake 019										
Date	Depth (m)									
	0.05	0.25	0.5	1.0	1.5	2.0	3.0	4.0	5.0	6.1 (bottom)
Jul 8	100	88	68	34	20	10	5.0	1.4	0.7	0.03
15	100	-	84	44	22	10	2.0	0.4	0.2	0.06
22	100	82	64	30	16	9	3.0	0.7	0.2	0.03
28	100	84	52	24	14	6	2.0	0.5	0.2	0.02
Aug 6	100	84	66	38	20	10	3.8	1.0	0.3	0.03
12	100	74	52	24	10	5	1.0	0.3	0.02	0.01
20	100	74	52	20	9	4	0.8	0.2	0.05	0.02
24	100	82	54	22	10	4	1.0	0.2	0.05	0.02
Sep 13	100	72	42	18	6	3	0.6	0.2	0.1	0.06
22	100	80	60	28	14	7	1.8	0.5	0.1	0.06
Oct 9	100	82	64	32	14	8	2.4	0.7	0.2	0.08

Appendix 2. Water temperature (°C), dissolved oxygen (mg/l), and per cent saturation (%) in Lake 885. February 1976 to February 1977.

Date	Depth (m)											
	0			1			2			2.7		
	Temp	DO	% Sat	Temp	DO	% Sat	Temp	DO	% Sat	Temp	DO	% Sat
Feb 19, 76	0.0	0.3	2.1	0.2	0.1	0.7	1.8	0.0	0.4	3.0	0.1	0.2
Mar 2	-	0.4	-	-	0.2	-	-	0.2	-	-	0.1	-
21	0.5	0.4	2.9	1.0	0.3	2.2	2.5	0.1	0.7	4.0	0.1	0.8
Apr 12	-	9.7	-	-	10.3	-	-	9.6	-	-	2.1	-
27	9.5	16.3	147.4	9.0	16.2	144.8	6.1	15.9	132.2	4.8	15.9	127.8
May 18	14.0	8.5	85.2	14.0	8.4	84.2	13.5	8.4	83.2	13.5	8.2	81.3
Jun 1	22.5	9.0	107.0	22.0	9.0	105.7	20.0	7.9	89.4	17.2	2.2	23.6
8	20.0	8.7	99.0	20.0	8.8	99.5	19.2	7.0	77.9	17.0	1.1	11.7
13	20.0	7.8	88.2	20.0	7.4	83.7	20.0	7.2	81.4	20.0	7.1	80.3
22	19.8	6.0	67.1	19.8	5.9	66.4	19.2	6.0	66.8	19.0	5.4	59.9
27	19.2	5.5	61.0	19.2	5.4	60.2	18.5	5.0	55.2	18.5	4.3	47.5
Jul 6	23.0	13.0	155.1	22.9	13.2	157.1	22.9	13.1	156.5	21.9	12.9	150.9
13	20.0	12.6	142.5	20.0	12.6	143.1	20.0	12.6	142.6	19.8	12.2	137.4
20	19.8	16.9	190.3	19.8	15.6	175.7	17.3	10.8	115.9	17.0	9.0	96.0
26	20.4	9.8	111.6	20.4	9.9	112.7	19.8	9.3	104.7	19.8	7.6	85.6
Aug 4	20.5	13.5	154.3	20.0	13.7	155.4	18.0	3.6	39.2	17.0	0.2	2.4
10	21.0	7.4	84.8	20.0	8.0	90.7	19.0	5.6	61.8	18.0	0.0	0.0
17	20.0	3.4	38.2	19.0	2.9	32.6	18.2	2.2	24.0	18.0	0.0	0.0
22	20.0	0.3	3.4	19.9	0.0	0.0	19.8	0.0	0.0	19.5	0.0	0.0
26	20.1	0.1	1.3	20.1	0.2	2.3	20.0	0.6	6.8	19.2	0.0	0.0
31	17.0	5.7	60.8	16.9	5.6	59.6	16.7	5.3	56.0	16.4	1.1	11.6
Sep 9	13.4	9.6	94.9	13.4	9.4	93.0	13.4	9.3	92.0	13.4	9.1	90.0
20	14.0	6.5	65.1	14.0	6.3	63.1	14.0	6.2	62.1	14.0	5.7	57.1
Oct 6	5.0	8.3	67.1	5.0	8.3	67.5	5.0	7.2	58.2	5.0	8.2	66.4
19	3.2	9.3	71.6	3.2	9.3	71.6	3.2	9.0	69.3	4.0	5.8	45.7
Nov 17	1.8	8.1	60.1	2.5	6.1	46.1	2.8	5.8	44.2	2.8	5.3	40.4
Dec 14	1.0	2.4	17.4	1.8	2.0	14.8	2.5	1.5	11.3	3.0	1.2	9.2
Jan 18, 77	0.0	0.8	5.6	0.6	0.6	4.3	1.8	0.7	5.3	3.0	0.7	5.4
Feb 15	0.0	0.6	4.2	1.0	0.0	0.0	2.2	0.0	0.0	3.0	0.0	0.0

Appendix 3. Water temperature (°C), dissolved oxygen (mg/l), and per cent saturation (%) in Lake 255. February 1976 to February 1977.

Date	Depth (m)											
	0			1			2			2.5		
	Temp	DO	% Sat	Temp	DO	% Sat	Temp	DO	% Sat	Temp	DO	% Sat
Feb 18, 76	0.0	1.1	0.0	1.0	0.2	1.4	2.0	0.1	0.7	2.5	0.0	0.4
Mar 2	-	0.4	-	-	0.0	-	-	0.0	-	-	0.3	-
18	0.8	0.8	5.8	1.0	0.8	5.9	3.0	0.3	2.3	4.7	0.0	0.0
Apr 13	-	4.6	-	-	3.2	-	-	1.0	-	-	0.8	-
29	11.1	11.5	108.0	10.9	11.2	104.7	10.2	11.2	103.0	9.8	10.3	93.8
May 19	16.0	9.0	94.1	15.0	9.6	98.9	15.0	9.6	98.4	15.0	9.3	95.1
Jun 2	21.0	8.9	102.6	21.0	9.0	103.6	21.0	8.9	102.5	20.0	9.0	101.8
7	21.0	9.0	103.7	21.0	8.9	102.4	20.8	9.0	103.3	20.5	8.8	101.0
15	17.8	7.6	82.4	17.6	7.5	81.0	17.6	7.5	81.0	17.2	6.8	72.9
23	20.1	8.7	98.5	20.0	8.7	98.4	20.0	8.8	99.5	19.5	9.0	100.8
29	18.8	8.8	97.3	18.8	8.9	98.4	18.2	8.9	97.3	18.2	8.8	96.0
Jul 7	24.8	9.7	119.0	23.8	9.0	109.1	23.0	8.9	106.2	23.0	8.3	98.8
14	19.8	7.6	85.4	19.8	7.5	84.4	19.5	7.5	83.5	19.0	7.4	82.1
21	21.0	9.4	108.3	21.0	9.2	105.9	20.8	9.1	104.5	20.5	8.8	101.0
27	22.0	8.3	97.3	22.0	8.3	96.9	22.0	8.3	97.3	21.5	8.6	100.1
Aug 5	19.0	7.8	86.6	19.0	8.3	92.1	18.8	8.0	88.5	18.0	7.7	83.9
11	21.8	8.9	104.0	21.5	8.8	102.2	21.0	8.6	99.1	20.5	7.7	87.9
18	20.8	9.1	104.2	20.0	8.9	100.7	19.0	8.8	97.7	19.0	6.3	69.9
23	20.0	7.8	88.2	19.9	7.6	85.7	19.5	7.9	88.5	19.4	7.2	80.5
Sep 10	14.4	8.5	85.9	14.4	8.7	88.0	14.4	9.0	91.0	14.4	9.3	94.0
21	13.8	8.2	81.6	13.8	8.2	81.7	13.2	9.0	88.7	13.2	7.6	74.7
Oct 7	4.8	10.6	85.2	4.8	10.7	86.0	4.8	10.6	85.2	4.8	10.5	84.4
20	1.5	12.7	93.4	2.5	12.4	93.8	3.0	12.6	96.5	3.0	12.4	95.0
Nov 18	3.0	14.9	114.2	3.5	15.2	118.1	3.5	15.2	118.1	3.8	15.0	117.5
Dec 15	1.2	9.5	69.3	2.5	9.9	74.9	2.8	8.5	64.8	3.0	8.1	62.1
Jan 18, 77	0.0	1.1	7.9	0.8	1.0	7.2	2.0	1.0	7.5	2.6	0.6	4.5
Feb 16	0.0	0.4	2.8	1.8	0.0	0.0	2.8	0.0	0.0	3.5	0.0	0.0

Appendix 4. Water temperature (°C), dissolved oxygen (mg/l), and per cent saturation (%) in Lake 200. February 1976 to February 1977.

Date	Depth (m)											
	0			1			3			5.4		
	Temp	DO	% Sat	Temp	DO	% Sat	Temp	DO	% Sat	Temp	DO	% Sat
Feb 18, 76	0.0	2.5	17.6	0.5	2.1	15.0	1.8	2.0	14.8	2.0	0.0	0.0
28	-	-	-	-	-	-	-	-	-	-	-	-
Mar 18	0.0	0.5	3.9	0.5	0.2	1.4	0.9	0.0	0.0	0.7	0.0	0.0
Apr 12	-	6.6	-	-	6.6	-	-	0.4	-	-	0.0	-
28	9.0	12.5	111.7	8.0	12.5	108.9	7.0	12.5	106.3	3.8	2.0	15.7
May 19	14.0	9.0	90.2	14.0	9.3	93.2	14.0	9.2	91.9	13.5	9.0	89.2
Jun 3	20.5	7.1	81.6	20.5	7.2	82.2	17.0	4.6	49.6	14.0	0.0	0.0
10	23.0	6.8	81.3	22.5	7.1	83.9	21.5	4.8	55.7	16.0	2.5	26.1
16	17.8	6.9	75.4	17.8	6.7	72.7	17.0	6.7	71.5	15.5	0.4	4.1
25	21.4	7.3	84.7	21.0	7.3	83.9	20.4	7.0	79.7	-	-	-
30	19.5	9.9	110.9	19.0	8.6	95.4	18.8	7.6	84.1	15.5	0.5	5.2
Jul 8	22.2	5.1	60.0	22.1	5.3	62.0	20.0	4.2	47.5	14.2	0.0	0.0
15	18.0	6.4	69.7	18.0	6.5	70.7	17.0	6.1	65.5	13.0	0.0	0.0
22	20.1	5.2	58.8	20.1	5.3	60.0	18.0	2.5	27.8	15.0	0.0	0.0
28	19.2	4.6	51.2	19.2	4.3	47.9	18.5	4.2	46.6	12.0	0.0	0.0
Aug 6	19.0	8.0	88.8	19.0	8.2	91.0	18.2	6.6	72.1	13.5	0.0	0.0
12	21.0	7.6	87.7	21.0	7.5	86.4	20.0	6.2	70.0	14.0	0.0	0.0
20	21.0	7.0	80.6	20.9	6.8	78.2	20.0	5.4	61.1	15.6	0.0	0.0
24	21.4	7.6	88.0	21.2	7.5	86.5	20.8	7.4	84.9	13.5	0.0	0.0
Sep 13	13.9	7.6	76.0	13.9	7.6	76.0	13.9	7.5	75.0	13.9	7.5	75.0
22	13.0	8.0	78.4	13.0	8.0	78.4	13.0	8.2	80.4	13.0	7.6	74.5
Oct 9	6.0	9.8	81.3	6.0	9.7	80.8	6.0	9.6	80.0	6.0	9.6	80.0
21	2.0	11.0	82.1	2.0	10.9	81.3	2.0	10.9	81.3	2.0	11.0	82.1
Nov 18	3.0	11.6	88.9	3.0	11.5	88.1	3.2	11.6	89.4	3.8	10.7	83.8
Dec 15	0.5	8.2	58.7	1.8	8.1	60.1	2.0	7.7	57.5	2.5	5.8	43.9
Jan 18, 77	0.0	3.3	23.3	1.4	3.8	27.9	1.9	3.3	24.5	2.9	2.4	18.3
Feb 16	0.0	1.9	13.4	0.5	1.2	8.7	1.8	0.7	5.2	2.5	0.7	5.2

Appendix 5. Water temperature (°C), dissolved oxygen (mg/l), and per cent saturation (%) in Lake 675. February 1976 to February 1977.

Date	Depth (m) 0			1			2			3.4		
	Temp	DO	% Sat	Temp	DO	% Sat	Temp	DO	% Sat	Temp	DO	% Sat
Feb 18, 76	0.5	1.5	10.7	1.2	1.6	11.7	2.0	1.4	10.4	3.0	1.0	7.7
Mar 2	-	0.9	-	-	0.6	-	-	0.2	-	-	0.2	-
18	0.5	1.6	11.4	0.7	1.1	7.9	1.9	0.8	5.9	2.8	0.0	0.0
Apr 13	-	6.8	-	-	6.3	-	-	4.8	-	-	0.0	-
29	9.9	9.9	90.4	9.4	9.4	84.8	6.9	6.9	58.5	5.8	5.8	47.8
May 18	14.0	9.6	96.2	13.5	9.0	89.2	13.0	8.7	85.3	13.0	8.9	87.2
Jun 2	20.0	7.9	89.4	20.0	7.8	88.2	19.0	6.1	67.7	18.0	3.9	42.5
7	20.7	5.6	64.1	20.5	4.3	49.1	20.3	4.2	47.8	19.9	2.7	30.5
15	17.9	6.0	65.1	17.9	6.1	66.1	17.8	5.9	64.0	17.3	5.9	63.4
23	19.0	6.5	72.0	19.0	6.4	71.0	19.0	6.5	72.1	19.0	5.8	64.4
29	18.2	6.0	65.6	18.2	6.0	66.1	18.2	6.0	65.6	18.2	5.9	64.5
Jul 7	22.1	6.7	78.6	21.5	6.6	76.6	21.2	6.4	74.2	21.2	5.2	60.1
14	20.0	6.4	72.2	20.0	6.0	67.8	19.8	5.9	66.2	19.0	5.9	65.5
21	19.8	7.6	85.7	19.8	7.6	85.6	19.8	7.3	82.2	19.0	3.4	37.7
27	21.0	6.4	73.7	21.0	6.6	76.0	21.0	6.6	75.8	20.5	6.2	71.3
Aug 5	19.0	7.6	84.2	19.0	7.5	83.5	18.9	7.4	81.9	18.5	7.1	78.2
11	20.5	7.5	85.6	20.5	7.5	85.8	20.5	7.6	86.5	20.0	3.4	39.0
18	20.0	7.7	87.5	19.2	7.7	85.7	19.0	7.3	80.8	19.0	3.7	41.5
23	19.8	6.5	73.1	19.5	6.3	71.1	19.3	6.2	69.1	19.0	6.0	66.6
Sep 10	14.0	7.3	73.1	14.0	7.3	73.1	13.9	7.2	72.0	13.9	6.9	69.0
21	13.5	8.4	83.0	13.5	8.6	85.2	13.4	9.1	90.5	13.2	7.5	73.9
Oct 7	5.0	9.9	80.0	5.0	10.1	81.6	5.0	10.0	80.8	5.0	10.0	80.8
20	2.0	11.6	86.6	2.2	11.3	84.8	2.2	11.4	85.5	2.2	11.4	85.5
Nov 17	2.0	12.4	92.5	2.8	12.5	95.3	2.8	12.7	96.8	2.8	12.4	94.5
Dec 14	0.5	6.7	47.9	1.2	6.2	45.2	1.8	6.2	47.2	2.6	5.9	44.7
Jan 18, 77	0.0	2.3	16.2	0.8	1.6	11.5	1.2	1.9	13.9	2.0	1.2	8.9
Feb 15	0.0	0.5	3.7	0.0	0.3	2.1	1.5	0.3	2.1	2.0	0.1	0.8

Appendix 6. Water temperature (°C), dissolved oxygen (mg/l), and per cent saturation (%) in Lake 879. February 1976 to February 1977.

Date	Depth (m) 0			1			2			2.3		
	Temp	DO	% Sat	Temp	DO	% Sat	Temp	DO	% Sat	Temp	DO	% Sat
Feb 19, 76	0.0	2.4	16.9	0.5	1.8	12.9	2.0	2.0	14.9	2.5	0.8	6.0
28	-	1.5	-	-	0.4	-	-	0.3	-	-	0.2	-
Mar 21	0.0	1.2	8.5	0.8	0.7	5.0	1.5	0.2	1.5	2.2	0.0	0.0
Apr 13	-	7.8	-	-	7.2	-	-	8.1	-	-	6.1	-
27	8.0	14.7	128.2	8.1	14.7	128.5	8.0	14.4	125.5	5.6	14.4	118.2
May 18	14.0	8.0	80.2	14.0	7.9	79.1	14.0	7.9	79.1	14.0	7.9	79.1
Jun 1	23.0	8.7	103.8	22.8	8.3	98.6	21.5	7.9	91.7	19.8	3.5	39.4
8	20.0	5.5	62.2	20.0	6.3	71.3	20.0	5.6	63.3	19.8	4.1	46.4
13	20.8	7.6	87.2	20.8	7.6	87.2	20.8	7.6	87.2	20.8	7.6	87.2
22	19.0	10.2	113.2	19.0	10.2	113.8	19.0	10.0	111.0	18.8	9.2	101.6
27	19.0	8.1	89.9	18.2	8.1	88.5	17.9	7.0	76.1	17.5	6.9	74.3
Jul 6	22.0	9.5	111.1	22.0	9.9	116.6	21.8	9.0	105.1	21.8	8.9	104.0
13	20.0	7.7	87.1	20.0	7.4	83.7	19.8	7.2	80.7	19.0	7.0	77.8
20	19.0	10.9	121.0	19.0	10.4	115.4	18.0	10.1	110.0	17.5	3.9	42.1
26	20.8	9.0	103.9	20.1	9.1	103.3	19.9	6.2	70.2	19.8	4.8	54.0
Aug 4	20.0	9.8	110.8	20.0	9.9	111.9	18.2	6.8	74.7	17.5	1.0	11.3
10	20.5	8.1	93.0	20.0	7.1	80.5	19.2	3.7	41.4	19.0	2.5	27.7
17	19.0	8.6	95.4	18.8	8.3	91.8	18.2	6.3	68.8	18.0	5.4	58.8
22	20.0	7.1	80.3	19.9	6.9	77.9	19.5	6.0	67.2	19.0	5.4	59.9
Sep 9	13.4	7.5	74.2	13.4	7.3	72.2	12.9	7.1	69.5	12.9	6.7	65.5
20	13.5	7.6	75.3	13.5	7.5	74.3	13.5	7.5	74.3	13.2	7.5	73.9
Oct 6	4.5	10.4	82.9	4.5	10.8	86.4	4.5	10.6	84.5	4.5	10.0	79.7
19	3.2	11.8	90.9	3.5	11.8	91.7	4.2	10.7	84.6	4.5	9.5	75.7
Nov 17	2.0	20.0	149.2	3.0	14.1	108.0	3.2	12.9	99.4	3.2	-	-
Dec 14	1.0	5.9	42.8	1.5	5.1	37.5	2.5	3.9	29.5	3.0	3.1	23.7
Jan 18, 77	0.0	1.0	7.1	0.5	0.0	0.0	2.0	0.0	0.0	2.5	0.0	0.0
Feb 15	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	3.0	0.0	0.0

Appendix 7. Water temperature (°C), dissolved oxygen (mg/l), and per cent saturation (%) in Lake 019. February 1976 to February 1977.

Date	Depth (m)														
	0			1			3			5			6.1		
	Temp	DO	% Sat	Temp	DO	% Sat	Temp	DO	% Sat	Temp	DO	% Sat	Temp	DO	% Sat
Feb 20,76	0.0	6.0	42.4	0.0	6.0	42.4	1.0	5.4	39.2	2.0	2.1	15.7	3.9	0.1	0.8
29	-	6.2	-	-	5.9	-	-	4.6	-	-	2.1	-	-	0.0	-
Mar 22	1.0	5.1	37.0	1.3	4.7	34.4	2.3	3.4	25.6	3.1	1.1	8.4	4.0	0.0	0.0
Apr 12	-	6.4	-	-	8.1	-	-	5.8	-	-	-	-	-	3.3	-
29	8.3	12.5	109.8	8.2	14.1	123.6	8.0	12.9	112.5	4.7	3.4	27.3	4.0	0.0	0.0
May 20	13.7	9.1	90.6	13.7	8.8	87.8	13.6	9.0	89.5	12.8	7.8	76.7	11.4	6.7	63.2
Jun 3	20.0	7.9	89.4	20.0	7.8	88.2	19.0	7.4	82.6	16.0	0.4	4.2	14.0	0.0	0.0
11	20.0	8.5	96.1	20.0	8.5	96.1	19.0	8.4	93.2	16.5	3.3	34.9	14.0	0.0	0.0
16	17.2	6.8	73.0	17.2	7.0	75.0	17.0	6.8	73.1	17.0	6.8	72.6	16.9	4.4	46.8
25	21.0	6.8	78.0	20.5	6.7	76.5	20.5	6.4	73.0	20.2	5.3	60.1	19.0	0.6	6.6
30	20.0	11.5	130.1	19.3	11.3	126.1	18.2	9.6	104.9	17.9	4.8	52.2	17.5	0.0	0.0
Jul 8	21.8	7.5	87.4	21.8	7.1	82.9	21.0	7.2	82.8	19.0	4.8	53.2	16.5	0.0	0.0
15	18.0	6.0	65.9	18.0	5.9	64.3	17.2	5.6	60.1	16.8	5.2	55.3	16.0	0.3	3.7
22	20.0	8.2	92.9	20.0	8.4	95.0	19.5	8.3	92.9	17.5	1.2	12.9	16.8	0.0	0.0
28	18.5	6.7	73.6	18.8	6.6	73.0	17.5	6.5	70.0	17.2	6.6	70.7	15.2	0.0	0.0
Aug 6	19.2	8.6	95.8	19.0	8.8	97.7	18.8	7.4	81.8	18.0	1.8	19.6	17.0	0.0	0.0
12	21.5	9.4	109.2	21.5	9.4	108.9	20.5	6.6	75.1	19.0	0.0	0.0	17.0	0.0	0.0
20	20.5	8.6	89.2	20.1	8.5	96.3	19.2	5.3	59.0	18.5	0.5	5.5	18.0	0.0	0.0
24	21.0	7.2	83.1	20.8	6.8	78.6	20.4	6.5	74.0	20.0	3.5	40.0	19.0	0.0	0.0
Sep 13	14.4	8.2	82.9	14.4	8.2	82.9	14.4	8.2	82.9	14.4	8.2	82.9	14.4	8.2	82.9
22	14.0	7.4	74.1	14.0	7.7	77.1	14.0	7.6	76.1	14.0	7.1	71.1	14.0	7.5	75.1
Oct 9	7.0	10.2	86.7	7.0	10.4	88.4	7.0	10.1	85.9	6.5	10.0	83.9	6.5	10.0	83.9
21	3.0	13.0	99.6	3.0	11.2	85.8	3.0	12.1	92.7	3.0	11.4	87.3	3.0	10.6	81.2
Nov 18	1.0	11.7	85.0	2.5	12.2	92.3	2.8	12.3	93.7	3.0	12.6	96.5	3.0	11.4	87.3
Dec 15	0.5	10.5	75.2	1.5	10.2	75.0	2.0	10.0	74.6	2.5	10.3	77.9	3.0	7.2	55.2
Jan 18, 77	0.0	6.4	45.5	0.4	6.4	46.1	0.8	5.6	40.4	1.3	4.3	31.3	2.1	1.9	14.2
Feb 16	0.0	5.0	35.3	0.5	5.0	35.8	2.0	4.1	30.5	2.5	3.0	22.7	3.8	3.3	26.2

Appendix 8. Specific conductance and ionic composition in six selected lakes. February 1976 and August 1976. Lake surface and bottom samples except HCO_3 and CO_3 at 1 m depth.

Lake	Date	Depth (m)	Specific Conduct. (µmhos/cm)	mg/l										
				Cations						Anions				Total Ions
				Na	K	Mg	Ca	Fe	Mn	Cl	SO_4	HCO_3	CO_3	
885	Feb 19	0	1835	115.0	44.1	147	74	0.03	0.40	38	620	-	-	1709.53
		1	-	-	-	-	-	-	-	-	-	647	24	-
		2.7	1845	112.0	44.3	144	62	0.03	0.35	46	631	-	-	1710.68
	Aug 10	0	1350	92.9	34.7	115	27	0.04	0.01	44	411	-	-	1071.65
		1	-	-	-	-	-	-	-	-	-	294	53	-
		2.7	1370	92.9	37.1	111	29	0.04	0.15	44	414	-	-	1075.19
255	Feb 18	0	1150	15.7	22.4	95	79	0.08	0.58	40	291	-	-	994.76
		1	-	-	-	-	-	-	-	-	-	451	0	-
		2.5	1130	14.9	22.2	90	78	0.11	0.60	36	293	-	-	985.81
	Aug 11	0	870	13.4	19.1	79	56	0.04	0.01	52	256	-	-	721.55
		1	-	-	-	-	-	-	-	-	-	232	14	-
		2.5	900	12.9	18.5	88	58	0.04	0.01	44	229	-	-	695.45
200	Feb 18	0	1470	13.3	22.4	128	105	0.03	0.83	10	649	-	-	1209.56
		1	-	-	-	-	-	-	-	-	-	281	0	-
		5.4	1450	12.4	21.4	131	104	0.03	0.83	9	634	-	-	1193.66
	Aug 12	0	1330	11.3	19.1	113	102	0.04	0.60	19	518	-	-	1017.04
		1	-	-	-	-	-	-	-	-	-	234	0	-
		5.4	1330	11.4	19.1	114	102	0.04	0.20	27	478	-	-	985.74
675	Feb 18	0	2180	75.4	40.0	201	98	0.06	0.28	2	1070	-	-	1998.74
		1	-	-	-	-	-	-	-	-	-	512	0	-
		3.4	2200	76.1	39.5	199	98	0.11	0.35	11	1083	-	-	2019.06
	Aug 11	0	1950	69.0	35.3	176	103	0.04	0.01	18	872	-	-	1675.35
		1	-	-	-	-	-	-	-	-	-	386	16	-
		3.4	1940	69.0	35.9	186	106	0.04	0.01	19	889	-	-	1706.95

Appendix 8. (Cont.)

Lake	Date	Depth (m)	Specific Conduct. (µmhos/cm)	mg/l Cations Na	K	Mg	Ca	Fe	Mn	Anions Cl	SO_4	HCO_3	CO_3	Total Ions
879	Feb 19	0	1190	26.9	29.2	97	88	0.06	0.58	16	427	-	-	1051.74
		1	-	-	-	-	-	-	-	-	-	367	0	-
		2.3	1190	26.7	29.7	89	87	0.08	0.60	18	427	-	-	1045.08
	Aug 10	0	790	18.4	20.6	72	51	0.04	0.00	26	212	-	-	656.04
		1	-	-	-	-	-	-	-	-	-	220	36	-
		2.3	800	18.5	19.7	72	59	0.04	0.01	24	215	-	-	664.25
019	Feb 20	0	960	31.1	30.5	82	54	0.00	0.03	30	266	-	-	908.63
		1	-	-	-	-	-	-	-	-	-	415	0	-
		6.1	950	30.0	30.2	77	53	0.11	0.20	20	252	-	-	877.51
	Aug 12	0	850	26.8	27.1	82	57	0.00	0.01	34	172	-	-	706.91
		1	-	-	-	-	-	-	-	-	-	270	38	-
		6.1	870	25.9	27.1	69	57	0.00	0.01	30	151	-	-	668.01

Appendix 9. Dissolved organic carbon (DOC) in six selected lakes. February 1976 to February 1977. Concentrations are in mg/l.

Lake 885				
Date	Depth (m)			
	0	1	2	2.7
Feb 19	25.1	25.1	26.9	25.1
Mar 2	26.2	27.4	25.6	-
21	22.4	25.1	21.8	21.3
Apr 12	10.5	12.6	19.3	25.3
27	15.7	14.8	20.7	17.3
May 18	21.2	20.1	19.8	19.0
Jun 1	19.8	20.1	20.1	19.0
8	17.5	18.4	18.1	19.5
13	19.0	18.1	18.4	18.7
22	17.8	19.2	18.1	19.2
27	17.8	17.5	18.7	17.5
Jul 6	19.2	17.5	20.1	19.8
13	20.9	21.2	19.5	22.4
20	20.9	21.8	21.8	21.5
26	23.2	24.3	24.3	23.2
Aug 4	24.1	24.1	25.2	24.1
10	24.3	24.6	25.8	22.9
17	24.9	25.8	26.6	24.3
22	25.8	26.0	26.9	25.5
Sep 9	22.1	25.5	27.7	27.7
20	26.0	28.3	26.3	26.0
Oct 6	26.9	26.3	26.6	24.1
19	26.0	26.9	24.6	25.5
Nov 17	25.5	25.8	28.9	26.0
Dec 14	31.1	28.6	25.8	28.9
Jan 18	33.7	28.6	32.0	30.9
Feb 15	39.9	38.5	38.2	38.5

Lake 255				
Date	Depth (m)			
	0	1	2	2.5
Feb 18	24.2	22.7	19.7	19.3
Mar 2	23.6	19.3	18.4	18.6
18	18.6	20.4	17.3	17.9
Apr 13	8.3	12.1	17.9	19.3
29	19.5	17.5	17.8	18.1
May 19	16.7	16.1	17.3	16.4
Jun 2	17.5	17.3	16.7	18.4
7	16.4	15.6	15.3	16.4
15	16.4	16.4	15.6	17.3
23	15.3	17.5	15.8	16.1
29	17.0	17.3	17.8	17.5
Jul 7	16.1	16.1	16.4	16.4
14	16.7	17.0	18.4	17.3
21	18.4	18.1	18.4	18.1
27	17.8	17.3	17.3	18.1
Aug 5	17.5	17.8	18.4	17.5
11	17.5	17.3	18.7	18.1
18	18.1	17.5	17.3	18.4
23	19.8	20.4	20.1	20.7
Sep 10	20.7	20.4	20.1	22.1
21	22.1	22.6	22.6	23.5
Oct 7	22.1	22.1	22.1	22.4
20	21.2	21.8	21.8	22.4
Nov 18	23.2	22.4	22.6	22.4
Dec 15	26.3	27.2	26.3	26.9
Jan 18	28.9	28.0	28.3	28.3
Feb 16	31.4	31.7	31.7	32.3

Appendix 9. (cont.)

Date	Lake 200 Depth (m) 0	1	3	5.4	Date	Lake 675 Depth (m) 0	1	2	3.4
Feb 18	18.6	17.3	17.0	18.2	Feb 18	21.2	28.5	27.4	28.5
28	22.0	18.8	16.1	18.2	Mar 2	29.2	28.7	30.5	31.4
Mar 18	18.4	16.8	14.1	17.3	18	30.1	27.4	29.4	31.4
Apr 12	9.9	8.1	16.4	14.4	Apr 13	7.2	10.8	26.5	28.0
28	14.7	14.4	17.0	17.0	29	22.4	22.9	22.6	26.0
May 19	15.8	15.6	14.4	14.4	May 18	24.3	25.8	25.2	25.2
Jun 3	15.6	15.6	14.7	12.5	Jun 2	27.5	24.3	24.9	22.1
10	14.4	14.7	15.6	15.3	7	24.9	23.8	22.9	22.4
16	13.6	15.0	15.3	15.0	15	23.5	23.8	23.8	24.1
25	15.3	15.0	15.6	15.0	23	22.9	22.9	24.9	23.8
30	15.3	15.6	16.4	14.2	29	18.1	23.5	23.8	24.1
Jul 8	16.4	17.5	15.6	12.7	Jul 7	22.6	22.9	25.2	24.3
15	16.1	17.5	17.5	14.2	14	23.5	24.6	23.8	24.3
22	19.2	19.2	17.5	15.3	21	25.5	23.5	24.9	24.1
28	15.6	16.4	16.4	13.0	27	23.2	24.3	22.6	24.3
Aug 6	16.4	16.4	17.3	19.5	Aug 5	22.9	24.9	26.0	23.5
12	15.0	15.6	16.4	10.2	11	23.8	22.9	24.3	25.2
20	16.7	16.1	15.3	16.7	18	23.8	23.5	24.1	24.1
24	17.3	18.1	16.7	17.5	23	25.5	28.3	27.5	26.0
Sep 13	17.0	17.3	18.1	19.0	Sep 10	29.4	28.0	27.7	28.3
22	19.8	19.8	20.3	20.1	21	27.2	28.0	28.3	27.7
Oct 9	20.7	18.1	20.4	20.4	Oct 7	27.2	27.5	24.6	27.7
21	19.0	18.4	18.7	19.0	20	26.9	27.5	26.9	27.7
Nov 18	20.4	19.5	19.8	20.1	Nov 17	30.9	31.1	32.0	30.6
Dec 15	23.8	23.2	23.2	23.2	Dec 14	32.3	32.6	36.2	34.8
Jan 18	22.4	26.9	25.5	25.5	Jan 18	35.4	35.4	35.4	35.7
Feb 16	24.9	25.5	22.9	25.2	Feb 15	39.6	40.5	41.1	38.5

Appendix 9. (Cont.)

Lake 879					Lake 019					
Date	Depth (m)				Date	Depth (m)				
	0	1	2	2.3		0	1	3	5	6.1
Feb 19	18.6	20.4	20.4	19.7	Feb 20	15.5	15.2	15.0	14.6	14.1
28	19.5	18.6	19.3	17.9	29	13.9	15.2	15.0	16.4	15.0
Mar 21	17.9	17.0	17.0	17.5	Mar 22	17.9	17.7	14.6	14.1	13.5
Apr 13	6.1	9.6	18.6	16.6	Apr 12	11.2	13.5	21.8	-	14.4
27	16.1	15.3	15.0	15.0	29	15.8	-	15.6	17.8	15.6
May 18	14.4	13.9	16.1	15.0	May 20	14.7	16.4	15.3	15.3	13.6
Jun 1	15.6	16.1	17.0	16.7	Jun 3	15.6	15.6	16.1	14.4	13.6
8	15.6	14.7	14.4	14.4	11	14.7	15.0	14.4	14.7	12.5
13	15.6	15.6	15.6	15.3	16	13.0	14.7	13.9	13.6	13.9
22	18.4	15.7	15.3	16.4	25	14.4	13.9	13.9	13.9	13.9
27	16.1	15.0	15.8	16.7	30	14.7	14.4	14.2	15.0	12.5
Jul 6	15.8	16.1	17.0	15.8	Jul 8	17.3	16.4	16.7	15.6	15.6
13	16.7	17.3	17.0	16.4	15	15.0	14.7	15.3	15.0	14.2
20	16.7	16.4	16.7	17.0	22	16.1	16.1	16.1	14.7	13.6
26	17.8	18.4	18.1	19.0	28	15.6	15.3	15.0	16.1	11.3
Aug 4	16.4	17.5	17.3	17.3	Aug 6	15.3	15.6	15.8	15.3	15.0
10	17.3	16.1	17.3	17.5	12	15.0	14.2	14.7	13.6	10.8
17	17.3	15.6	17.0	16.4	20	14.4	15.3	14.4	14.7	14.2
22	31.7	20.7	18.4	20.1	24	16.7	16.4	16.7	16.1	17.0
Sep 9	18.7	18.7	19.0	18.7	Sep 13	18.4	17.5	17.5	17.5	18.1
20	19.5	19.8	20.7	20.9	22	19.5	18.7	18.1	19.0	19.0
Oct 6	22.1	21.2	21.5	22.6	Oct 9	18.1	18.4	17.8	17.5	19.5
19	21.5	21.8	22.4	22.4	21	17.5	17.5	17.3	18.1	19.0
Nov 17	24.9	26.3	24.6	-	Nov 18	19.5	19.5	18.7	19.2	19.5
Dec 14	27.5	27.7	27.5	29.2	Dec 15	23.8	20.7	21.2	22.1	21.2
Jan 18	32.6	31.7	32.6	31.7	Jan 18	24.6	25.2	24.9	24.9	24.9
Feb 15	39.1	32.3	34.5	34.0	Feb 16	25.5	24.3	23.8	22.9	22.9

Appendix 10. Nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), dissolved organic nitrogen (DON), and total dissolved nitrogen (TDN) in Lake 885. February 1976 to February 1977. Concentrations are in µg/l.

Date	Depth (m)															
	0				1				2				2.7			
	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN
Feb 19, 76	<5	669	2211	2880	<5	669	2121	2790	<5	669	2301	2700	<5	663	2187	2850
Mar 2	<5	604	2356	2960	<5	571	1949	2520	<5	610	1850	2460	<5	590	2050	2640
21	<5	557	2108	2665	<5	563	2167	2730	<5	631	2244	2875	<5	733	2142	2875
Apr 12	21	408	561	990	50	16	1094	1160	8	18	1924	1950	35	499	2336	2870
27	<5	0	1440	1440	<5	0	1390	1390	<5	0	1810	1810	<5	0	1290	1290
May 18	<5	16	1574	1590	<5	27	1503	1530	<5	18	1592	1610	<5	0	1490	1490
Jun 1	<5	1	1669	1670	<5	1	1729	1730	5	11	1619	1630	<5	0	1550	1550
8	6	0	1504	1510	7	0	1693	1700	6	0	1364	1370	8	0	1472	1480
13	21	0	1579	1600	9	0	1421	1430	9	0	1361	1370	8	0	1482	1490
22	3	191	1456	1650	3	157	1720	1880	3	148	1569	1720	-	163	1564	1730
27	14	314	1552	1880	14	319	1527	1860	14	331	1545	1890	-	353	1343	1710
Jul 6	6	10	1644	1660	6	5	1639	1650	6	10	1764	1780	-	15	1629	1650
13	5	56	1649	1710	5	41	1764	1810	5	40	1815	1860	-	35	1860	1900
20	6	8	1926	1940	6	2	2112	2120	6	15	2039	2060	-	24	1950	1980
26	<5	37	2003	2040	<5	36	2004	2040	<5	35	2125	2160	-	74	1916	1990
Aug 4	<5	18	2302	2320	<5	15	2415	2430	<5	1	2319	2320	-	483	2327	2810
10	<5	46	2264	2310	<5	26	2354	2380	<5	54	2326	2380	-	997	2843	3840
17	<5	358	2512	2870	<5	379	2691	3070	<5	426	2644	3070	-	808	2562	3370
22	5	740	2450	3190	5	724	2616	3340	5	727	2723	3450	-	761	2589	3350
26	-	893	-	-	-	892	-	-	-	893	-	-	-	1052	-	-
31	-	1232	-	-	-	1229	-	-	-	1155	-	-	-	1286	-	-
Sep 9	<5	645	2185	2830	<5	643	2417	3060	<5	658	2222	2880	-	636	2374	3010
20	8	533	2329	2870	8	596	2296	2900	8	598	2364	2970	-	532	2500	3040
Oct 6	39	1175	2596	3810	39	1160	2451	3650	39	1192	2449	3680	-	1096	2675	3810
19	79	1342	2489	3910	77	1345	2418	3840	79	1371	2610	4060	63	1476	2461	4000
Nov 17	141	1512	2427	4080	147	1547	2292	3980	152	1621	2547	4320	154	1618	2608	4380
Dec 14	140	1811	2429	4380	142	1748	2430	4320	142	1779	2439	4360	93	1850	2507	4450
Jan 18, 77	<5	2258	3132	5390	<5	2307	3013	5320	<5	2344	2666	5010	<5	2346	2924	5270
Feb 15	<5	2274	3496	5770	<5	2351	3199	5550	<5	2396	2864	5260	<5	2430	3020	5450

Appendix 11. Nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), dissolved organic nitrogen (DON), and total dissolved nitrogen (TDN) in Lake 255. February 1976 to February 1977. Concentrations are in µg/l.

Date	Depth (m)															
	0				1				2				2.5			
	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN
Feb 18, 76	10	393	2587	2990	5	294	1931	2230	<5	308	1822	2130	5	315	1630	1950
Mar 2	<5	323	2537	2860	<5	311	1759	2070	<5	263	1647	1910	<5	404	1546	1950
18	<5	238	1832	2070	<5	214	1606	1820	<5	233	1457	1690	<5	239	1581	1820
Apr 13	295	112	1773	2180	430	123	1647	2200	105	268	1177	1550	15	313	1502	1830
29	<5	0	1260	1260	<5	0	1180	1180	<5	0	1160	1160	<5	0	1280	1280
May 19	<5	0	1170	1170	<5	0	1180	1180	8	37	1125	1170	<5	0	1270	1270
Jun 2	<5	25	1385	1410	6	21	1543	1570	5	33	1492	1530	7	42	1431	1480
7	11	30	1219	1260	9	19	1382	1410	9	21	1270	1300	11	38	1431	1480
15	8	10	1292	1310	8	9	1323	1340	8	10	1312	1330	-	0	1352	1360
23	4	0	1296	1300	4	0	1246	1250	4	0	1276	1280	-	0	1226	1230
29	5	0	1205	1210	5	0	1165	1170	5	0	1095	1100	-	0	1145	1150
Jul 7	<5	47	1203	1250	<5	28	1302	1330	<5	12	1278	1290	-	9	1301	1310
14	<5	33	1267	1300	<5	34	1256	1290	<5	33	1377	1410	-	33	1407	1440
21	5	58	1767	1830	5	78	1247	1330	5	16	1379	1400	-	70	1275	1350
27	<5	5	1405	1410	<5	8	1342	1350	<5	5	1515	1520	-	4	1366	1370
Aug 5	<5	13	1427	1440	<5	13	1367	1380	<5	13	1507	1520	-	8	1452	1460
11	<5	11	1399	1410	<5	12	1438	1450	<5	20	1420	1440	-	28	1432	1460
18	<5	0	1570	1570	<5	6	1744	1750	<5	4	1696	1700	-	29	1681	1710
23	<5	51	1509	1560	<5	25	1655	1680	<5	21	1489	1510	-	4	1516	1520
Sep 10	<5	23	1667	1690	<5	18	1602	1620	<5	20	1510	1530	-	14	1656	1670
21	<5	11	1639	1650	<5	8	1602	1610	<5	11	1579	1590	-	17	1543	1560
Oct 7	8	0	1692	1700	8	0	1642	1650	8	0	1692	1700	-	0	1612	1620
20	<5	0	1470	1470	<5	0	1580	1580	<5	0	1580	1580	-	-	1530	1530
Nov 18	<5	9	1791	1800	<5	0	1750	1750	<5	9	1691	1700	<5	0	1770	1770
Dec 15	31	50	1899	1980	32	45	1813	1890	36	54	1880	1970	40	58	1822	1920
Jan 18, 77	14	181	1865	2060	14	163	1933	2110	6	172	2182	2360	<5	177	2023	2200
Feb 16	<5	330	2220	2550	<5	326	2224	2550	<5	346	2214	2560	<5	345	2195	2540

Appendix 12. Nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), dissolved organic nitrogen (DON), and total dissolved nitrogen (TDN) in Lake 200. February 1976 to February 1977. Concentrations are in µg/l.

Date	Depth (m) 0				1				3				5.4			
	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN
Feb 18, 76	10	485	1775	2270	5	459	1606	2070	5	464	1331	1800	5	479	1356	1840
28	<5	479	1951	2430	<5	488	1872	2360	<5	532	1868	2400	<5	441	1599	2040
Mar 18	<5	584	1576	2160	<5	591	1269	1860	<5	563	1127	1690	<5	830	1260	2090
Apr 12	340	104	1006	1450	365	87	538	990	12	533	1575	2120	<5	1243	1617	2860
28	<5	0	1270	1270	<5	0	960	960	<5	0	1080	1080	<5	0	1330	1330
May 19	<5	0	1140	1140	<5	0	1110	1110	<5	0	1150	1150	<5	0	1170	1170
Jun 3	6	2	1162	1170	<5	0	1130	1130	<5	0	1160	1160	<5	495	1355	1850
10	8	8	1084	1100	117	8	1075	1200	35	6	1089	1130	16	92	1092	1200
16	10	0	1040	1050	10	0	1040	1050	10	0	1050	1060	-	60	1090	1160
25	5	0	1075	1080	5	0	1005	1010	5	0	1005	1010	-	0	1035	1040
30	<5	0	1200	1200	<5	2	1068	1070	<5	0	1270	1270	-	0	1190	1190
Jul 8	<5	2	1128	1130	<5	0	1080	1080	<5	0	1060	1060	-	1887	983	2870
15	<5	36	1064	1100	<5	34	1176	1210	<5	27	1243	1270	-	710	1020	1730
22	<5	37	1273	1310	<5	19	1261	1280	<5	18	1322	1340	-	377	1143	1520
28	<5	54	1086	1140	<5	49	1161	1210	<5	54	1156	1210	-	1383	1107	2490
Aug 6	<5	8	1152	1160	<5	6	1134	1140	<5	11	1209	1220	-	1291	3849	5140
12	<5	1	1159	1160	<5	11	1199	1210	<5	0	1150	1150	-	989	3451	4440
20	<5	18	1212	1230	<5	7	1223	1230	<5	57	1173	1230	-	1510	2170	3680
24	<5	0	1210	1210	<5	0	1260	1260	<5	0	1220	1220	-	1067	12733	13800
Sep 13	<5	24	1266	1290	<5	24	1326	1350	<5	22	1288	1310	-	29	1281	1310
22	<5	33	1237	1270	<5	37	1183	1220	<5	35	1245	1280	-	37	1183	1220
Oct 9	<5	50	1230	1280	<5	47	1283	1330	<5	47	1293	1340	-	50	1250	1300
21	<5	85	1275	1360	<5	122	1168	1290	<5	100	1170	1270	-	108	1212	1320
Nov 18	9	192	1319	1520	8	190	1282	1480	8	194	1328	1530	9	249	1372	1630
Dec 15	24	293	1763	2080	24	356	1310	1690	24	224	1532	1780	28	474	1348	1850
Jan 18, 77	16	532	1662	2210	15	506	1579	2100	14	531	1565	2110	10	575	1625	2210
Feb 16	<5	571	1719	2290	<5	563	1487	2050	<5	598	1492	2090	<5	609	1531	2140

Appendix 13. Nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), dissolved organic nitrogen (DON), and total dissolved nitrogen (TDN) in Lake 675. February 1976 to February 1977. Concentrations are in µg/l.

Date	Depth (m)															
	0				1				2				3.4			
	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN
Feb 18, 76	15	337	2438	2790	20	323	2337	2680	15	343	2272	2630	20	383	2317	3720
Mar 2	<5	360	2440	2800	<5	354	2446	2800	<5	352	2128	2480	<5	394	2106	2500
18	5	394	2866	3265	<5	357	2783	3140	<5	371	2234	2605	5	513	2197	2715
Apr 13	155	58	2967	3180	165	36	1979	2180	50	20	1160	1230	25	469	686	1180
29	<5	0	1430	1430	9	0	1061	1070	9	0	1571	1580	8	0	-	-
May 18	<5	0	1870	1870	<5	0	1900	1900	<5	10	1780	1790	<5	39	1751	1790
Jun 2	<5	5	1995	2000	<5	10	2260	2270	<5	3	1907	1910	7	23	1500	1530
7	7	8	1805	1820	8	0	1852	1860	6	2	1842	1850	12	10	1888	1910
15	10	3	1807	1820	10	10	1810	1830	10	3	1837	1850	-	12	1848	1870
23	10	21	1719	1750	10	29	1831	1870	10	26	1734	1770	-	32	1808	1850
29	15	29	1546	1590	15	30	1715	1760	15	33	1682	1730	-	29	1736	1780
Jul 7	<5	10	1780	1790	<5	17	2003	2020	<5	18	1882	1900	-	-	-	1900
14	<5	29	1801	1830	<5	30	1860	1890	<5	26	1864	1890	-	26	2004	2030
21	5	12	1733	1750	5	36	1829	1870	5	114	1751	1870	-	128	1757	1890
27	<5	10	1760	1770	<5	5	1845	1850	<5	4	1826	1830	-	5	1885	1890
Aug 5	<5	1	1779	1780	<5	2	1838	1840	<5	0	1870	1870	-	0	1890	1890
11	6	10	1724	1740	6	7	1757	1770	6	3	1801	1810	-	10	1784	1800
18	<5	5	1875	1880	<5	0	2060	2060	<5	0	1980	1980	-	0	2040	2040
23	<5	6	1944	1950	<5	0	1860	1860	<5	22	1948	1970	-	39	1901	1940
Sep 10	<5	5	2045	2050	<5	7	1863	1870	<5	7	1883	1890	-	7	2083	2090
21	<5	0	1930	1930	<5	0	2000	2000	<5	0	1920	1920	-	0	1900	1900
Oct 7	<5	0	2020	2020	<5	0	1900	1900	<5	0	1930	1930	-	0	1940	1940
20	<5	0	1720	1720	<5	0	1790	1790	<5	0	1830	1830	-	0	1840	1840
Nov 17	<5	40	2240	2280	<5	20	2090	2110	<5	0	2060	2060	-	3	2127	2130
Dec 14	36	135	2389	2560	31	105	2284	2420	28	96	2306	2430	28	104	2008	2140
Jan 18, 77	6	339	2495	2840	8	339	2583	2930	9	330	2541	2880	10	341	2419	2770
Feb 15	<5	375	2875	3250	<5	356	2694	3050	<5	391	2719	3110	<5	391	2599	2990

Appendix 14. Nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), dissolved organic nitrogen (DON), and total dissolved nitrogen (TDN) in Lake 879. February 1976 to February 1977. Concentrations are in μg/l.

Date	Depth (m)															
	0				1				2				2.3			
	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN
Feb 19, 76	60	502	1998	2560	55	498	1847	2400	45	481	1944	2470	40	563	1647	2250
28	20	559	2011	2590	20	580	1340	1940	10	508	1482	2000	<5	609	2061	2670
Mar 21	<5	431	1674	2105	<5	369	1901	2270	<5	526	1704	2230	<5	615	1990	2605
Apr 13	410	106	1414	1930	770	158	1202	2130	350	97	1203	1650	115	303	982	1400
27	<5	0	1370	1370	<5	0	1140	1140	<5	0	1270	1270	<5	0	1120	1120
May 18	<5	0	1190	1190	<5	0	1140	1140	<5	56	1244	1300	<5	25	1205	1230
Jun 1	<5	60	1250	1310	<5	0	1520	1520	<5	14	1266	1280	<5	1	1259	1260
8	26	106	1308	1440	30	110	1450	1590	28	110	1252	1390	33	129	1318	1480
13	18	6	1306	1330	14	0	1426	1440	13	0	1267	1280	14	0	1306	1320
22	14	64	1432	1510	14	64	1622	1700	14	67	1539	1620	-	51	1425	1490
27	67	201	1452	1720	67	188	1435	1690	67	217	1436	1720	-	203	1710	1980
Jul 6	<5	0	1350	1350	<5	0	1420	1420	<5	0	1530	1530	-	5	1435	1440
13	<5	28	1412	1440	<5	26	1444	1470	<5	26	1404	1430	-	28	1452	1480
20	5	5	1500	1510	5	3	1512	1520	5	0	1515	1520	-	0	1515	1520
26	<5	34	1286	1320	<5	30	1350	1380	<5	23	1517	1540	-	17	1403	1420
Aug 4	7	2	1501	1510	7	7	1526	1540	7	1	1592	1600	-	4	1699	1710
10	15	2	1473	1490	15	11	1484	1510	15	63	1492	1570	-	79	1536	1630
17	<5	24	1706	1730	<5	15	1605	1620	<5	12	1628	1640	-	4	1576	1580
22	<5	30	1680	1710	<5	35	1565	1600	<5	10	1690	1700	-	22	1598	1620
Sep 9	<5	11	1699	1710	<5	5	1705	1710	<5	1	1649	1650	-	5	1795	1800
20	<5	6	1534	1540	<5	7	1533	1540	<5	0	1580	1580	-	13	1707	1720
Oct 6	<5	0	1620	1620	<5	0	1790	1790	<5	0	1700	1700	-	0	1700	1700
19	<5	0	1540	1540	<5	3	1607	1610	<5	18	1722	1740	-	55	1775	1830
Nov 17	27	24	2179	2230	25	3	1952	1980	29	0	1971	2000	-	-	-	-
Dec 14	70	522	2398	2990	77	351	2282	2710	82	383	2325	2790	86	410	2294	2790
Jan 18, 77	<5	973	2657	3630	<5	963	2737	3700	<5	977	2853	3830	<5	980	2740	3720
Feb 15	<5	1292	3098	4390	<5	1229	3041	4270	<5	1234	2976	4210	<5	1214	2826	4040

Appendix 15. Nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), dissolved organic nitrogen (DON), and total dissolved nitrogen (TDN) in Lake 019. February 1976 to February 1977. Concentrations are in μg/l.

Date	Depth (m) 0				1				3				5				6.1			
	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN	NO_3-N	NH_3-N	DON	TDN
Feb 20,76	15	288	1297	1600	15	265	1340	1620	15	291	1334	1640	5	555	1040	1600	<5	671	1509	2180
29	<5	278	1842	2120	<5	278	1442	1720	<5	286	1024	1310	<5	448	1212	1660	<5	653	1347	2000
Mar 22	15	336	2659	3010	15	306	1524	1845	10	350	1215	1575	30	467	1223	1720	<5	1054	1416	2470
Apr 12	463	59	1408	1930	677	81	1052	1810	80	253	1157	1490	-	-	-	-	25	306	1199	1530
29	<5	0	990	990	9	0	-	-	14	0	856	870	8	0	1112	1120	<5	1036	1914	2950
May 20	<5	0	1150	1150	6	0	1114	1120	6	0	1134	1140	<5	0	1100	1100	<5	0	1090	1090
Jun 3	6	3	1131	1140	5	0	1135	1140	<5	0	1120	1120	<5	0	1100	1100	<5	192	1098	1290
11	7	9	1054	1070	28	9	1153	1190	43	7	1110	1160	12	69	1089	1170	9	1300	1111	2420
16	11	0	1079	1090	11	0	1149	1160	11	0	1069	1080	-	0	1119	1130	-	2	1727	1740
25	9	93	1148	1250	9	74	1047	1130	9	95	1296	1400	-	91	1170	1270	-	224	1007	1240
30	<5	0	1140	1140	<5	0	1230	1230	<5	10	1070	1080	-	58	1162	1220	-	270	1110	1380
Jul 8	<5	0	1110	1110	<5	1	1269	1270	<5	0	1160	1160	-	100	1090	1190	-	1278	942	2220
15	<5	51	1029	1080	<5	55	1045	1100	<5	62	1138	1200	-	72	1208	1280	-	645	955	1600
22	<5	28	1182	1210	<5	23	1227	1250	<5	19	1181	1200	-	96	1224	1320	-	416	1234	1650
28	<5	7	1003	1010	<5	12	1008	1020	<5	24	996	1020	-	31	989	1020	-	1213	1527	2740
Aug 6	<5	0	970	970	<5	2	1018	1020	<5	2	1038	1040	-	2	988	990	-	843	1637	2480
12	<5	0	820	820	<5	0	1060	1060	<5	0	1070	1070	-	74	1156	1230	-	663	1377	2040
20	<5	8	1172	1180	<5	12	1168	1180	<5	9	1151	1160	-	7	1143	1150	-	359	1201	1560
24	<5	0	1100	1100	<5	0	1130	1130	<5	0	1130	1130	-	0	1210	1210	-	416	1304	1720
Sep 13	<5	18	1112	1130	<5	13	1247	1260	<5	18	1242	1260	-	13	1207	1220	-	13	1277	1290
22	<5	9	1071	1080	<5	9	1101	1110	<5	5	1075	1080	-	5	1165	1170	-	5	1135	1140
Oct 9	<5	0	1110	1110	<5	0	1160	1160	<5	0	1160	1160	-	0	1120	1120	-	0	1100	1100
21	<5	4	1046	1050	<5	2	1118	1120	<5	0	1070	1070	<5	0	1090	1090	<5	0	1150	1150
Nov 18	7	35	1168	1210	<5	25	1125	1150	<5	3	1127	1130	<5	3	1127	1130	5	21	1184	1210
Dec 15	13	120	1107	1240	9	108	1123	1240	11	114	1115	1240	15	120	1085	1220	16	235	1009	1260
Jan 18,77	6	313	1351	1670	6	313	1391	1710	7	321	1362	1690	6	385	1309	1700	<5	449	1351	1800
Feb 16	<5	354	1926	2280	<5	334	1406	1740	<5	363	1447	1810	<5	422	1398	1820	<5	418	1442	1860

Appendix 16. Soluble reactive phosphorus (SRP), dissolved organic phosphorus (DOP), and total dissolved phosphorus (TDP) in Lake 885. February 1976 to February 1977. Concentrations are in μg/l.

Date	Depth (m)											
	0			1			2			2.7		
	SRP	DOP	TDP	SRP	DOP	TDP	SRP	DOP	TDP	SRP	DOP	TDP
Feb 19, 76	161	25	186	159	39	198	158	30	188	160	22	182
Mar 2	160	22	182	155	19	174	157	17	174	155	31	186
21	145	35	180	146	40	186	175	37	212	187	37	224
Apr 12	75	0	75	34	35	69	47	42	89	131	96	227
27	1	38	39	1	34	35	4	35	39	1	34	35
May 18	22	39	61	19	40	59	19	38	57	22	37	59
Jun 1	22	36	58	25	33	58	39	27	66	71	25	96
8	27	27	54	26	38	64	39	27	66	97	29	126
13	26	33	59	36	33	69	39	28	67	39	30	69
22	98	31	129	97	34	131	98	37	135	100	39	139
27	145	22	167	144	25	169	148	29	177	151	26	177
Jul 6	38	46	84	43	43	86	44	48	92	45	41	86
13	2	40	42	3	43	46	3	41	44	3	45	48
20	5	36	41	2	41	43	3	40	43	0	43	43
26	8	38	46	6	46	50	8	40	48	7	43	50
Aug 4	14	31	45	5	42	47	5	44	49	5	48	53
10	6	42	48	2	50	52	4	46	50	27	53	80
17	3	50	53	0	55	55	4	53	57	20	55	75
22	11	54	65	10	63	73	11	62	73	12	67	79
26	24	-	-	31	-	-	39	-	-	49	-	-
31	23	-	-	24	-	-	21	-	-	36	-	-
Sep 9	11	52	63	8	61	69	6	59	65	23	46	69
20	13	67	80	13	69	82	13	69	82	15	73	88
Oct 6	37	59	96	34	64	98	34	62	96	39	65	104
19	32	61	93	30	63	93	31	64	95	34	63	97
Nov 17	33	48	81	38	47	85	31	56	87	32	55	87
Dec 14	56	72	128	63	65	128	57	73	130	74	76	150
Jan 18, 77	156	69	225	153	80	233	158	67	225	159	74	233
Feb 15	176	101	277	172	97	269	177	92	269	184	89	273

Appendix 17. Soluble reactive phosphorus (SRP), dissolved organic phosphorus (DOP), and total dissolved phosphorus (TDP) in Lake 255. February 1976 to February 1977. Concentrations are in µg/l.

Date	Depth (m)											
	0			1			2			2.5		
	SRP	DOP	TDP	SRP	DOP	TDP	SRP	DOP	TDP	SRP	DOP	TDP
Feb 18, 76	45	27	72	19	23	42	19	21	40	17	17	34
Mar 2	27	11	38	18	32	50	10	30	40	30	24	54
18	1	23	24	0	28	28	0	20	20	2	28	30
Apr 13	21	33	54	18	56	74	0	172	172	3	277	280
29	0	32	32	0	46	46	0	32	32	0	40	40
May 19	0	23	23	0	21	21	0	25	25	1	28	29
Jun 2	3	24	27	6	21	27	5	22	27	16	15	31
7	3	20	23	4	21	25	4	21	25	27	0	27
15	4	26	30	6	26	32	4	26	30	6	24	30
23	0	24	24	7	19	26	0	22	22	0	24	24
29	1	19	20	8	18	26	4	18	22	6	16	22
Jul 7	8	22	30	17	11	28	6	20	26	17	9	26
14	0	23	23	3	22	25	3	22	25	5	20	25
21	0	23	23	0	23	23	0	23	23	0	23	23
27	2	24	26	2	24	26	9	19	28	2	26	28
Aug 5	1	21	22	0	22	22	1	21	22	0	22	22
11	0	25	25	0	25	25	0	25	25	2	29	31
18	0	22	22	0	26	26	0	24	24	3	25	28
23	2	25	27	0	31	31	1	26	27	0	29	29
Sep 10	0	25	25	0	27	27	1	20	21	7	20	27
21	14	20	34	11	21	32	13	19	32	2	30	32
Oct 7	0	26	26	0	32	32	4	24	28	0	24	24
20	0	48	48	0	42	42	1	29	30	0	24	24
Nov 18	0	25	25	0	27	27	0	25	25	0	25	25
Dec 15	0	28	28	0	26	26	0	24	24	0	26	26
Jan 18, 77	3	24	27	3	26	29	3	32	35	1	30	31
Feb 16	43	36	79	43	38	81	43	38	81	30	33	63

Appendix 18. Soluble reactive phosphorus (SRP), dissolved organic phosphorus (DOP), and total dissolved phosphorus (TDP) in Lake 200: February 1976 to February 1977. Concentrations are in µg/l.

Date	Depth (m)											
	0			1			3			5.4		
	SRP	DOP	TDP	SRP	DOP	TDP	SRP	DOP	TDP	SRP	DOP	TDP
Feb 18, 76	42	20	62	36	16	52	36	22	58	36	20	56
28	49	57	106	51	13	64	49	5	54	62	0	62
Mar 18	45	55	100	41	37	78	38	26	64	78	18	96
Apr 12	26	17	43	16	7	23	10	13	23	10	309	319
28	4	21	25	3	18	21	0	19	19	2	29	31
May 19	0	25	25	0	25	25	0	25	25	0	21	21
Jun 3	0	24	24	1	25	26	3	21	24	174	30	204
10	10	32	42	14	24	38	2	30	32	24	30	54
16	0	28	28	2	28	30	2	26	28	42	26	68
25	0	28	28	2	22	24	0	24	24	0	22	22
30	0	19	19	0	19	19	0	19	19	18	11	29
Jul 8	0	30	30	0	26	26	0	30	30	374	0	374
15	0	25	25	0	25	25	0	27	27	121	14	135
22	6	36	42	12	26	38	34	30	64	64	50	114
28	2	30	32	6	26	32	2	30	32	309	465	774
Aug 6	1	21	22	7	17	24	3	17	20	497	143	640
12	0	25	25	2	29	31	0	27	27	273	294	567
20	0	24	24	2	24	26	1	27	28	496	0	496
24	0	25	25	1	28	29	0	27	27	513	416	929
Sep 13	3	26	29	0	29	29	1	28	29	7	20	27
22	0	30	30	0	28	28	0	30	30	0	26	26
Oct 9	0	26	26	0	28	28	0	26	26	1	27	28
21	9	19	28	0	28	28	0	26	26	0	28	28
Nov 18	4	23	27	4	25	29	3	26	29	8	25	33
Dec 15	13	31	44	12	32	44	10	34	44	21	33	54
Jan 18, 77	28	29	57	25	30	55	26	29	55	29	28	57
Feb 16	33	34	67	30	35	65	33	36	69	33	36	69

Appendix 19. Soluble reactive phosphorus (SRP), dissolved organic phosphorus (DOP), and total dissolved phosphorus (TDP) in Lake 675. February 1976 to February 1977. Concentrations are in μg/l.

Date	Depth (m) 0			1			2			3.4		
	SRP	DOP	TDP	SRP	DOP	TDP	SRP	DOP	TDP	SRP	DOP	TDP
Feb 18, 76	16	24	40	12	24	36	13	27	40	18	22	40
Mar 2	11	29	40	6	28	34	5	35	40	10	32	42
18	3	305	308	3	201	204	4	44	48	17	29	46
Apr 13	14	80	94	11	37	48	0	84	84	0	100	100
29	0	32	32	0	16	16	0	30	30	0	-	-
May 18	0	37	37	0	39	39	0	39	39	0	41	41
Jun 2	14	21	35	3	34	37	3	28	31	1	32	33
7	7	22	29	2	27	29	4	27	31	6	23	29
15	6	30	36	2	32	34	2	32	34	2	30	32
23	0	28	28	0	32	32	0	28	28	0	34	34
29	8	20	28	4	28	32	6	28	34	2	30	32
Jul 7	8	28	36	4	40	44	2	38	40	0	38	38
14	3	28	31	3	36	39	1	32	33	0	37	37
21	0	31	31	1	36	37	0	35	35	2	35	37
27	2	34	36	4	36	40	3	37	40	2	38	40
Aug 5	0	28	28	1	27	28	2	26	28	1	29	30
11	0	33	33	0	37	37	0	35	35	2	35	37
18	0	30	30	0	34	34	0	32	32	0	34	34
23	1	38	39	5	38	43	0	41	41	4	37	41
Sep 10	5	30	35	2	35	37	17	16	33	9	36	45
21	0	40	40	0	40	42	12	30	42	13	29	42
Oct 7	0	36	36	0	36	36	0	36	36	0	36	36
20	0	30	30	0	106	106	0	96	96	0	40	40
Nov 17	0	35	35	0	33	33	0	31	31	0	33	33
Dec 14	8	32	40	0	38	38	0	36	36	8	32	40
Jan 18, 77	6	41	47	6	49	55	9	42	51	6	43	49
Feb 15	13	56	69	11	52	63	15	50	65	14	49	63

Appendix 20. Soluble reactive phosphorus (SRP), dissolved organic phosphorus (DOP), and total dissolved phosphorus (TDP) in Lake 879. February 1976 to February 1977. Concentrations are in μg/l.

Date	Depth (m)											
	0			1			2			2.3		
	SRP	DOP	TDP	SRP	DOP	TDP	SRP	DOP	TDP	SRP	DOP	TDP
Feb 19, 76	33	21	54	33	25	58	34	22	56	41	21	62
28	47	341	388	49	87	136	64	232	296	126	184	310
Mar 21	27	29	56	31	33	64	55	19	74	160	22	182
Apr 13	50	0	50	108	18	126	6	46	52	9	43	52
27	3	32	35	6	23	29	2	33	35	4	35	39
May 18	3	30	33	2	41	43	2	33	35	3	34	37
Jun 1	20	24	44	18	34	52	21	35	56	23	45	68
8	57	33	90	57	35	92	57	23	80	58	32	90
13	50	27	77	35	36	71	34	45	79	36	37	73
22	4	51	55	6	47	53	2	47	49	2	45	47
27	34	41	75	37	40	77	41	40	81	-	-	83
Jul 6	9	41	50	10	42	52	12	58	70	16	44	60
13	13	45	58	10	50	60	11	47	58	8	52	60
20	0	47	47	6	45	51	3	48	51	10	43	53
26	3	37	40	12	34	46	4	42	46	4	42	46
Aug 4	0	45	45	5	42	47	5	48	53	8	57	65
10	0	50	50	2	50	52	2	48	50	3	47	50
17	0	57	57	1	52	53	0	53	53	3	48	51
22	1	64	65	3	54	57	3	52	55	4	53	57
Sep 9	2	47	49	4	49	53	12	37	49	10	39	49
20	3	43	46	13	39	52	5	45	50	2	58	60
Oct 6	0	46	46	0	46	46	0	44	44	0	44	44
19	0	41	41	0	45	45	0	47	47	0	51	51
Nov 17	0	49	49	0	51	51	0	47	47	-	-	-
Dec 14	45	65	110	37	71	108	46	66	112	51	69	120
Jan 18, 77	161	68	229	157	78	235	162	81	243	159	80	239
Feb 15	223	100	323	220	111	331	223	112	335	223	102	325

Appendix 21. Soluble reactive phosphorus (SRP), dissolved organic phosphorus (DOP), and total dissolved phosphorus (TDP) in Lake 019. February 1976 to February 1977. Concentrations are in µg/l.

Date	Depth (m)														
	0			1			3			5			6.1		
	SRP	DOP	TDP	SRP	DOP	TDP	SRP	DOP	TDP	SRP	DOP	TDP	SRP	DOP	TDP
Feb 20, 76	11	9	20	2	16	18	10	10	20	18	10	28	42	14	56
29	4	76	80	3	17	20	4	12	16	9	5	14	31	41	72
Mar 22	13	27	40	3	25	28	4	8	12	15	21	36	102	20	122
Apr 12	81	0	81	50	13	63	14	1	15	-	-	-	0	31	31
29	0	18	18	0	-	-	0	24	24	0	24	24	124	0	124
May 20	0	17	17	0	17	17	0	17	17	0	19	19	0	19	19
Jun 3	4	20	24	2	20	22	0	20	20	1	21	22	3	21	24
11	2	16	18	5	13	18	3	15	18	4	18	22	92	0	92
16	7	13	20	2	22	24	0	22	22	2	22	24	4	132	136
25	2	24	26	0	24	24	0	24	24	0	26	26	2	24	26
30	7	10	17	2	17	19	4	13	17	0	17	17	9	18	27
Jul 8	0	22	22	1	35	36	3	21	24	4	20	24	52	10	62
15	0	21	21	0	21	21	1	20	21	1	20	21	5	20	25
22	1	49	50	7	29	36	17	63	80	13	29	42	17	61	78
28	2	22	24	5	17	22	5	19	24	7	17	24	28	0	28
Aug 6	1	9	10	6	10	16	5	9	14	4	10	14	20	0	20
12	0	17	17	0	19	19	0	19	19	0	19	19	19	0	19
20	0	22	22	2	22	24	9	11	20	3	19	22	6	16	22
24	0	19	19	1	22	23	0	21	21	1	20	21	6	17	23
Sep 13	1	20	21	0	27	27	3	20	23	1	20	21	0	23	23
22	0	24	24	0	24	24	0	22	22	0	24	24	0	26	26
Oct 9	0	14	14	0	18	18	0	16	16	0	20	20	0	18	18
21	0	20	20	0	20	20	0	18	18	0	20	20	8	10	18
Nov 18	0	13	13	0	13	13	0	15	15	0	13	13	0	15	15
Dec 15	0	18	18	0	24	24	0	22	22	0	22	22	0	20	20
Jan 18, 77	0	23	23	1	24	25	0	21	21	3	24	27	2	25	27
Feb 16	5	30	35	1	26	27	1	26	27	6	27	33	4	29	33