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

by

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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
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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.

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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.

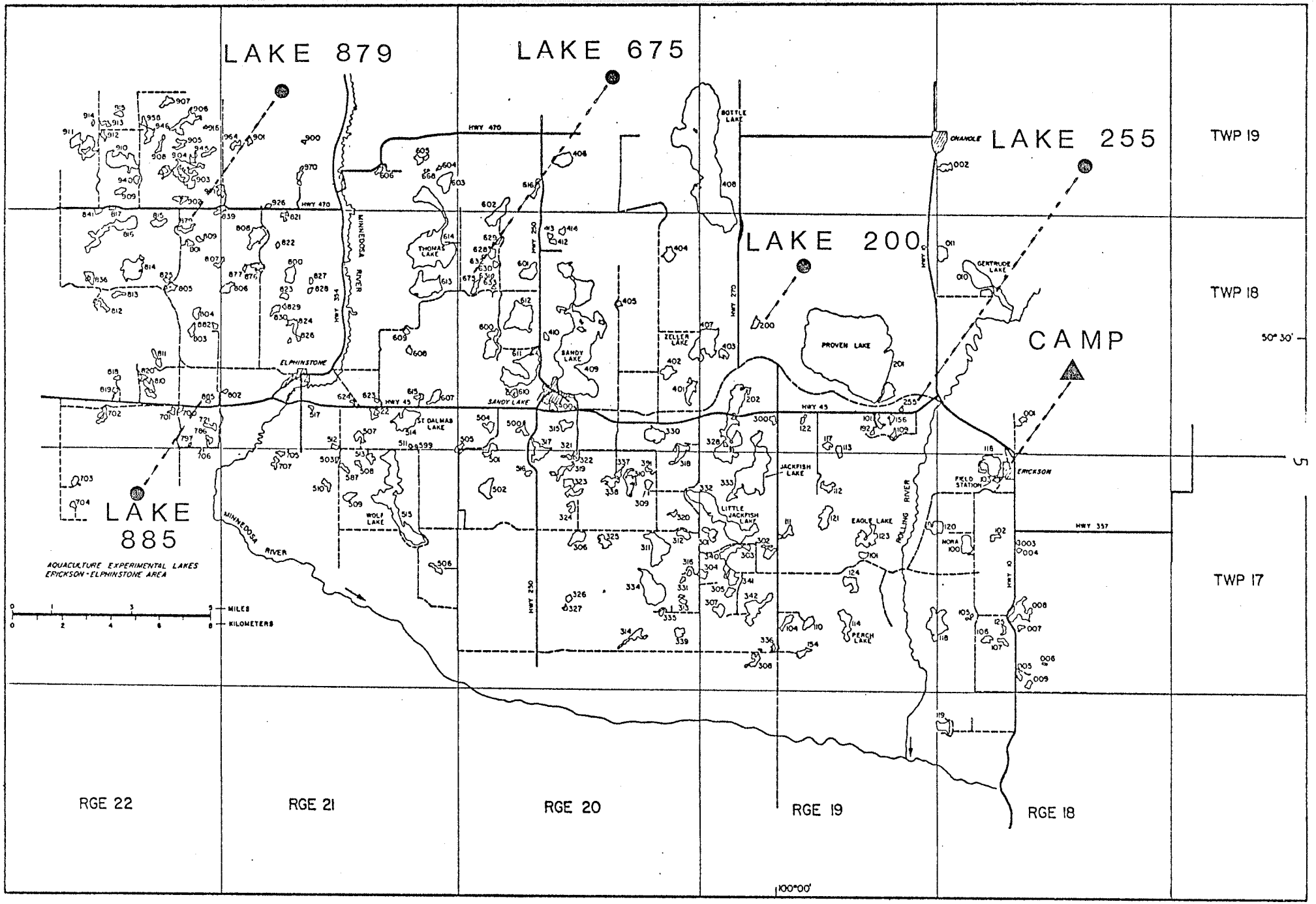

Figure 1. Map of the Aquaculture Experimental Lakes Area, southwestern Manitoba, showing locations of the lakes studied (●). Lake 019 is off this map, being about 30 km southwest of Erickson camp (▲).

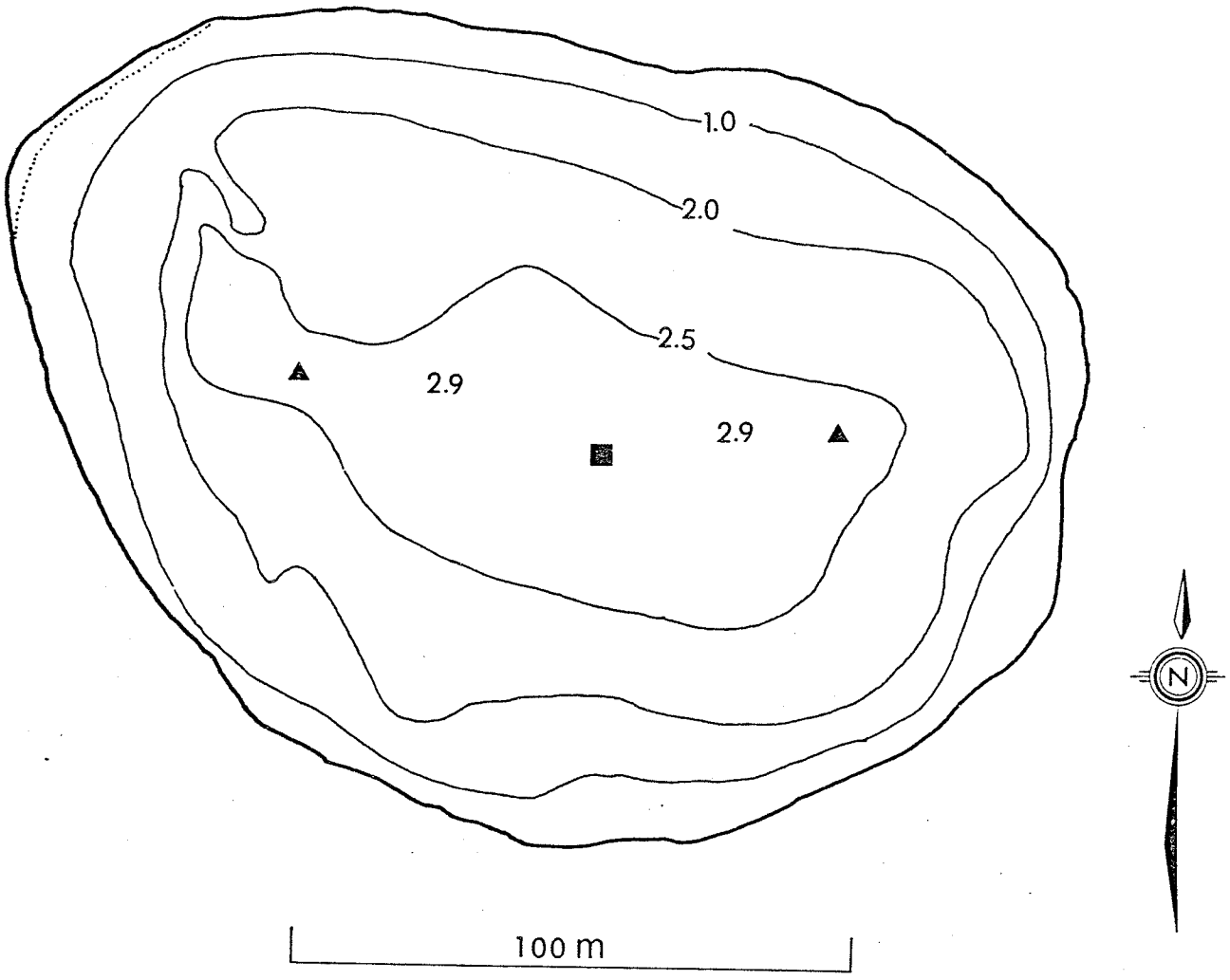

Figure 2a. Hydrographic map of Lake 885 (contours in meters).

..... Outline of emergent aquatic plants.

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

▲ Collection site for phytoplankton samples only.

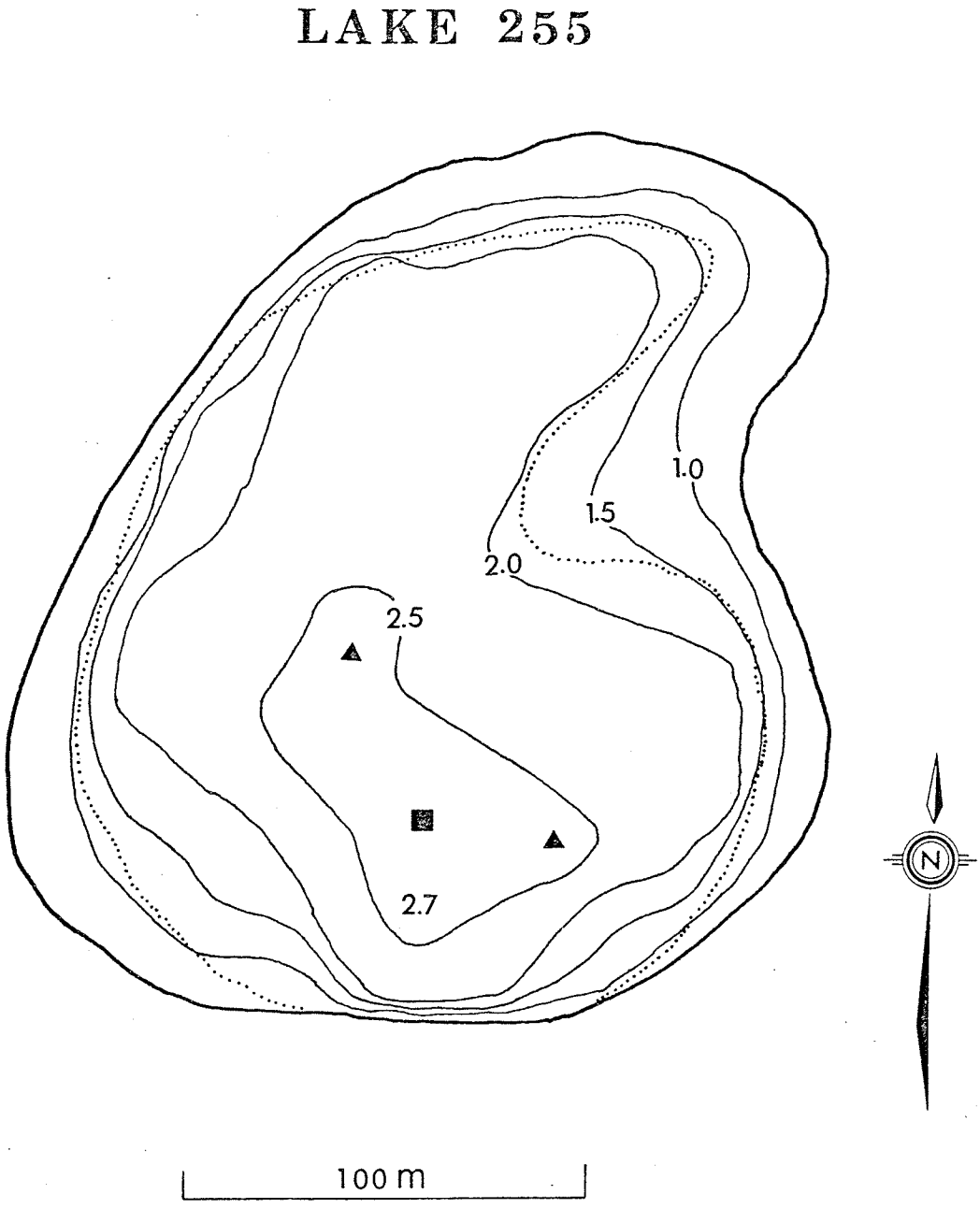

Fig. 2b. Hydrographic map of Lake 255 (contours in meters).

..... Outline of emergent aquatic plants.

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

▲ Collection site for phytoplankton samples only.

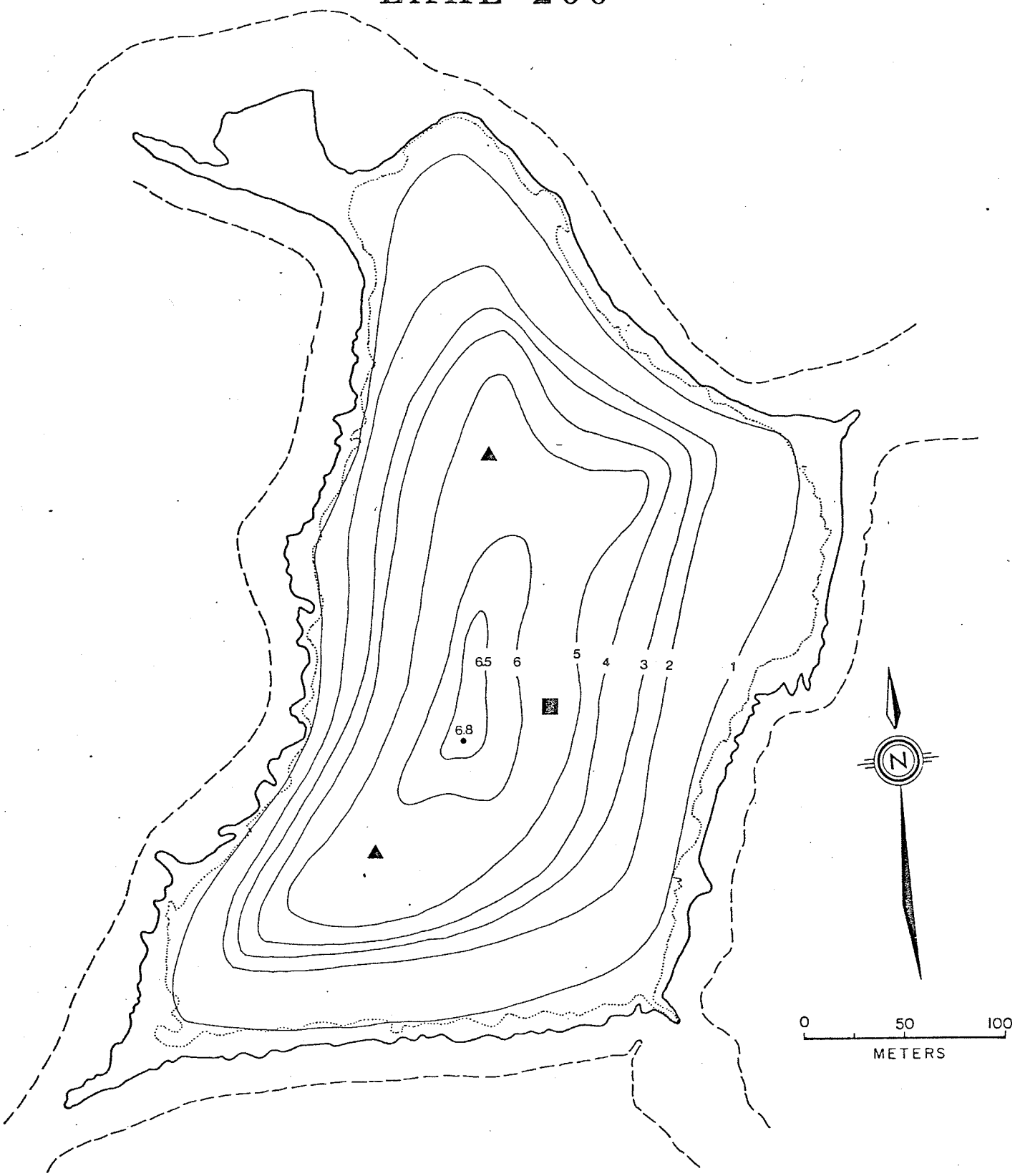

Figure 2c. Hydrographic map of Lake 200 (contours in meters).

..... Outline of emergent aquatic plants.

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

▲ Collection site for phytoplankton samples only.

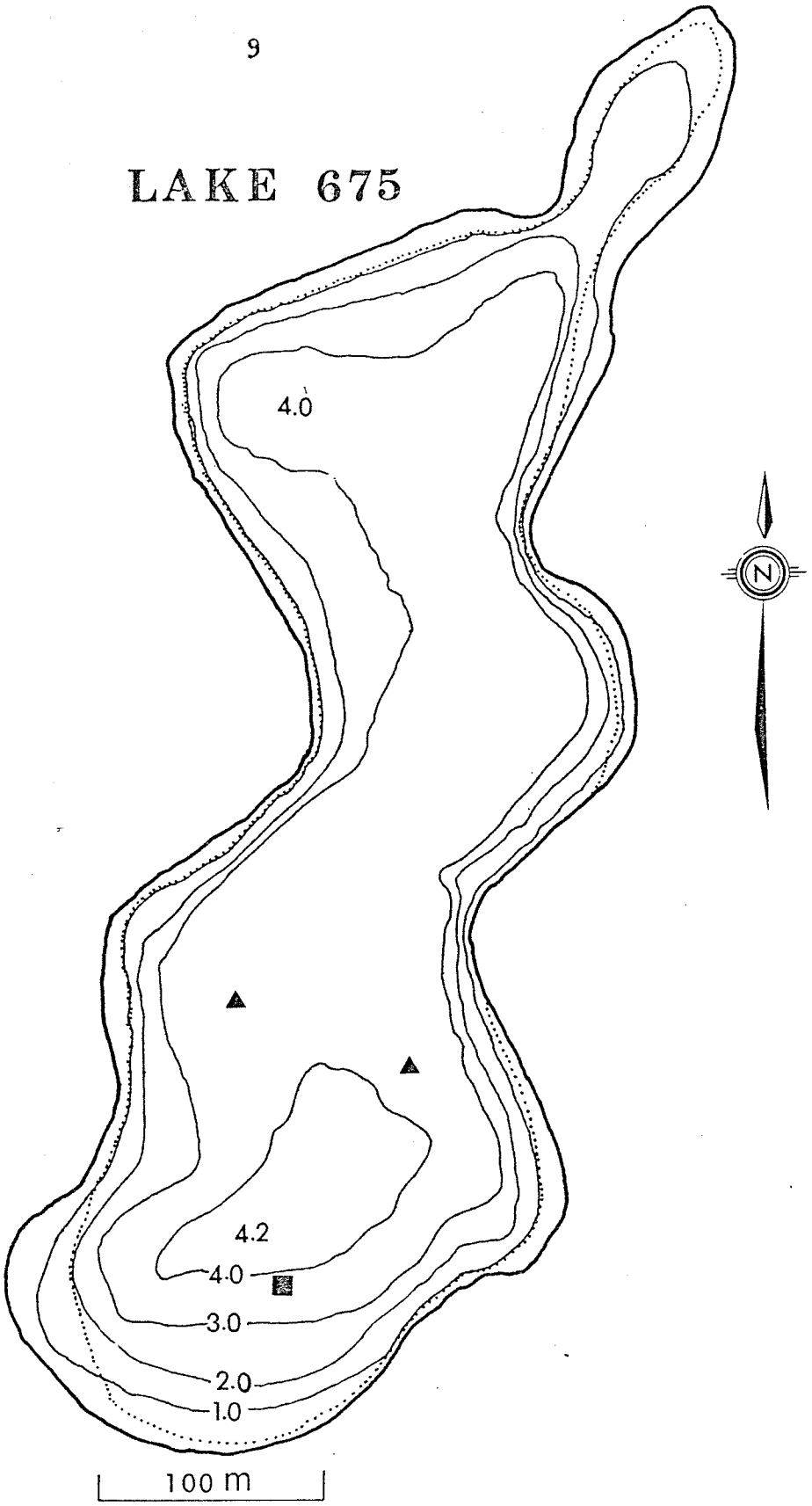

Figure 2d. Hydrographic map of Lake 675 (contours in meters).

..... Outline of emergent aquatic plants.

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

▲ Collection site for phytoplankton samples only.

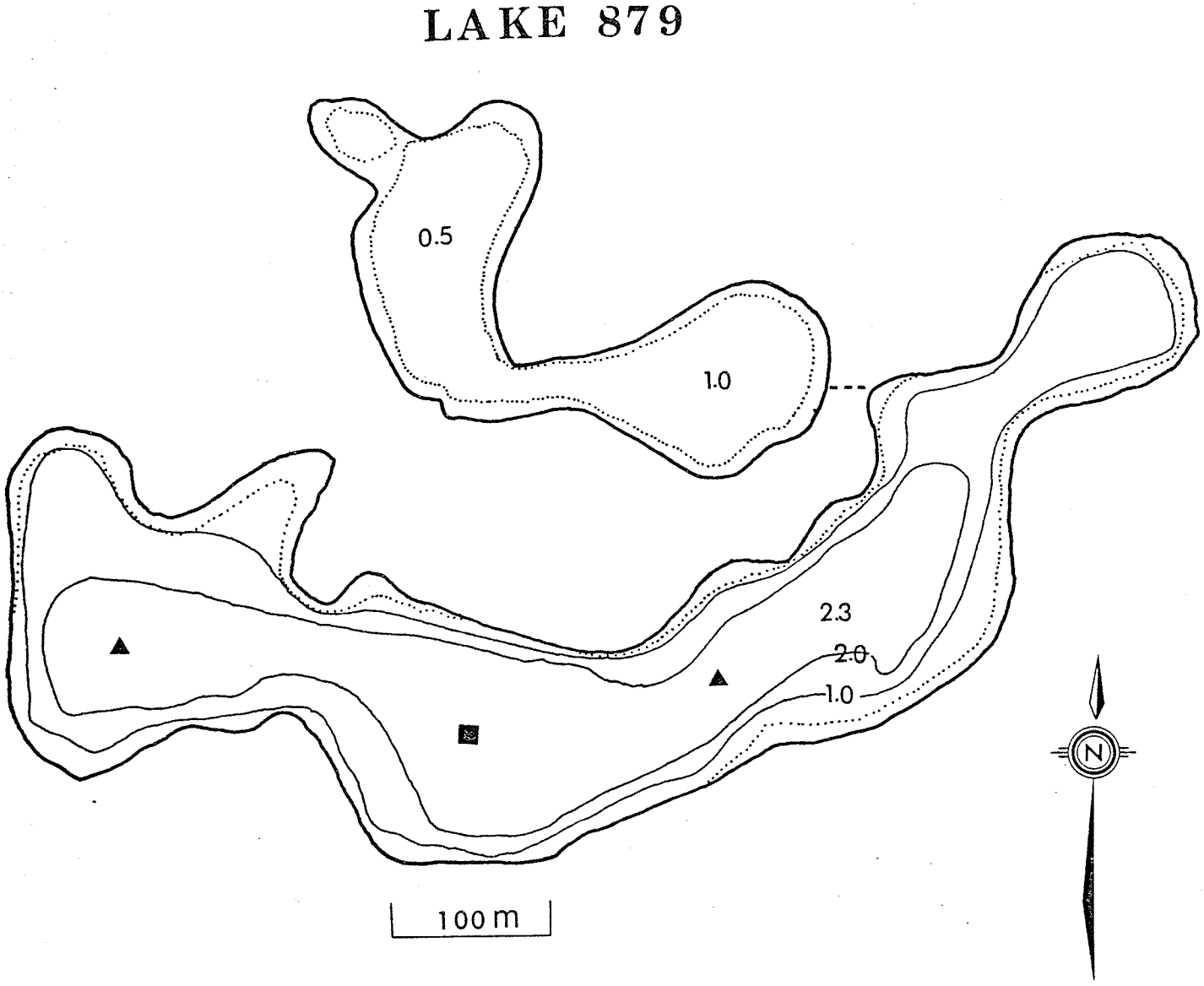

Figure 2e. Hydrographic map of Lake 879 (contours in meters).

..... 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

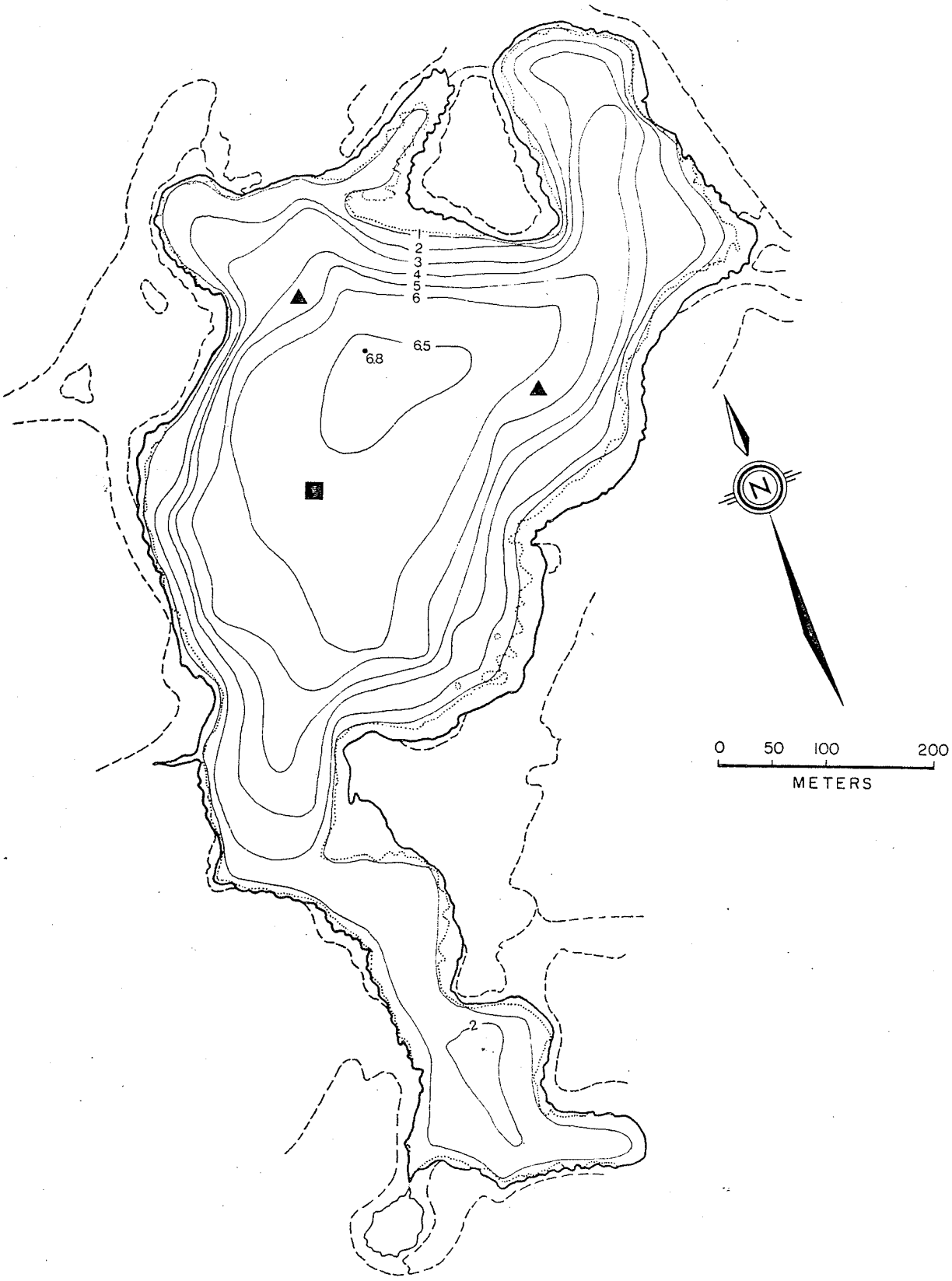

Figure 2f. Hydrographic map of Lake 019 (contours in meters).

..... 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

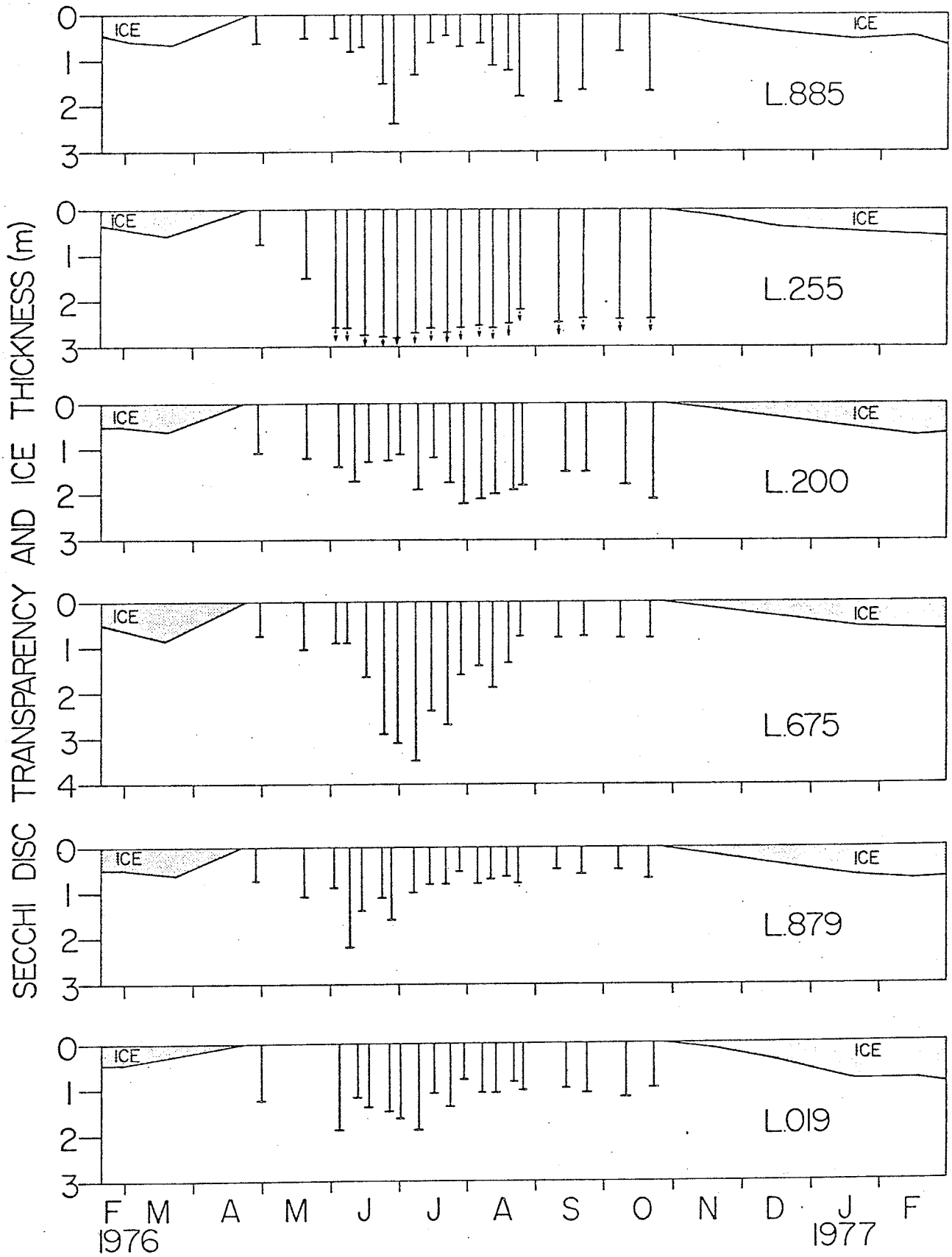

Figure 3. Ice thickness and Secchi disc transparency in six lakes of southwestern Manitoba, February 1976 to February 1977. Secchi disc reading in Lake 255 reaches the bottom most of the ice-free period.

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