Province of British Columbia
Ministry of Environment
ASSESSMENT AND PLANNING DIVISION

APD BULLETIN 30

WATER QUALITY DATA SUMMARY FOR GREEN LAKE, NEAR WHISTLER MOUNTAIN

By
C.J.P. McKean
R.N. Nordin
AQUATIC STUDIES BRANCH

Victoria, B.C.
June 1982

SUMMARY

Green Lake is located near the Whistler ski resort area. There is concern that large scale development in the area and residential subdivision within the watershed will affect the water quality of Green Lake.

Sampling was carried out between 1974 and 1978, and in more detail in 1979. The lake has a short water residence time (about 0.1 yr) because of large volumes of water being supplied from snow and glaciers in the area. Fine suspended material ("glacial flour") entering during the summer turns the water "milky-blue", a characteristic of many alpine lakes.

The natural phosphorus loading is high due to the large input of water and the large amounts of fine suspended material. However, because of the short water residence time, the lake phosphorus concentrations remain low. At spring overturn, values are 3.5-7.0 µg/L total phosphorus and 3-6 µg/L total dissolved phosphorus.

Biological productivity and the standing crop of both phytoplankton and zooplankton are very low during the summer. This is due to the low nutrient concentrations and poor light penetration.

Green Lake will likely show very little change in water quality as a consequence of residential development within the watershed. This prediction is based on the short water residence time and apparent physical limitation of biological growth during much of the summer.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF TABLES

ACKNOWLEDGEMENTS

The authors wish to acknowledge I. Boyd, B. Holms, R. Mackie, and W. Carolsfeld for assistance with field work; the typists and draft persons who helped prepare this report; the personnel of the Ministry of Environment's Environmental Laboratory who analyzed the collected samples; Dr. J.H. Wiens of the Terrestrial Studies Branch who assisted with the estimation of nutrient loading from septic fields; and Mr. G. Gough of the Waste Management Branch for his review and comments on the final draft.

1. INTRODUCTION

Deterioration of lake water quality caused by development is a concern in many areas of the province. The development of major recreational and residential facilities in the Whistler Mountain area has prompted the Lower Mainland Regional Office of the Waste Management Branch to initiate studies of Alta and Green lakes. This report deals with the limnology and the factors governing water quality for Green Lake. A separate report considers Alta Lake.

The Waste Management Branch gathered data for a number of years, and requested the Aquatic Studies Branch to examine the lake in more detail. The objective was to assess the general limnology and water quality and provide information which could be used to minimize any adverse effects on Green Lake. The lake provides summer recreation and is a very attractive feature of the area.

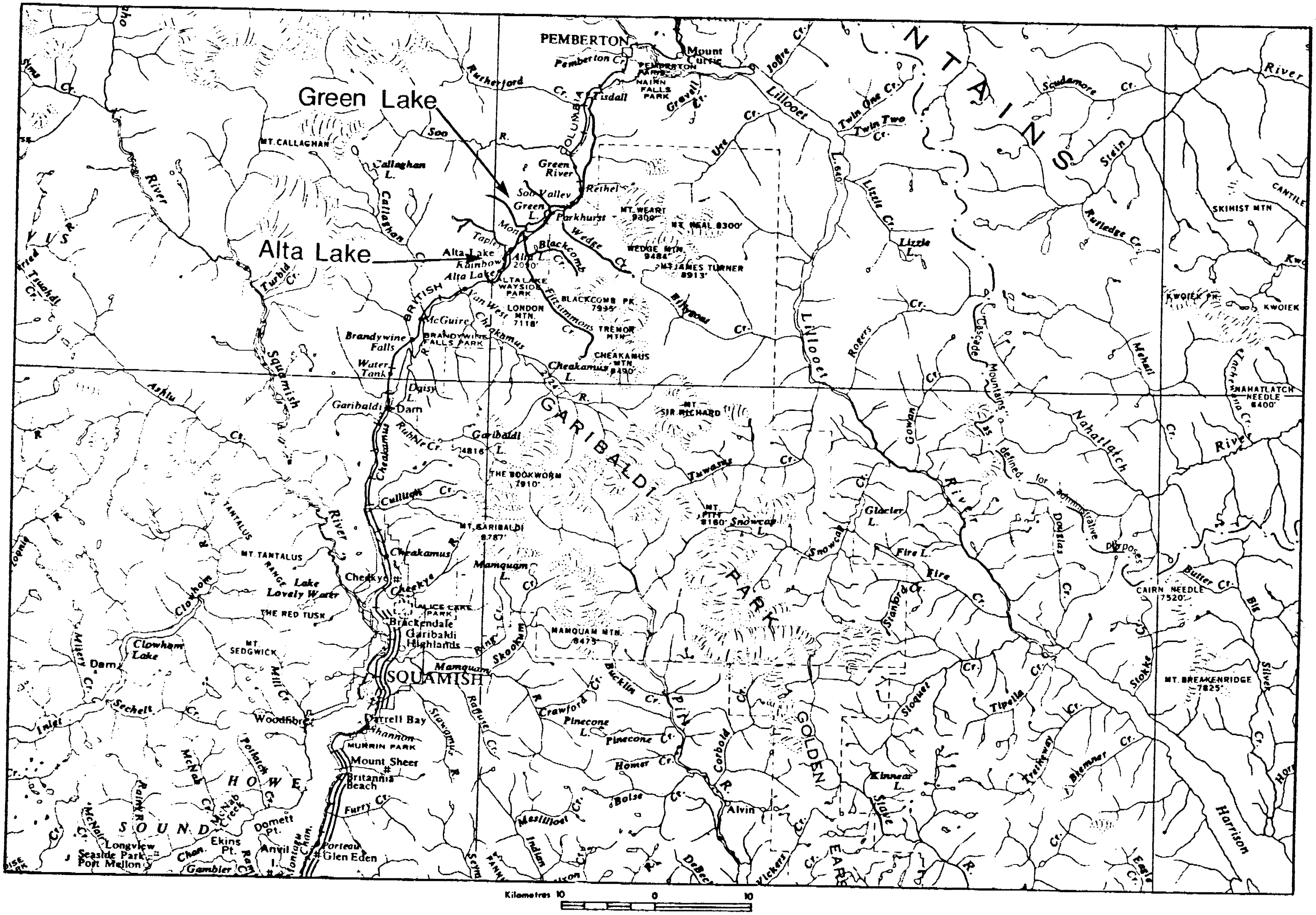

FIGURE 1: Location of Green Lake

2. GENERAL CHARACTERISTICS

Green Lake is situated at the head of the Green River. The river flows north east where it joins the Lillooet River, which flows south west to the Fraser River via Harrison Lake (Figure 1). The major inflows are Twenty-One Mile Creek (this includes the main outflow from Alta Lake), Nineteen Mile Creek and Fitzsimmons Creek (Figure 2). Alta Lake lies on the boundary between the Cheakamus and Green River watersheds. During freshet, high lake levels allow water to flow into both watersheds. Thus, Alta Lake is not considered entirely within the Green Lake watershed. The total watershed area draining into Green Lake is calculated to be 175 km^2.

The lake is approximately 545 m above sea level, and the watershed has a maximum elevation of 1 585 m (Table 1). Because of the high elevation, the watershed accumulates about 40 percent of its total annual precipitation in the form of snow (Table 2). Consequently, the major input of runoff occurs during the summer months. The mean stream flow at the outlet of Green Lake for the years 1914 and 1923 through 1948 is illustrated in Figure 3. All stream volumes were measured at a Water Survey of Canada gauge at the outlet of the lake.

The average volume of water that flows out of Green Lake is 260 000 cubic decametres (dam^3)/year. Based on the lake volume of 29 200 dam^3 the average flushing rate is estimated to be 9 times per year. The range for the annual residence time is 5.8 times per year (low runoff) to 13.1 times per year (high runoff).

There are several small glaciers within the Green Lake watershed. The largest is the Fitzsimmons Glacier at the head of Fitzsimmons Creek.

The bathymetry of Green Lake is presented in Figure 4. The lake has two basins of approximately 45 and 23 m maximum depth which are separated by

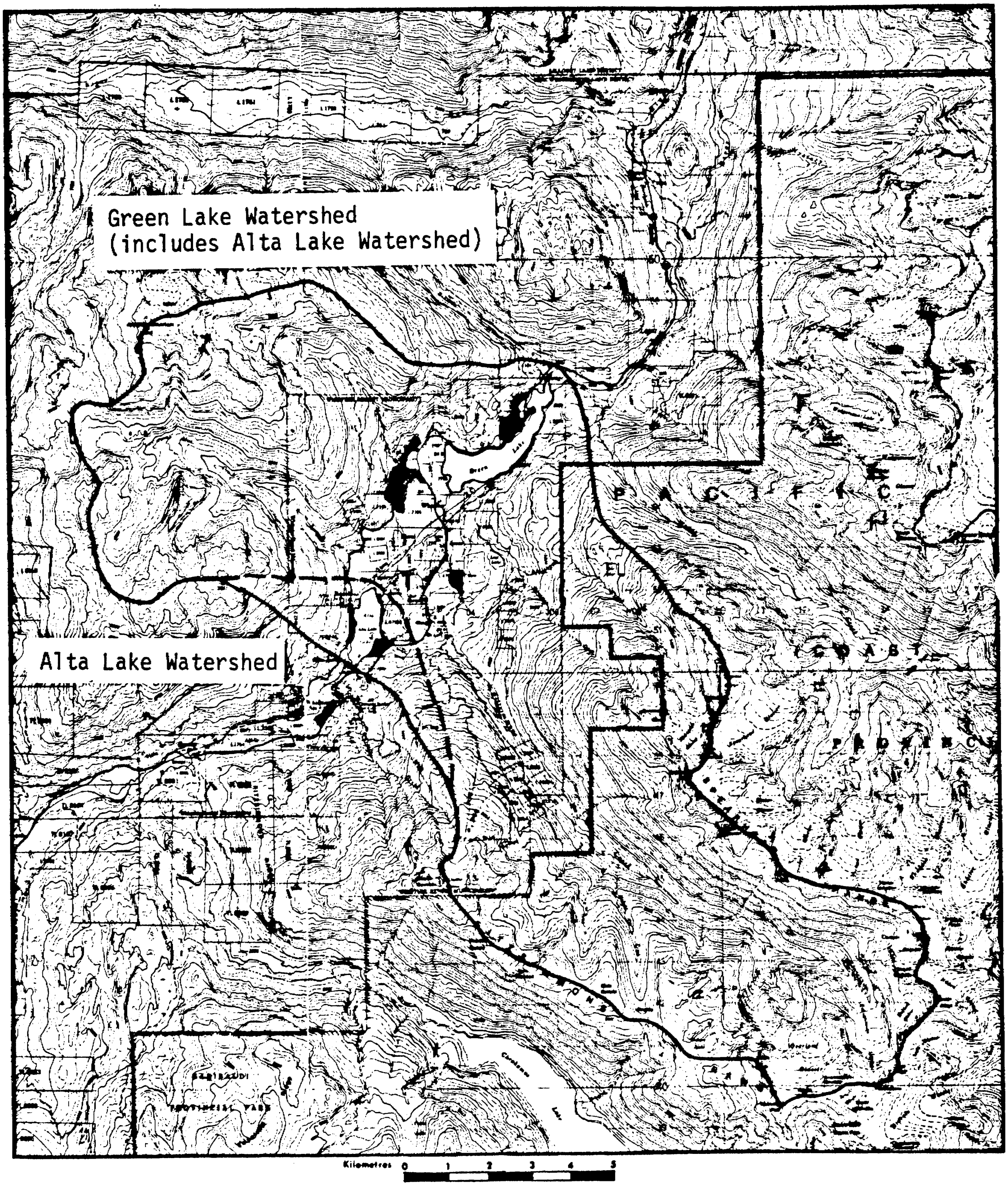

FIGURE 2: Outline of Green Lake Watershed

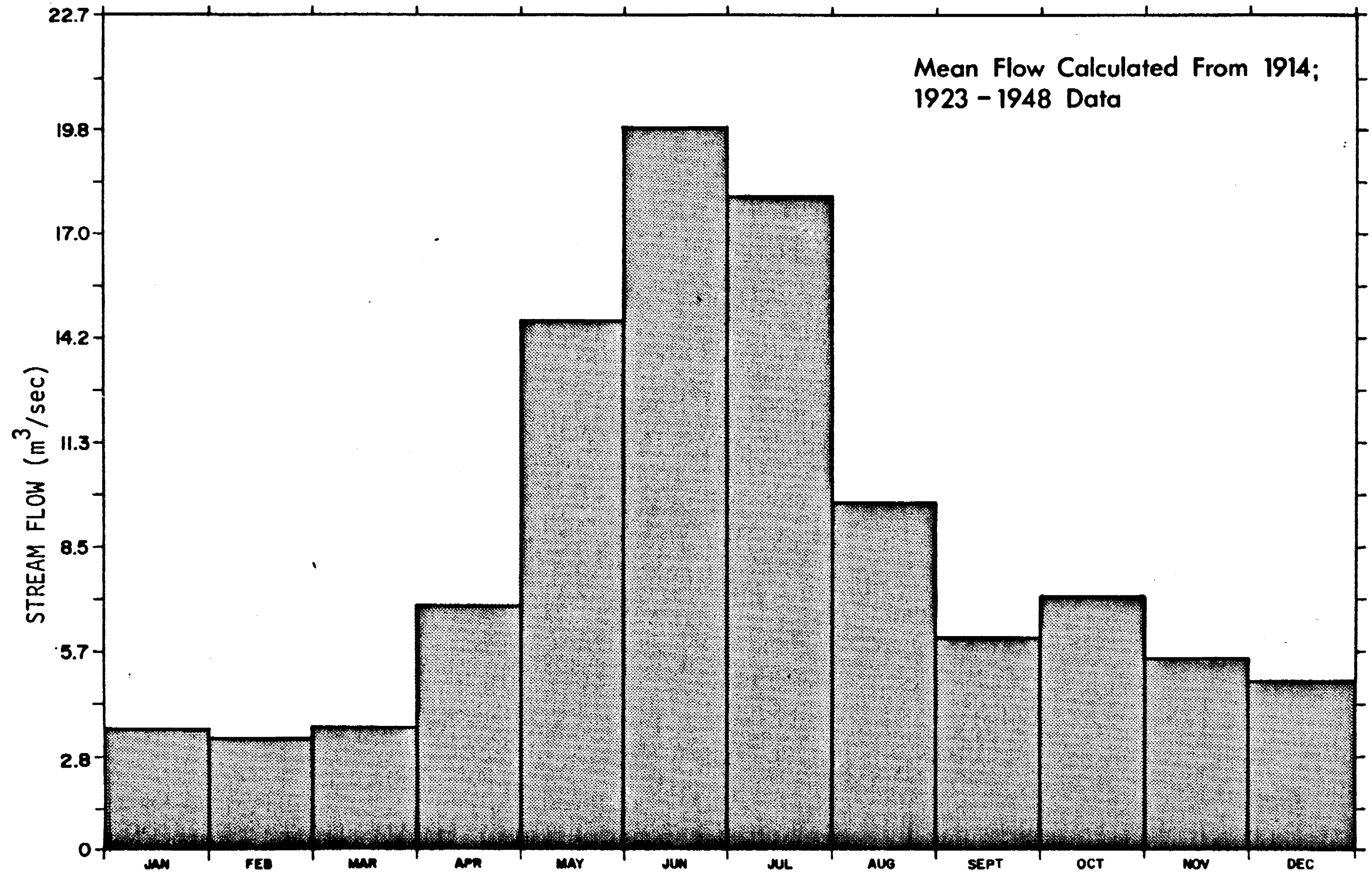

FIGURE 3: Hydrological Cycle of Green River at Outlet of Green Lake

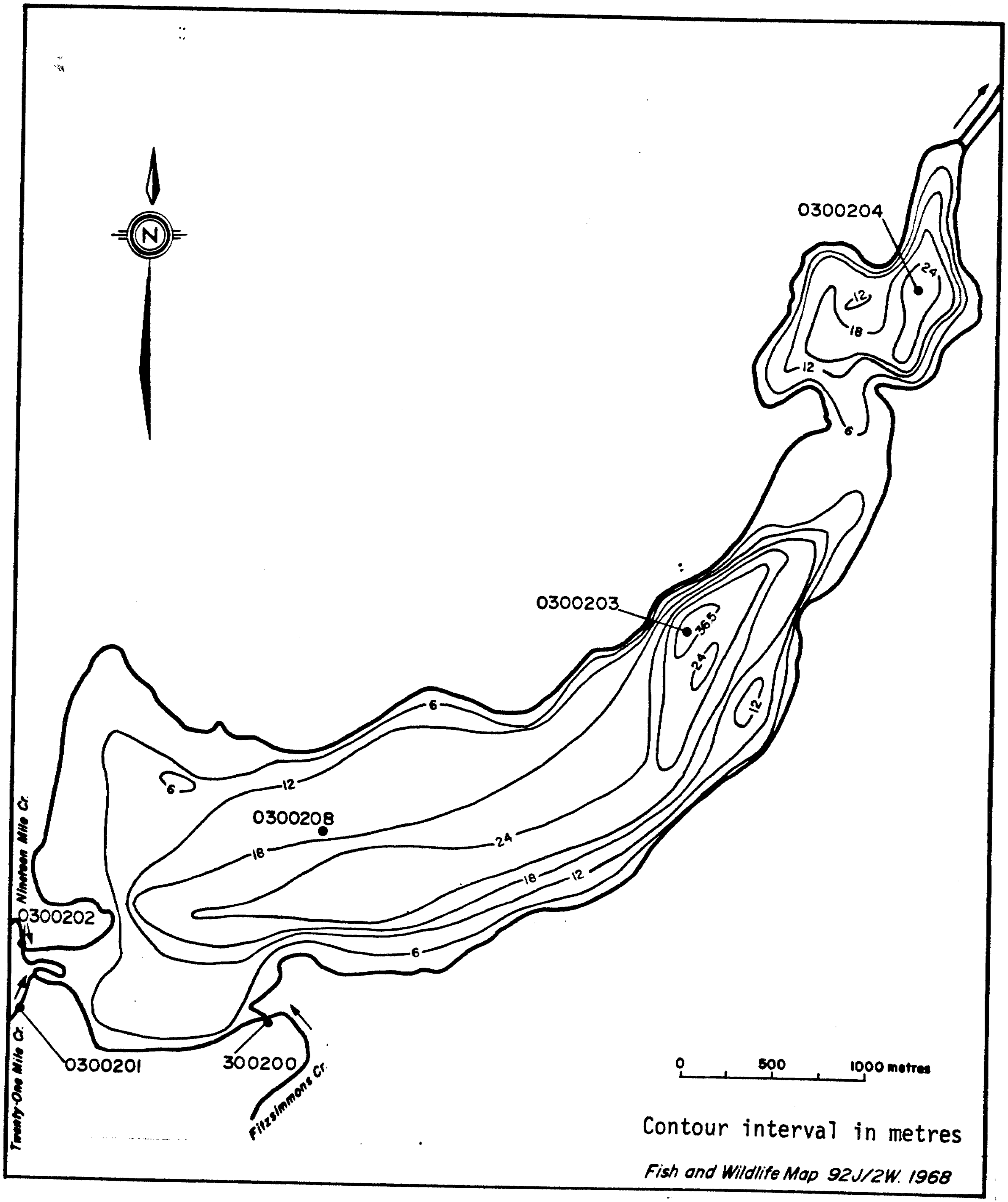

FIGURE 4: Lake Bathymetry and Location of Water Quality Monitoring Stations

TABLE 1

General Characteristics of Green Lake and Its Watershed

Lake elevation (m)	545
Lake area (ha)	205
Lake volume (dam^3)	29 200
Lake maximum depth (m)	40.2
Lake mean depth (m)	14.2
Watershed area (km^2)	175
Watershed maximum elevation (m)	1 585

TABLE 2

Average Precipitation Data near Green Lake*

Month	Average Total Precipitation 1941-1980 (cm)	Snow Precipitation		Rain Precipitation	
		Water Equivalent (cm)	% of Total	Water Equivalent (cm)	% of Total
January	21.13	16.48	78	4.65	22
February	15.82	10.13	64	5.69	36
March	11.31	7.75	69	3.56	31
April	8.13	2.11	26	6.02	74
May	4.88	0.13	3	4.75	97
June	4.60	0.0	0	4.60	100
July	3.76	0.0	0	3.76	100
August	5.19	0.0	0	5.19	100
September	8.13	0.0	0	8.13	100
October	17.98	1.98	11	16.00	89
November	19.20	7.21	38	11.99	62
December	22.93	13.56	59	9.37	41
TOTAL	143.06	59.35	41	83.71	59

* Precipitation site: Alta Lake
Altitude of site: 675 m

a shallow sill. The lake has several other shallow areas at the south and west shores. Presumably the shallow areas at the south end are from the buildup of sediments transported by the three major inflows.

Green Lake is oriented generally in the north-south direction. Winds during the summer were observed to be consistently from the south and frequently quite strong. Table 3 lists the wind observations recorded during field sampling trips.

Throughout the summer the prevailing winds at Squamish are from the southerly direction. Frequently these summer winds are noted to be 30-50 km/hr (Squamish Estuary Management Plan, 1981). Because the Cheakamus River and Green River valleys are in line with Howe Sound, frequent strong southerly winds are expected along the long axis of Green Lake throughout the summer.

TABLE 3

Field Wind Observations for Green Lake in 1979

Sampling Date in 1979	Time	Direction	Estimated Speed (km/hr)	Comments Made During Sampling
April 24	0615	South	-	Light
June 7	1600	South	>40	Very Windy
June 27	0830	-	Calm	-
July 18	0700	-	Calm	-
August 8	0915	South	25	-
August 29	0840	South	25	-
September 18	0915	North	-	Light
October 15	1615	-	Calm	-

The soil types immediately adjacent to Green Lake are presented in Figure 5. The map was generated from a soil survey conducted by Luttmerding (1971). Luttmerding details the characterization, composition and land suitability of the different soil types around Green Lake. Analysis of the soil types and their suitability for septic effluent are considered on page 38.

3. WATER QUALITY

Water quality monitoring stations were originally established by the Waste Management Branch of the Ministry of Environment. The location of the three stations on the lake and the location of the river stations are illustrated in Figure 4. Lake water quality data were gathered by the Aquatic Studies Branch every three weeks throughout the summer. The Lower Mainland Regional Office of the Waste Management Branch conducted a concurrent study of the streams of the area.

All data gathered during the study are stored on Ministry of Environment EQUIS computer storage system and are available on request.

3.1 TEMPERATURE

All temperature readings were taken with a Yellow Spring Instrument Co. YSI 57 combination electrode. Temperature profiles were taken in each basin on a regular basis from April through October, 1979. A single set of measurements was obtained in March 1980 when ice still covered the lake. All results for temperature are illustrated in Figures 6 and 7, and typical temperature profiles for both basins during the winter and summer are illustrated in Figure 8.

Figure 6 presents temperature versus water depth from the main basin at station 0300203. The maximum 1979 summer temperatures did not exceed 16°C. The low summer surface temperatures were the probable consequences of several factors. The lake's altitude, and the differential between day and

LEGEND

SOIL SERIES	SOIL CLASSIFICATION	DRAINAGE	PARENT MATERIAL
1	Orthic Humo-Ferric Podzol	Well to Rapid	Gravelly Alluvial Fans and Minor Glacial Outwash
2	Orthic Humo-Ferric Podzol	Well	Sandy Alluvial Fanns and Minor Glacial Outwash
3	Gleyed Orthic Regosol	Imperfect	Loamy Over Sandy Alluvial Fans
4	Gleyed Orthic Regosol	Imperfect	Gravelly Alluvial Fans
5	Rego Gleysol	Poor	Gravelly Alluvial Fans over Silty Glacio-Lacustrine
6	Orthic Humo-Ferric Podzol	Moderately well	Gravelly or Sandy Alluvial Fans and Glacial Outwash Over Silty Glacio-Lacustrine or Loamy Glacial Till
7	Orthic Humo-Ferric Podzol	Moderately well	Gravelly and Stony Colluvium and Ablation Till over Loamy Basal Till
8	Lithic Orthic Humo-Ferric Podzol	Rapid to Moderately Well	Shallow (<20") Stony and Gravelly Colluvium and glacial Till over Bedrock
9	Orthic Humo-Ferric Podzol	Moderately Well to Well	Gravelly and Stony Colluvium over Bedrock and Minor Basal Till
10	Rock Outcrop or Lithic Folisol	Rapid to Well	Exposed Bedrock or Shallow Organic Material over Bedrock
11	Rego Gleysol	Poor	Loamy over Sandy or Gravelly Alluvium
12	Terric Fibrisol	Very Poor	Organic Material (<4') over Loamy Alluvium
13	Typic Fibrisol	Very Poor	Deep (>4') Organic Material
14	Gleyed Orthic Regosol	Imperfect	Loamy over Gravelly Aluvium
15	Rego Gleysol	Very Poor	Shallow (<16") Organic Material over Loamy and Sandy Alluvium
16	Gleyed Orthic Regosol	Imperfect	Gravelly Aluvium
17	Bisequa Mini Humo-Ferric Podzol	Moderately Well	Sandy and Loamy Alluvial Fans over Silty Glacio-Lacustrine
18	Gleyed Orthic Humo-Ferric Podzol	Imperfect	Sandy Glacial Outwash

TOPOGRAPHIC CLASSES

	Single Slopes (regular surface)		Multiple Slopes (irregular surface)	Slope %
A	depresional to level	a	nearly level	0 to 0.5
B	very gently sloping	b	gently undulating	0.5 + to 2
C	gently sloping	c	undulating	2 + to 5
D	moderately sloping	d	gently rolling	5 + to 9
E	strongly sloping	e	moderately rolling	9 + to 15
F	steeply sloping	f	strongly rolling	15 + to 30
G	very steeply sloping	g	hilly	30 + to 60
H	extremely sloping	h	very hilly	Over 60

EXAMPLE OF MAP SYMBOL

Soil Series

$$\frac{14}{Cd}$$

Topographic Class

Proportion of map unit occupied by each soil series

6 4

$$\frac{8 - 10}{e\ f}$$

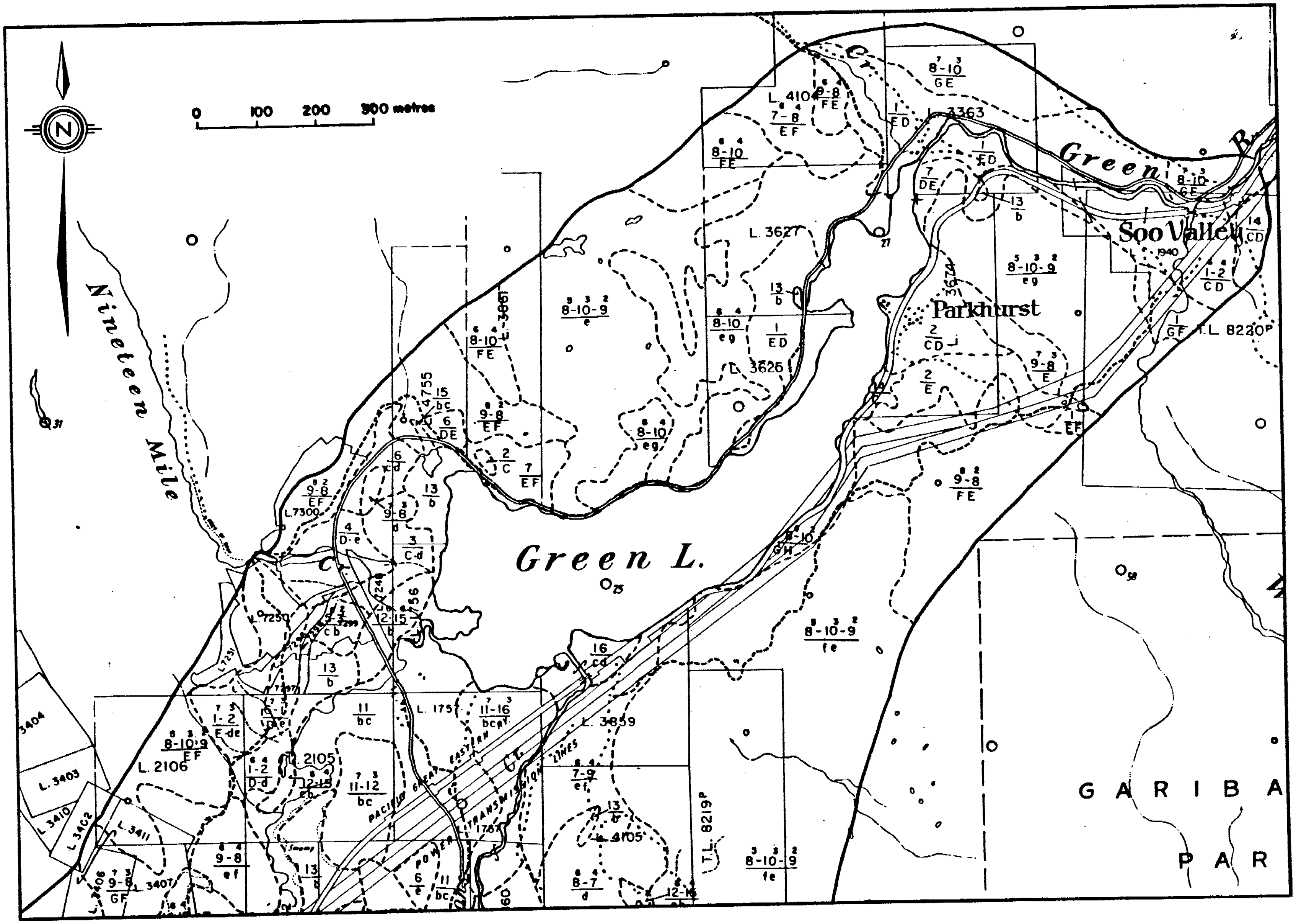

FIGURE 5: Soils Map of the Green Lake Watershed

night temperature would mean that much of the heat accumulated by the lake would be lost during the relatively cool nights. The poor light penetration would also tend to limit heat accumulation in the lake.

The surface water temperatures of the north basin, station 0300204, were consistently higher, probably due to the generally shallower depth and smaller volume.

The summer thermocline in both basins was very shallow, starting between 2 and 4 metres and extending only a few metres to a maximum depth of 4 to 5 metres (Figures 6 and 7). Although the lake is exposed to wind mixing by frequent strong winds along its long axis, the shallow thermocline persisted throughout the summer.

The dispersion of streams entering the lake is largely dependent on the temperature of the stream relative to that of the lake. Fitzsimmons Creek in June had a temperature of 10°C (Table 4) and flow would be expected to be at or near a depth of 2 metres. As the summer progressed, the cooler inflow temperatures with warmer lake temperatures would result in the stream inflows entering the lake at deeper depths. In July, the inflow temperature was 6.5° and the corresponding lake isotherm was at 25 m. In September, the inflow at 4.5° would flow along the bottom of the lake.

TABLE 4

Water Temperatures of Inflowing Creeks

Date	Year	Fitzsimmons Creek at Mouth 0300300 (°C)	Twenty-One Mile Creek at Hyw 99 0300201 (°C)	Nineteen Mile Creek at Mouth 0300202 (°C)
May 16	1979	6.0	6.2	5.0
June 27	1979	10.2	9.5	10.0
July 16	1975	6.5	9.0	-
September 29	1976	4.5	9.0	4.5
November 20	1979	3.2	4.0	-

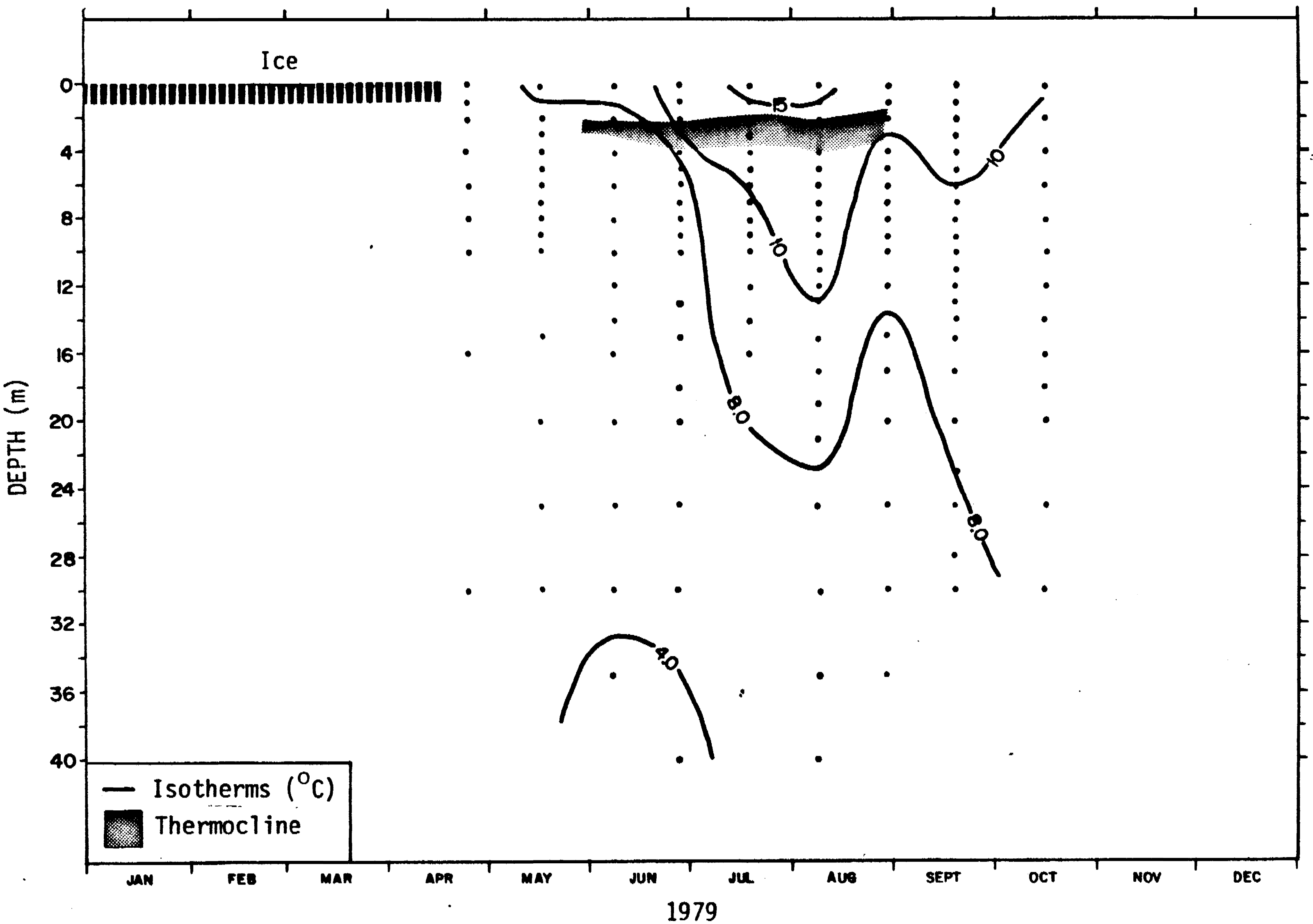

FIGURE 6: Temperature: Time-Depth Profiles for the Main Basin (site 0300203) of Green Lake in 1979

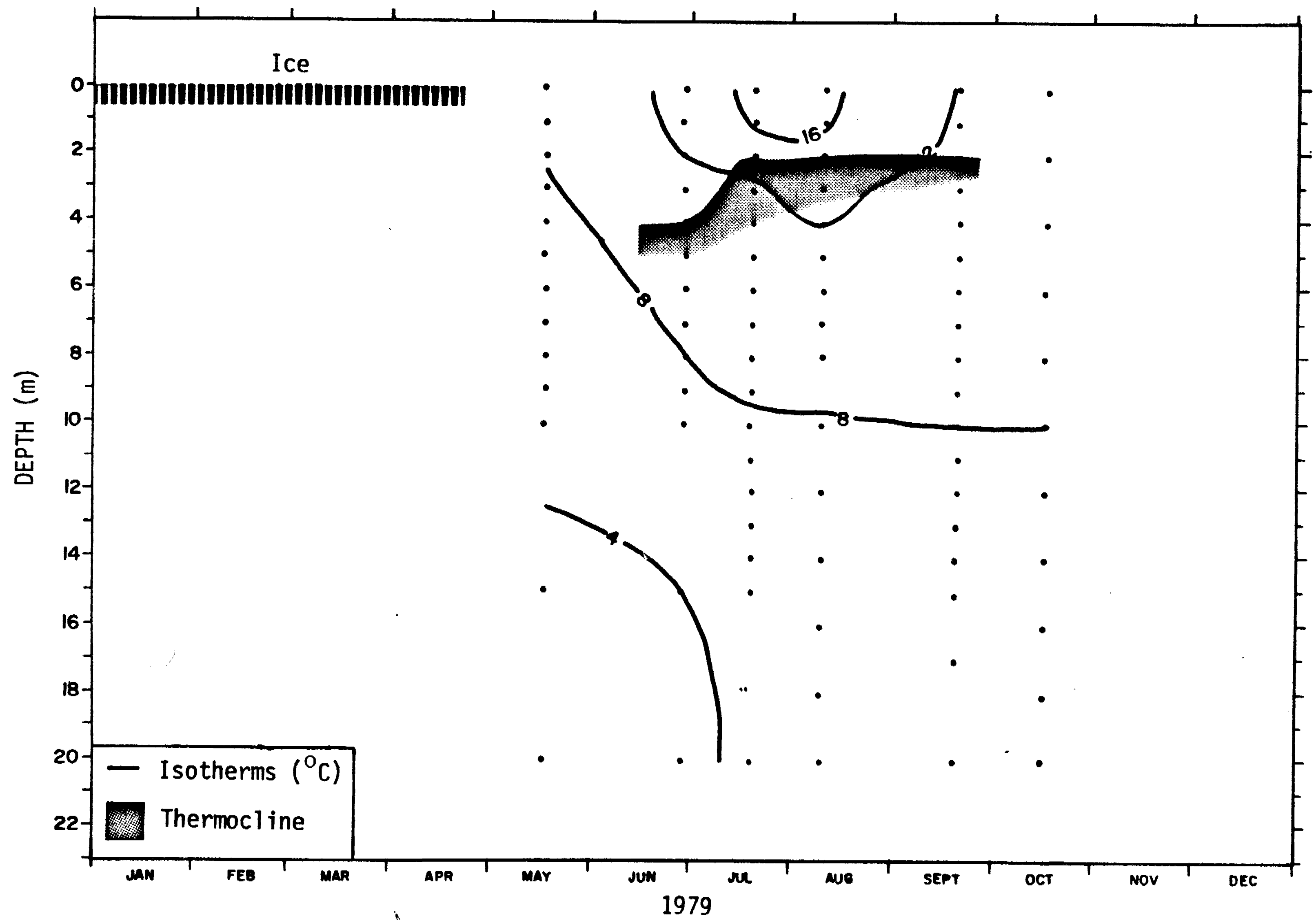

FIGURE 7: Temperature: Time-Depth Profiles for the North Basin (site 0300204) of Green Lake in 1979

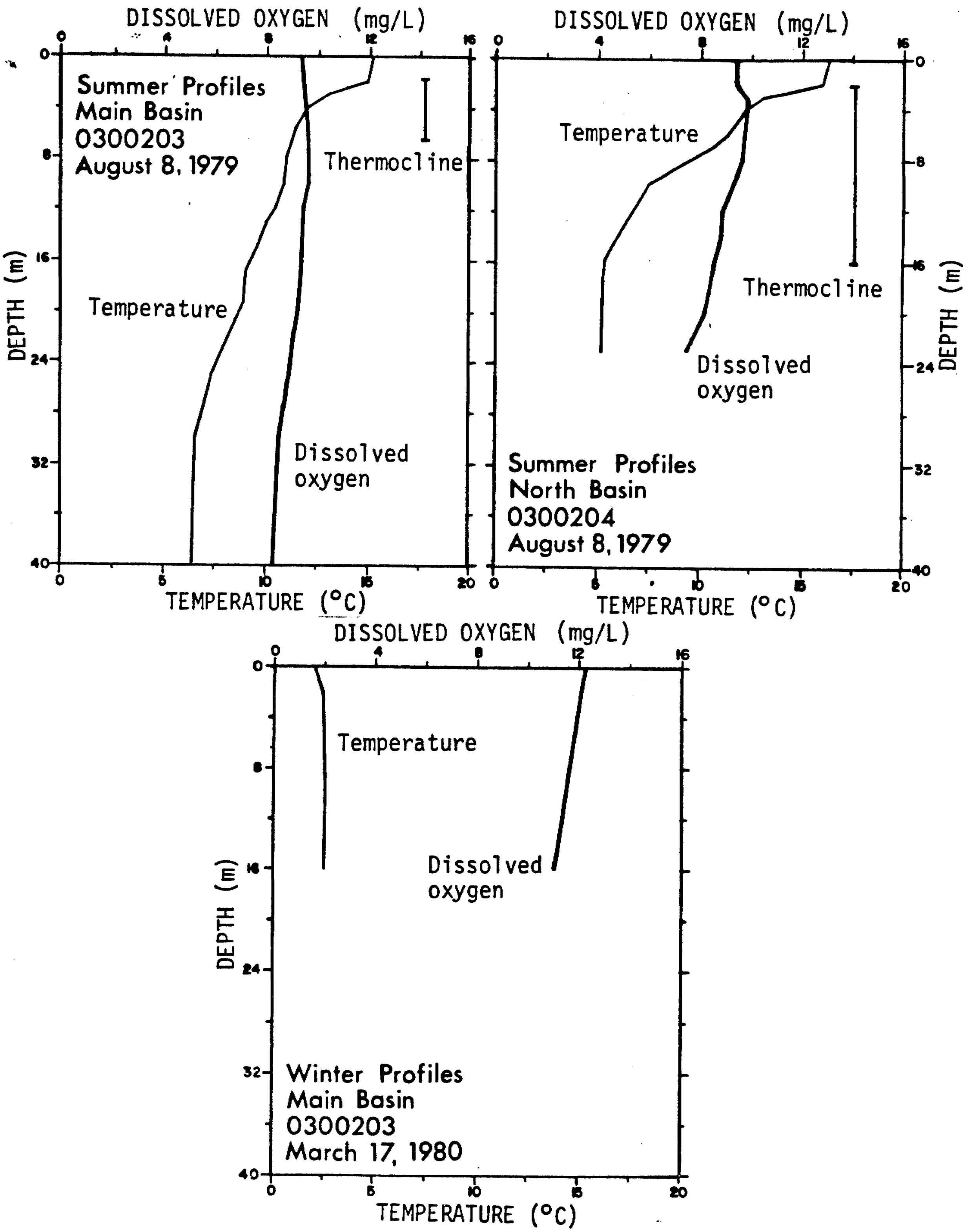

FIGURE 8: Typical Temperature and Dissolved Oxygen Profiles for the Main and North Basin in Winter and Spring

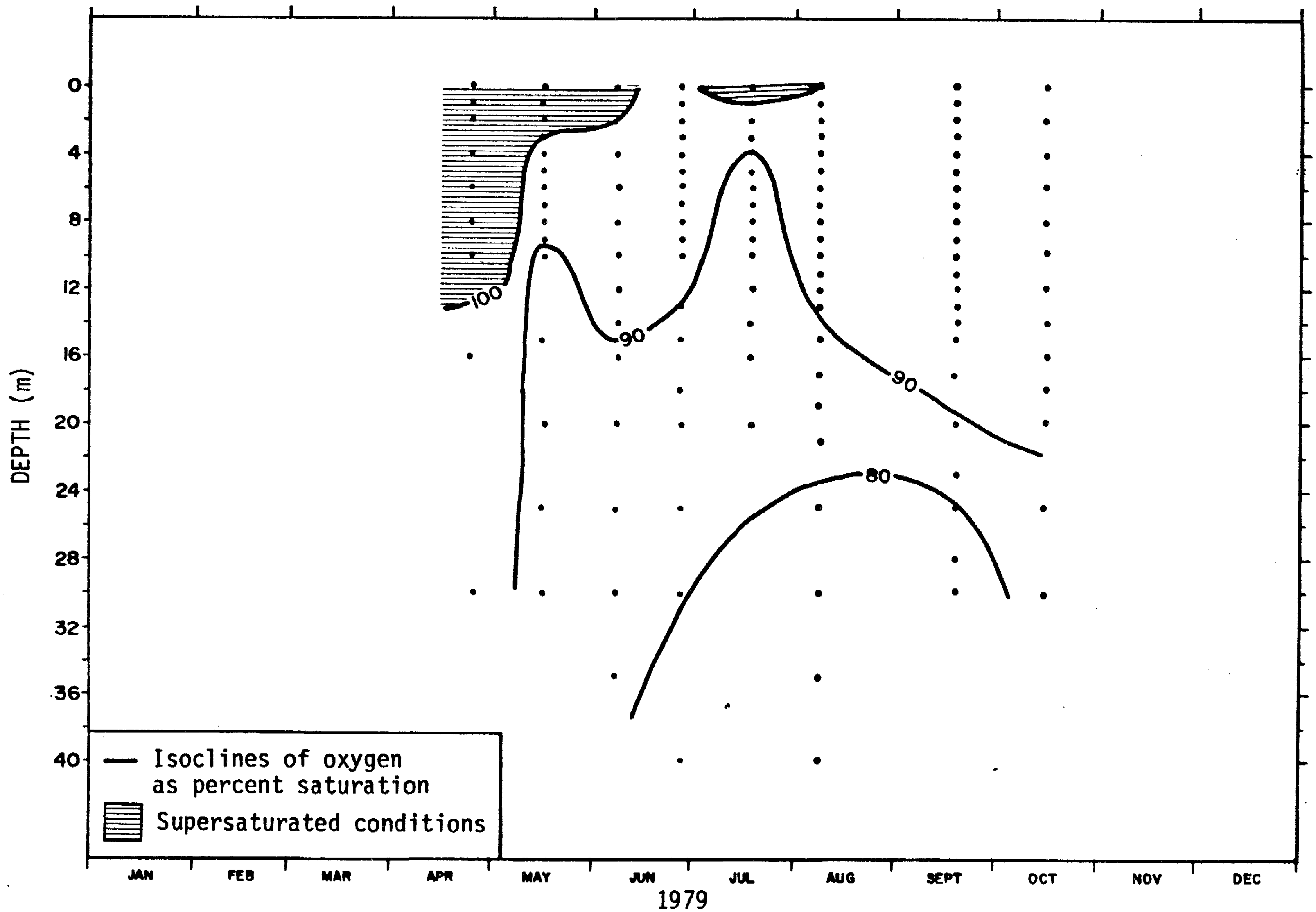

FIGURE 9: Dissolved Oxygen: Time-Depth Profile for the Main Basin (site 0300203) of Green Lake in 1979

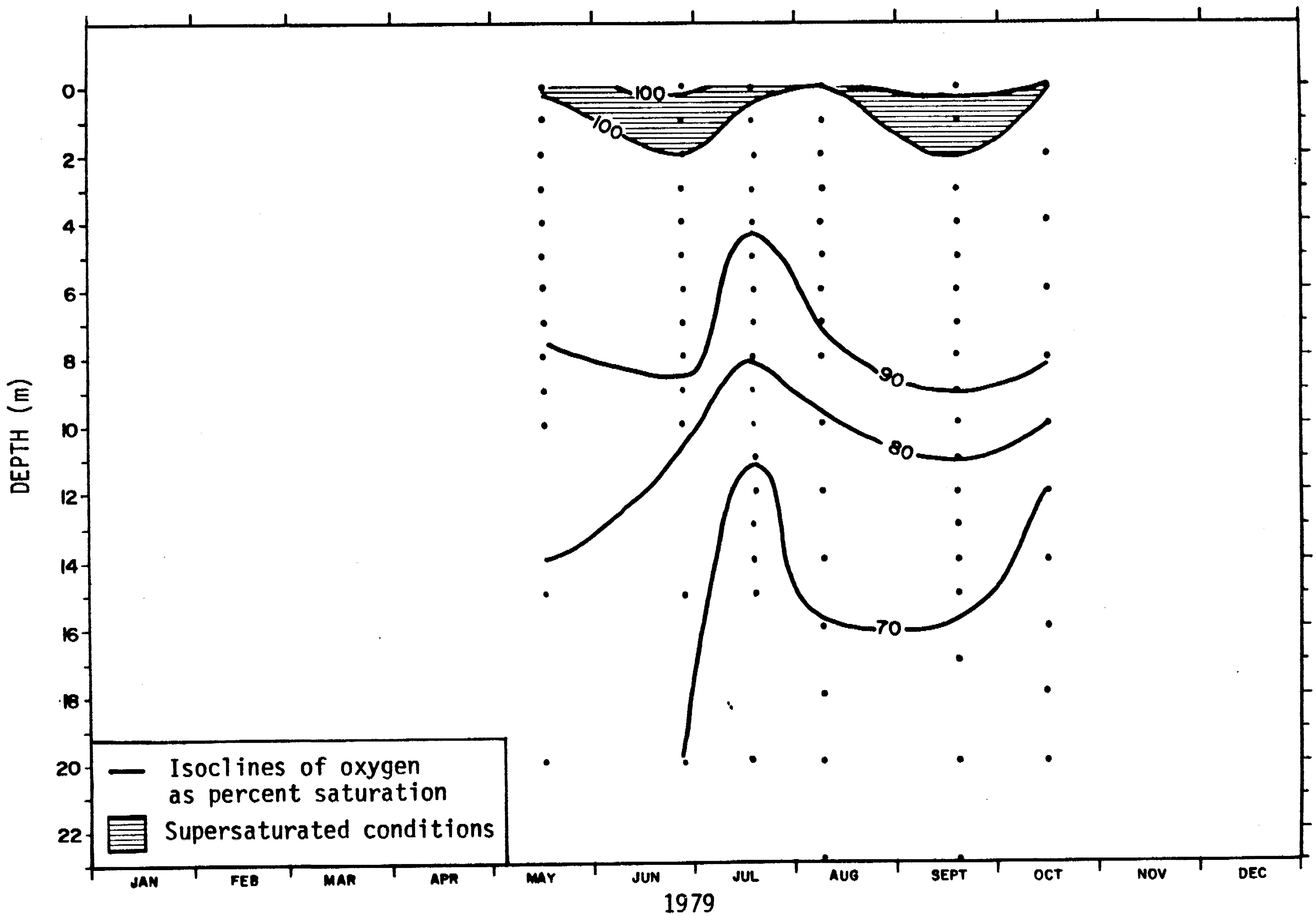

FIGURE 10: Dissolved Oxygen: Time-Depth Profile for the North Basin (site 0300204) of Green Lake in 1979

During the winter approximately 0.6 metres of ice accumulated on the lake. Below the ice, water temperature was approximately 1.75°C, while the temperature increased to a maximum of 2°C below 4 metres (Figure 8).

3.2 DISSOLVED OXYGEN

All dissolved oxygen readings were taken with a Yellow Springs Instrument Co. YSI 57 dissolved oxygen electrode. The Winkler titration method as outlined by the American Public Health Association (Standard Methods, 1971) was used to calibrate the meter's readings. All dissolved oxygen measurements are presented as percent saturation in Figures 9 and 10, and typical winter and summer profiles for both stations are illustrated in Figure 8. Oxygen measurements were taken immediately after the temperature reading at each depth throughout the entire monitoring program.

Supersaturated conditions during the summer are usually a result of biological productivity. Unlike more productive lakes, the supersaturated conditions were limited to the surface (Figures 9 and 10). Turbid conditions throughout the summer restricted algal photosynthesis to the top few metres.

Dissolved oxygen measurements below the summer thermocline decreased with depth and time (Figures 9 and 10). Biological utilization of oxygen during the decomposition of organic matter is the most common cause for the decline of the hypolimnetic concentrations. The lowest oxygen concentrations were 8.1 mg/L (67 percent saturation) at 30 m on September 18, 1979 in the main basin, and 6.2 mg/L (50 percent saturation) at 20 m on October 15, 1979, in the north basin.

The rate at which oxygen was consumed in the hypolimnion (zone of water below the thermocline) is summarized in Table 5.

TABLE 5

Oxygen Depletion Rates for Green Lake in 1979

Strata (m)	Strata Volume (106 m^3)	Mean O_2 Concentration on May 16, 1979 (mg/L)	Total O_2 in Strata on May 16, 1979 (kg)	Total O_2 Concentration on August 8, 1979 (mg/L)	Total O_2 in Strata on August 8, 1979 (kg)
12-18	5.55	10.4	57720	9.55	53000
18-24	3.063	10.3	31550	9.23	28270
24-30	1.177	10.3	12120	8.81	10370
30-36	0.015	10.3	150	8.45	130
		Total	101540	Total	91770

The oxygen depletion rate is calculated by the following formula:

$$\text{oxygen depletion rate (mg/cm}^2\text{/day)} = \frac{\text{change in total } O_2 \text{ mass}}{\text{area of hypolimnion at 12 m}} \div \text{Number of days between sampling times}$$

$$\text{oxygen depletion rate (mg/cm}^2\text{/day)} = \frac{9.770 \times 10^9 \text{mg}}{11.31 \times 10^9 \text{cm}^2} \div 84 \text{ days}$$

oxygen depletion rate = 0.010 $mg/cm^2/day$

The oxygen depletion rate for Green Lake was very low, indicating its low productivity (oligotrophic status).

Winter oxygen depletion is slower because of lower water temperatures On March 17, 1980 at a point west of station 0300203 the oxygen at 16 metres was reduced to 80 percent saturation.

3.3 WATER CLARITY

The water clarity of Green Lake ranged from very good at spring overturn to very poor in the summer. Secchi disc depths and turbidity values for the main basin are illustrated in Figure 11.

Secchi disc readings in the main basin ranged from a high of 6.1 metres on April 24, 1979 to a low of 0.39 metres on September 18, 1979. Surface turbidity is the main factor controlling the Secchi disc depth, and as expected, is inversely proportional to the Secchi readings.

Turbidity values for all depths in the main basin peaked in late August or early September. This is presumably the period when the glacial inflow via Fitzsimmons Creek is the highest proportion of the lake's total inflow. The result was a maximum suspended sediment concentration of 27 mg/L at 5 metres on August 28, 1979.

The maximum turbidity and suspended sediment concentrations were recorded at subsurface depths. The inflow from Fitzsimmons Creek carrying a significant load of fine particulate and colloidal material flowed into the lake below the surface as noted on page 12.

The suspended residue and turbidity values for the three inflow creeks are summarized in Table 6. The results clearly show the high suspended residue and turbidity values in Fitzsimmons Creek from June through September.

Secchi, turbidity and suspended sediment concentrations in the surface water of the north basin followed the same patterns as shown in Figure 11. Hypolimnetic water in the north basin was not influenced by the glacial input. Turbidity and suspended sediment concentrations remained below 2.5 N.T.U. and 2 mg/L respectively through the summer until October. Settling of suspended particulates was thought to be the cause for the high turbidity and suspended sediment concentrations at 20 metres in October.

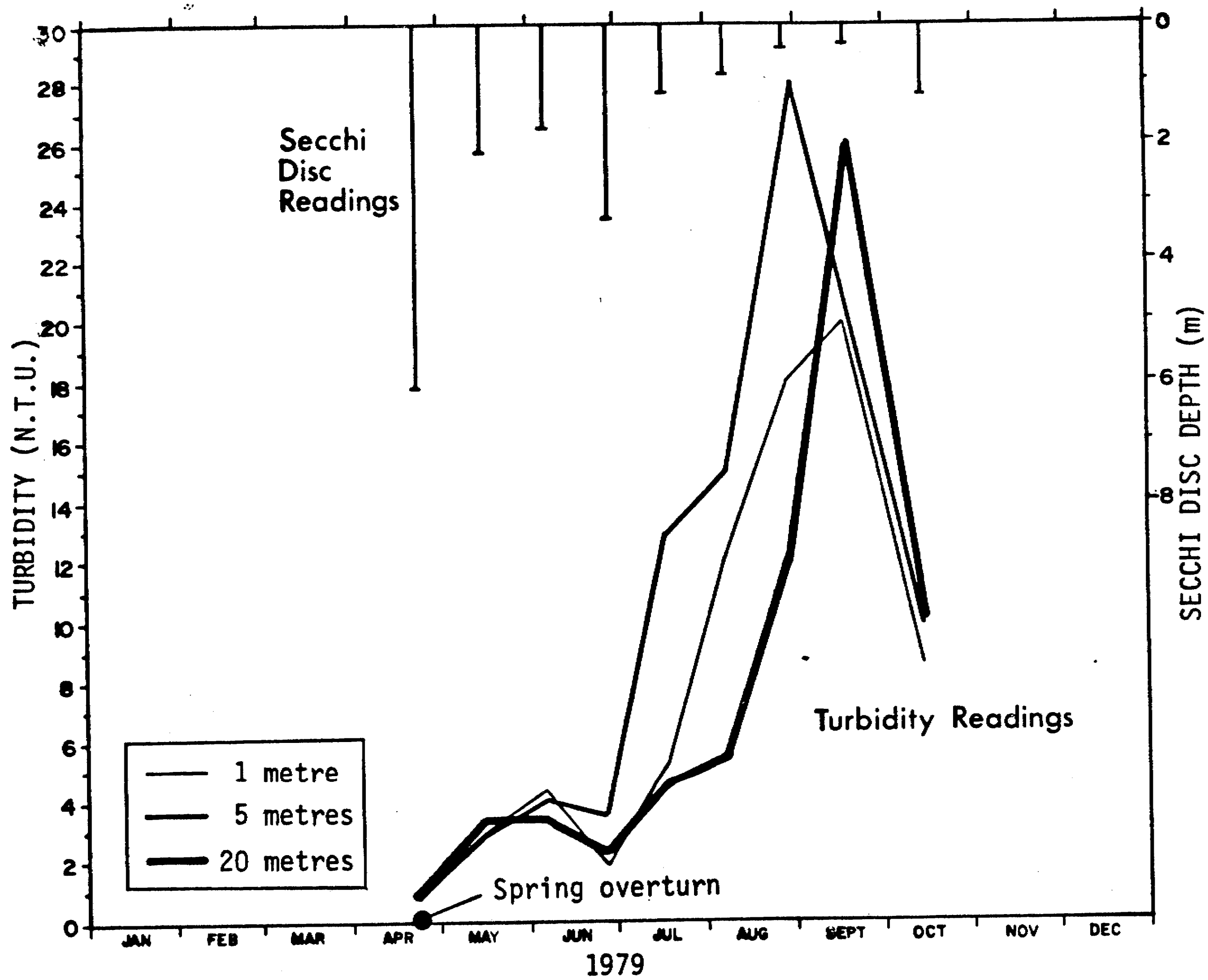

FIGURE 11: Secchi Disc and Turbidity Readings for the Main Basin (Site 0300203) of Green Lake in 1979

TABLE 6

Suspended Residues and Turbidity Values for the Inflow Creeks

Date	Year	Fitzsimmons Creek		Twenty-One Mile Creek		Nineteen Mile Creek	
		Suspended Residue (mg/L)	Turbidity (N.T.U.)	Suspended Residue (mg/L)	Turbidity (N.T.U.)	Suspended Residue (mg/L)	Turbidity (N.T.U.)
March 10	1981	3	0.8	-	-	-	-
May 16	1979	-	-	10	3.9	-	-
May 19	1977	4	0.8	2	0.5	2	0.2
June 27	1979	21	23	1	2.7	1	0.4
July 16	1975	62	34	1	-	<1	0.4
September 29	1976	16	11	2	0.7	1	0.3
November 20	1979	8	3.2	2	1.1	-	-

3.4 GENERAL IONS AND METALS

The general ions and metals measured in Green Lake and its three major inflows are summarized in Table 7. The lake has a low alkalinity and the water is considered soft. The remainder of the general ions are conservative and pose no problem to potential domestic water users.

Most of the metals were undetectable. Only aluminum, copper, iron and manganese were above detectable limits. None of the observed metal concentrations were above the B.C. Ministry of Health (1969) recommended domestic drinking water standards or objectives, or believed to be at levels toxic to the aquatic biota.

TABLE 7

Water Quality Summary of the Main Basin of Green Lake and Its Inflow Creeks

Parameter	Green Lake: Main Basin 0300203		Fitzsimmons Creek 0300200	Twenty-One Mile Creek 0300201	Nineteen Mile Creek 0300202
GENERAL IONS	Epilimnion	Hypolimnion			
1) Alkalinity - Total (mg/L)	24.0 ± 4.4 (n=8)	24.3 ± 3.8 (n=4)	33.5 ± 9.2 (n=11)	13.4 ± 4.6 (n=11)	13.3 ± 5.3 (n=7)
2) Carbon - Inorganic (mg/L)	4.8 ± 2.0 (n=12)	5.0 ± 1.8 (n=6)	8.1 ± 3.2 (n=7)	2.5 ± 1.5 (n=8)	1.75± 0.96 (n=4)
3) Calcium - Dissolved (mg/L)	11.1 ± 4.8 (n=6)	10.6 ± 3.7 (n=3)	17.1 ± 6.3 (n=5)	8.6 ± 3.6 (n=7)	8.4 ± 4.7 (n=5)
4) Chloride - Dissolved (mg/L)	0.9 (n=1)	-	0.73± 0.45 (n=9)	1.29± 1.35 (n=7)	<0.5 ± 0.0 (n=5)
5) Hardness (mg/L)	29.2 ±12.5 (n=6)	28.2 ± 9.7 (n=3)	44.6 ±16.4 (n=5)	23.1 ± 9.6 (n=7)	22.3 ±12.6 (n=5)
6) Magnesium - Dissolved (mg/L)	0.4 ± 0.15 (n=6)	0.41± 0.15 (n=3)	0.81± 0.22 (n=2)	0.39± 0.16 (n=7)	0.33± 0.18 (n=5)
7) pH (relative units)	7.4 ± 0.16 (n=19)	7.3 ± 0.15 (n=10)	7.6 ± 0.14 (n=13)	7.0 ± 0.15 (n=13)	7.3 ± 0.22 (n=9)
8) Potassium - Dissolved (mg/L)	0.5 (n=1)	-	-	-	-
9) Silicate - Reactive (mg/L)	4.0 ± 1.2 (n=7)	4.4 ± 1.2 (n=3)	5.2 ± 1.4 (n=12)	3.96± 1.37 (n=12)	3.6 ± 1.3 (n=8)
10) Sodium - Dissolved (mg/L)	1.8 (n=1)	-	-	-	-
11) Specific Conductance (µmho/cm)	71.1 ±18.4 (n=19)	75.0 ±18.7 (n=10)	101 ±31 (n=13)	52.5 ±21 (n=13)	43.2 ±22.5 (n=9)
12) Sulphate - Dissolved (mg/L)	8.9 ± 3.0 (n=15)	9.2 ± 1.4 (n=7)	15.7 ± 5.4 (n=8)	9.99± 4.45 (n=7)	7.1 ± 2.5 (n=4)
13) Total Dissolved Residues (mg/L)	49.2 ±10.5 (n=12)	50.7 ± 9 (n=6)	72.4 ±19.8 (n=5)	42.5 ±16.4 (n=4)	31.6 ±13.8 (n=7)
14) Total Inorganic Residues (mg/L)	41.0 ± 7.1 (n=12)	40.0 ± 6.1 (n=6)	65.5 ±14.0 (n=4)	28.0 ±19 (n=3)	8 (n=1)
METALS	Sampling Conducted During Unstratified Conditions				
1) Aluminum - Total (mg/L)	0.03 (n=1)		-	-	-
2) Arsenic - Total (mg/L)	<0.005 (n=1)		<0.05 (n=1)	-	-
3) Cadmium - Total (mg/L)	<0.005 (n=1)		<0.01 (n=1)	-	-
4) Chromium - Total (mg/L)	<0.005 (n=1)		0.02 (n=1)	-	-
5) Copper - Total (mg/L)	0.002 (n=1)		0.0047 ± 0.006 (n=9)	0.0027 ± 0.0027 (n=7)	0.002 ± 0.002 (n=5)
6) Iron - Total (mg/L)	0.3 (n=1)		0.90 ± 1.0 (n=9)	± 0.14 (n=10)	0.11 ± 0.035 (n=8)
7) Lead - Total (mg/L)	<0.001 (n=1)		0.013 ± 0.033 (n=9)	0.001 ± 0.0 (n=7)	<0.001 ± 0.0 (n=5)
8) Manganese - Total (mg/L)	0.03 (n=1)		0.03 (n=1)	-	<0.01 ± 0.0
9) Nickel - Total (mg/L)	<0.01 (n=1)		<0.01 ± 0.0 (n=9)	<0.01 ± 0.0 (n=7)	<0.01 ± 0.0 (n=5)
10) Zinc - Total (mg/L)	<0.005 (n=1)		0.051 ± 0.154 (n=12)	0.008 ± 0.01 (n=12)	0.001 ± 0.0005 (n=8)

3.5 NUTRIENTS

Based on nutrient concentrations, Green Lake is a typical oligotrophic lake. The spring overturn nutrient concentrations for 1975, 1977, 1979, and 1981 are listed in Table 8.

There is some variability in certain parameters between these years. These differences likely reflect interannual variations in the annual hydrologic pattern and volume.

The nutrient content of the snow covering Green Lake is summarized in Table 9.

The annual pattern of total phosphorus concentration in the main basin for 1979 is illustrated in Figure 12. The general summer trends were observed at all depths. The concentrations increased marginally following spring overturn and then decreased in June and July. The phosphorus concentrations increased to their highest point in late August and September, and decreased again in October.

The late summer phosphorus peak was largely in the suspended inorganic fraction and was likely caused by high concentrations of suspended phosphorus released from Fitzsimmons Glacier. Suspended phosphorus concentrations in Fitzsimmons Creek increased from 11 μg/L on May 16, 1979 to 33 μg/L on June 24. During this same time period dissolved phosphorus concentrations remained the same. Historical samples show that late summer total phosphorus concentrations can be as high as 74 μg/L. Presumably the majority of the phosphorus was in the suspended and inorganic state.

Twenty-One Mile Creek and Nineteen Mile Creek are the only other major inflow streams. Throughout the summer both creeks had low concentrations of dissolved and suspended phosphorus (Table 9).

TABLE 8

Green Lake Spring Overturn Nutrient Concentrations (main basin)

Nutrient	1975	1977	1979	1981
Organic Carbon (mg/L)	1.0 (n=2)	2.5 ± 0.7 (n=2)	3.0 (n=1)	<1.0 ± 0.0 (n=3)
Inorganic Carbon (mg/L)	5.0 (n=2)	—	8.0 (n=1)	7.0 ± 0.0 (n=3)
Ammonia - Nitrogen (mg/L)	0.005 (n=2)	—	0.007 ± 0.002 (n=3)	0.01 ± 0.0 (n=3)
NO_2+NO_3 - Nitrogen (mg/L)	0.040 (N=2)	0.025 ± .007 (n=2)	0.063 ± 0.0067 (n=3)	0.03 ± 0.0 (n=3)
Organic Nitrogen (mg/L)	0.055 ± 0.007 (n=2)	—	0.077 ± 0.04 (n=3)	0.04 ± 0.03 (n=3)
Total Nitrogen (mg/L)	0.070 ± 0.007 (n=2)	—	0.15 ± 0.03 (n=3)	0.05 ± 0.04 (n=3)
Ortho-Phosphorus (mg/L)	<0.003 ± 0.0 (n=2)	<0.003 ± 0.0 (n=2)	<0.003 ± 0.0 (n=3)	<0.003 ± 0.0 (n=3)
Total Dissolved Phosphorus (mg/L)	—	0.003 ± 0.0 (n=2)	0.006 ± 0.0 (n=3)	0.005 ± 0.0 (n=3)
Total Phosphorus (mg/L)	0.008 ± 0.0 (n=2)	0.0035 ±0.0004 (n=2)	0.0063 ± 0.0006 (n=3)	0.007 ± 0.001 (n=3)

TABLE 9

1979 Nutrient Content of the Snow Around Green Lake and the Inflow Streams

Nutrient	Snow	Fitzsimmons Creek	Nineteen Mile Creek	Twenty-One Mile Creek
Ortho-Phosphorus (mg/L)	<0.003 (n=1)	<0.003 ± 0.0 (n=12)	<0.003 ± 0.0 (n=11)	<0.003 ± 0.0 (n=11)
Total Dissolved Phosphorus (mg/L)	0.003 (n=1)	0.004 ± 0.001 (n=10)	0.004 ± 0.001 (n=7)	0.004 ± 0.0 (n=7)
Total Phosphorus (mg/L)	0.003 (n=1)	0.017 ± 0.019 (n=13)	0.007 ± 0.004 (n=12)	0.007 ± 0.004 (n=12)
Ammonia - Nitrogen (mg/L)	0.014 (n=1)	0.006 ± 0.001 (n=9)	0.008 ± 0.004 (n=8)	0.008 ± 0.004 (n=8)
Nitrate and Nitrite - Nitrogen (mg/L)	0.11 (n=1)	0.02 ± 0.003 (n=9)	0.023 ± 0.005 (n=6)	0.023 ± 0.005 (n=6)
Organic Nitrogen (mg/L)	0.05 (n=1)	0.16 ± 0.17 (n=9)	0.10 ± 0.06 (n=7)	0.10 ± 0.06 (n=7)
Total Nitrogen (mg/L)	0.17 (n=1)	0.14 ± 0.15 (n=5)	0.13 ± 0.08 (n=3)	0.13 ± 0.08 (n=3)

The phosphorus concentrations in the epilimnion of the north basin were also affected by the suspended phosphorus associated with glacial runoff. The concentrations fluctuated in the same manner and degree as the phosphorus concentrations in the main basin (Figures 12 and 13).

The hypolimnetic phosphorus concentrations in the north basin did not follow the same pattern as the concentrations in the main basin. The two basins are separated by a very shallow sill, consequently, the hypolimnion of the north basin is physically isolated from the main basin. As a result, the hypolimnetic phosphorus concentrations remained relatively unchanged until September 18. From September 18 to October 15 the concentrations increased dramatically, while for the same time period the surface concentrations decreased (Figure 13). High suspended sediment concentrations at 20 m suggest that suspended phosphorus residues previously observed in the epilimnion had settled into the hypolimnion.

The total nitrogen concentrations for the main basin fluctuated extensively throughout the summer (Figure 14). Inflow nitrogen concentrations were very similar to the total nitrogen concentration at spring overturn (Tables 7 and 8).

The change in the organic nitrogen content of the water caused the fluctuations in the nitrogen concentrations. Biological productivity would be the major cause for the fluctuation in organic and total nitrogen concentrations.

The 1979 phosphorus and nitrogen concentrations for both the main and north basins are illustrated in Figures 15-24.

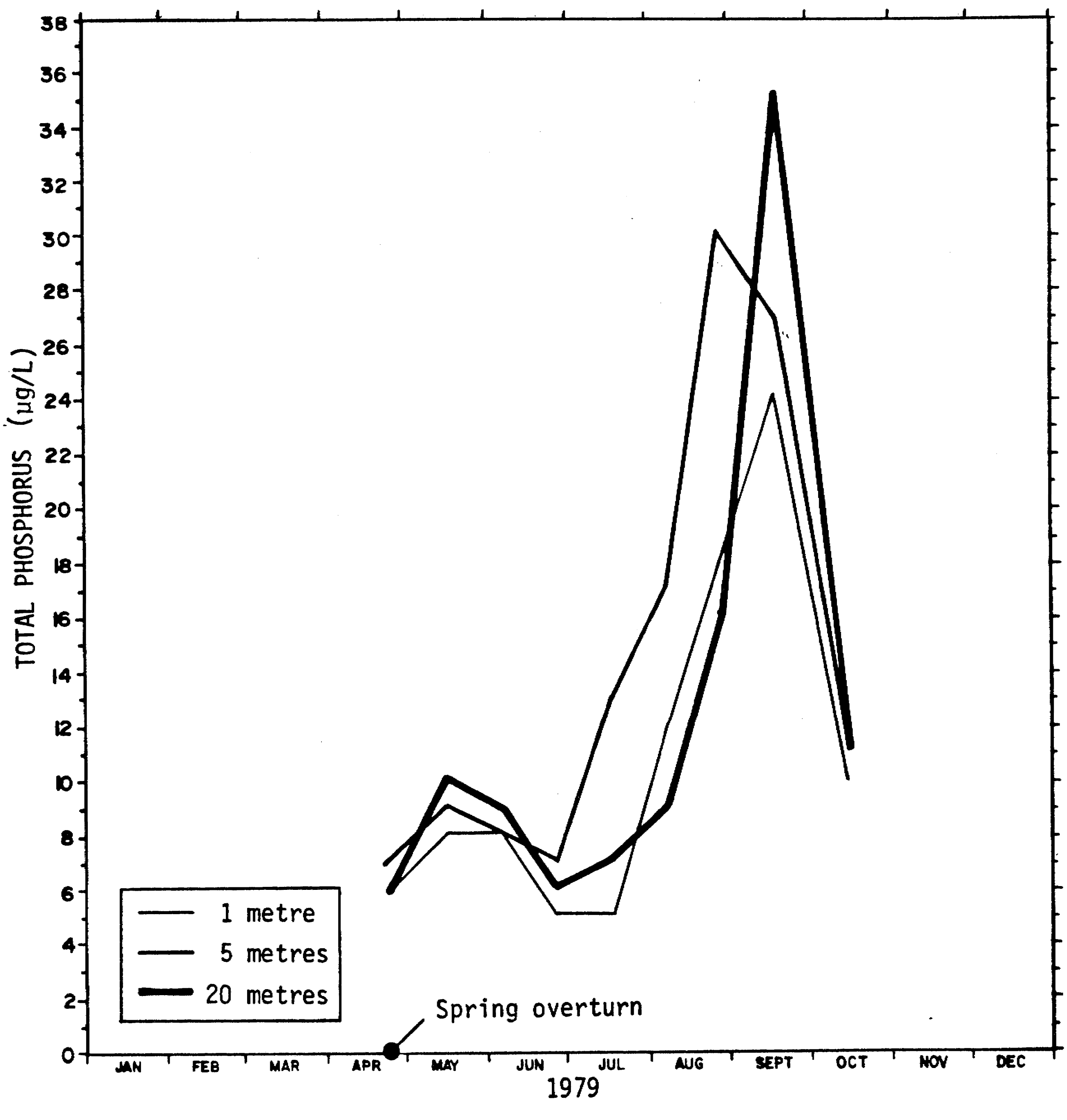

FIGURE 12: 1979 Total Phosphorus Concentrations at 3 Depths in the Main Basin (0300203)

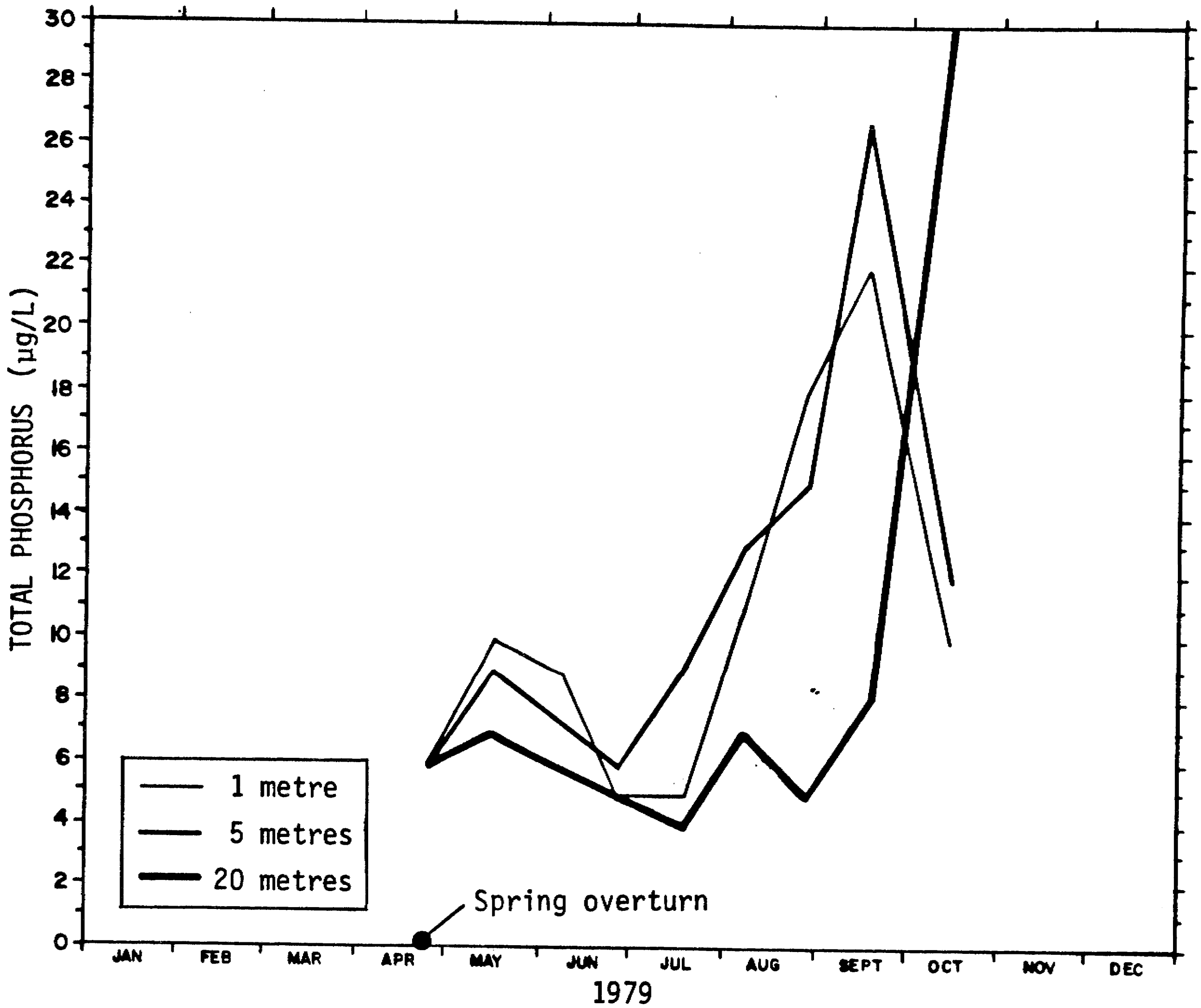

FIGURE 13: 1979 Total Phosphorus Concentrations at 3 Depths in the North Basin (0300204)

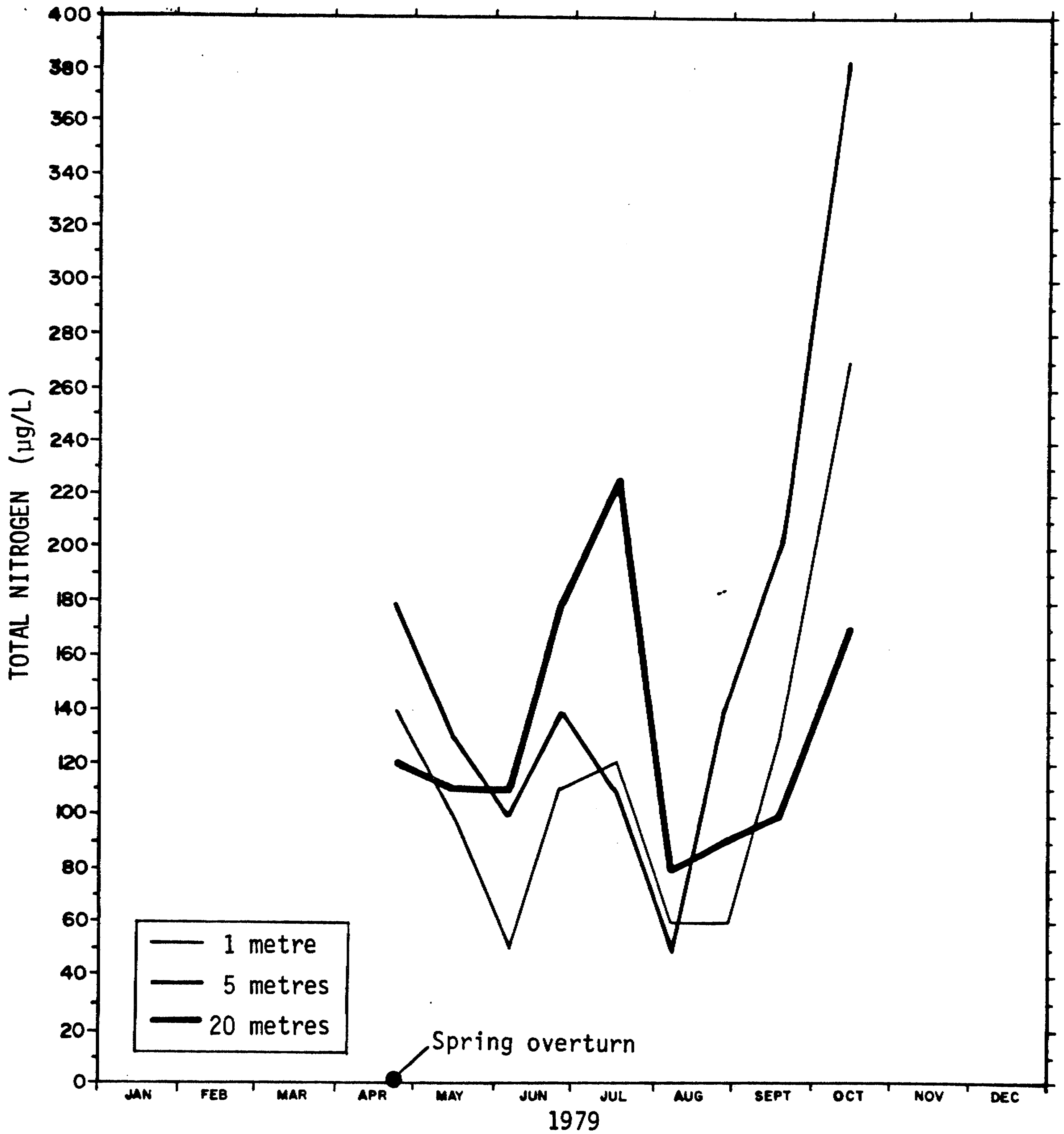

FIGURE 14: 1979 Total Nitrogen Concentrations at 3 Depths in the Main Basin (0300203)

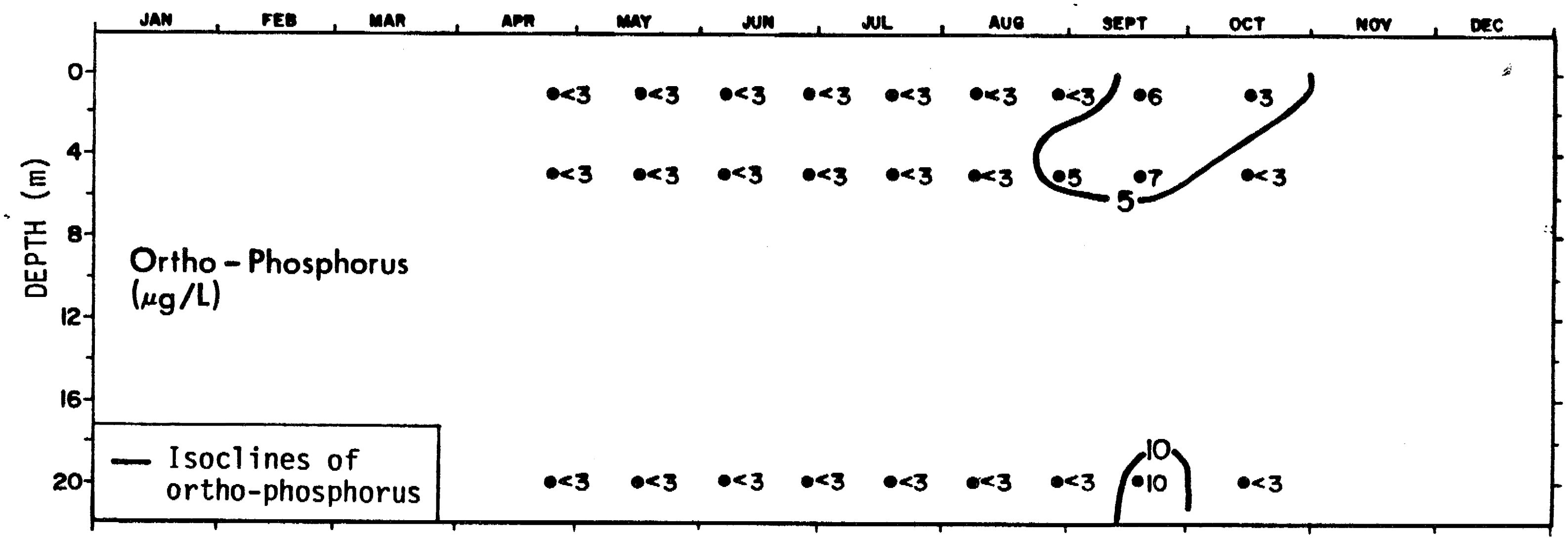

FIGURE 15: Ortho-Phosphorus Concentrations for the Main Basin (0300203) of Green Lake in 1979

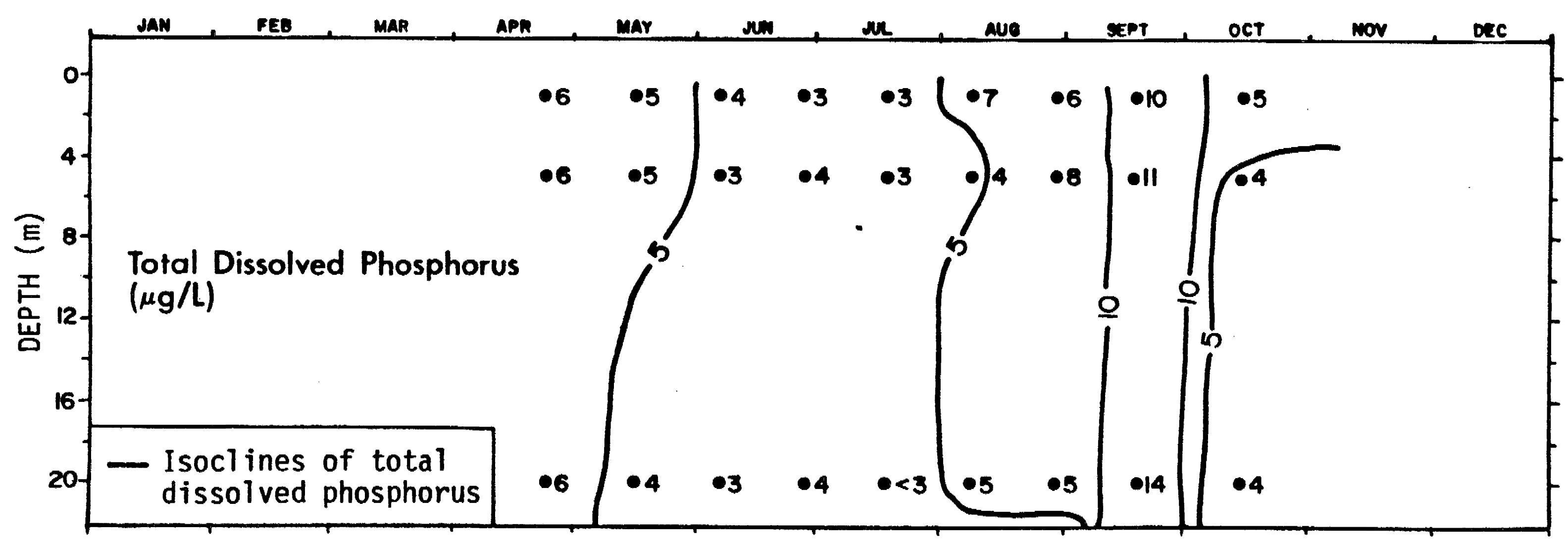

FIGURE 16: Total Dissolved Phosphorus Concentrations for the Main Basin (0300203) of Green Lake in 1979

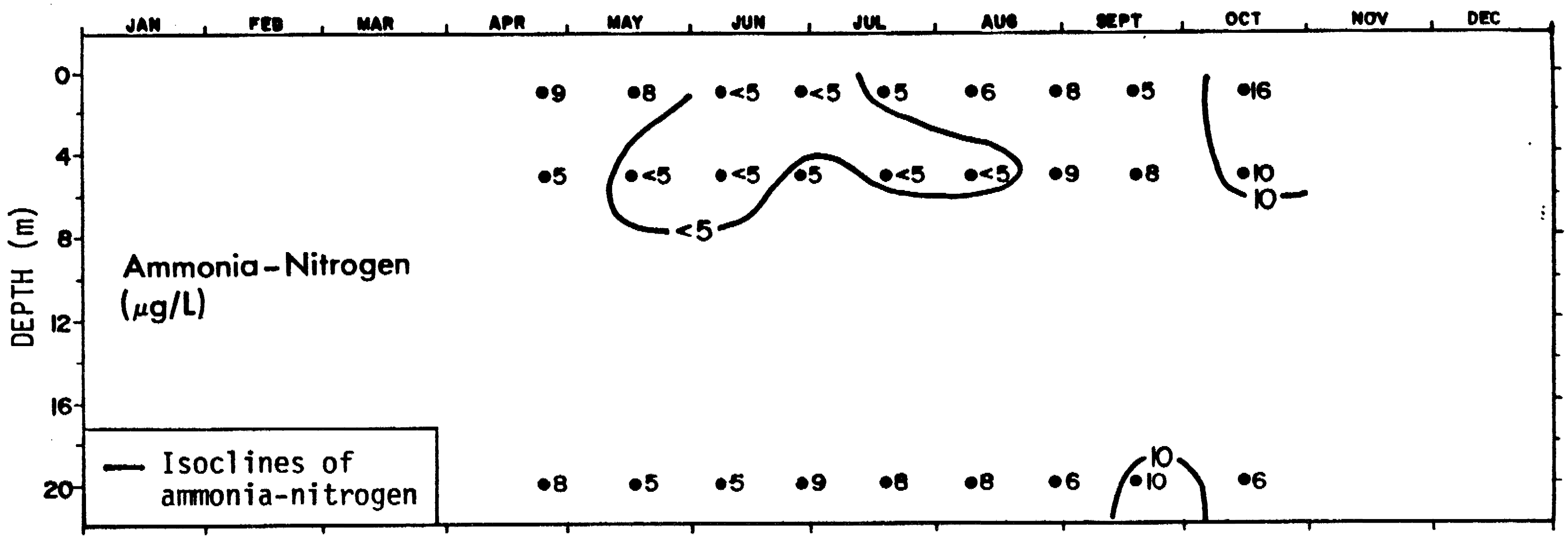

FIGURE 17: Ammonia-Nitrogen Concentration for the Main Basin (0300203) of Green Lake in 1979

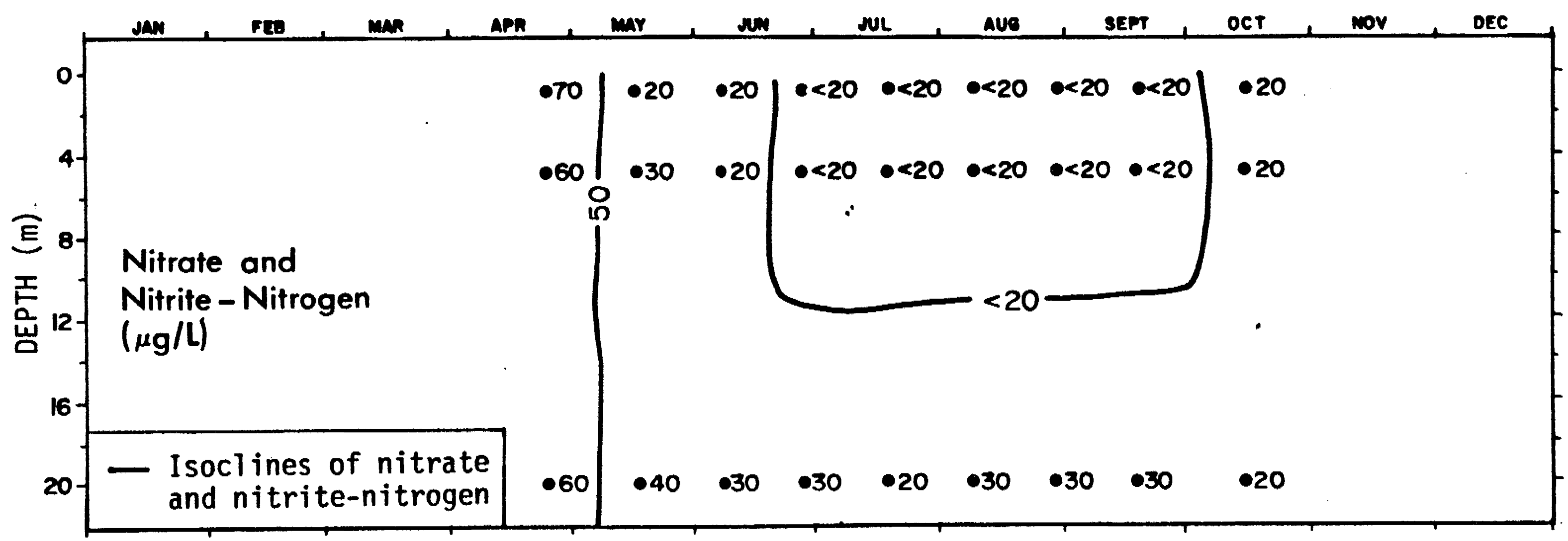

FIGURE 18: Nitrate and Nitrite-Nitrogen Concentration for the Main Basin (0300203) of Green Lake in 1979

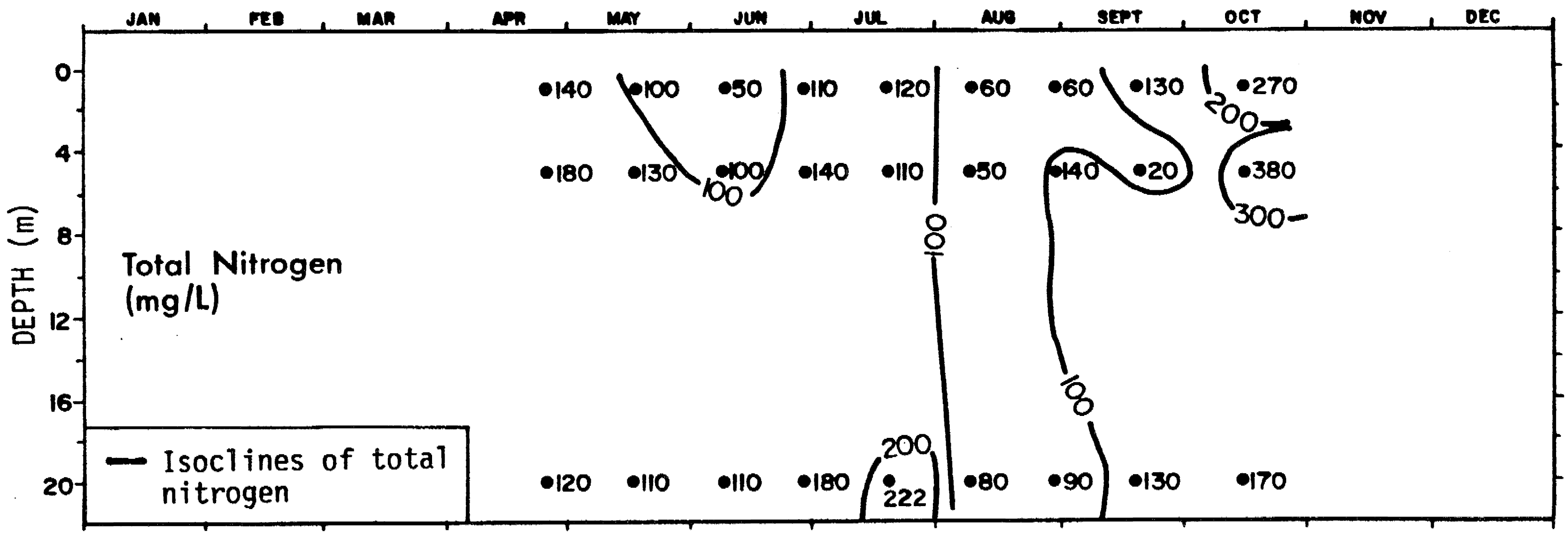

FIGURE 19: Total Nitrogen Concentrations for the Main Basin (0300203) of Green Lake in 1979

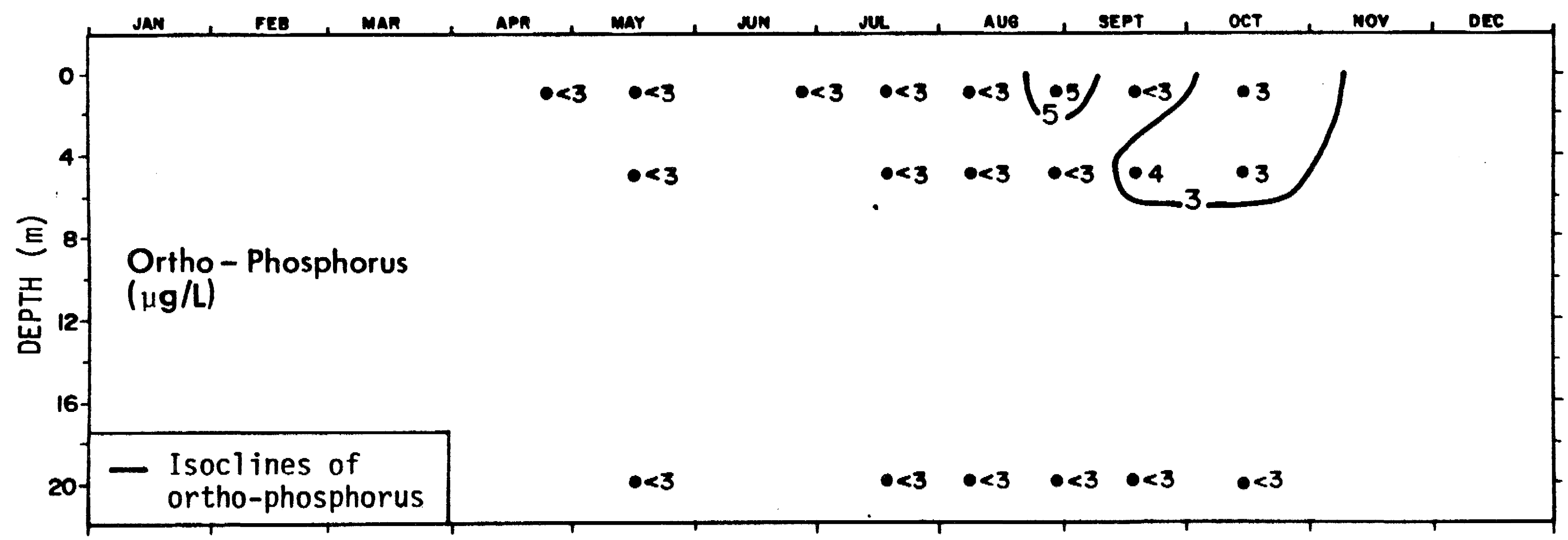

FIGURE 20: Ortho-Phosphorus Concentrations in the North Basin (0300204) of Green Lake in 1979

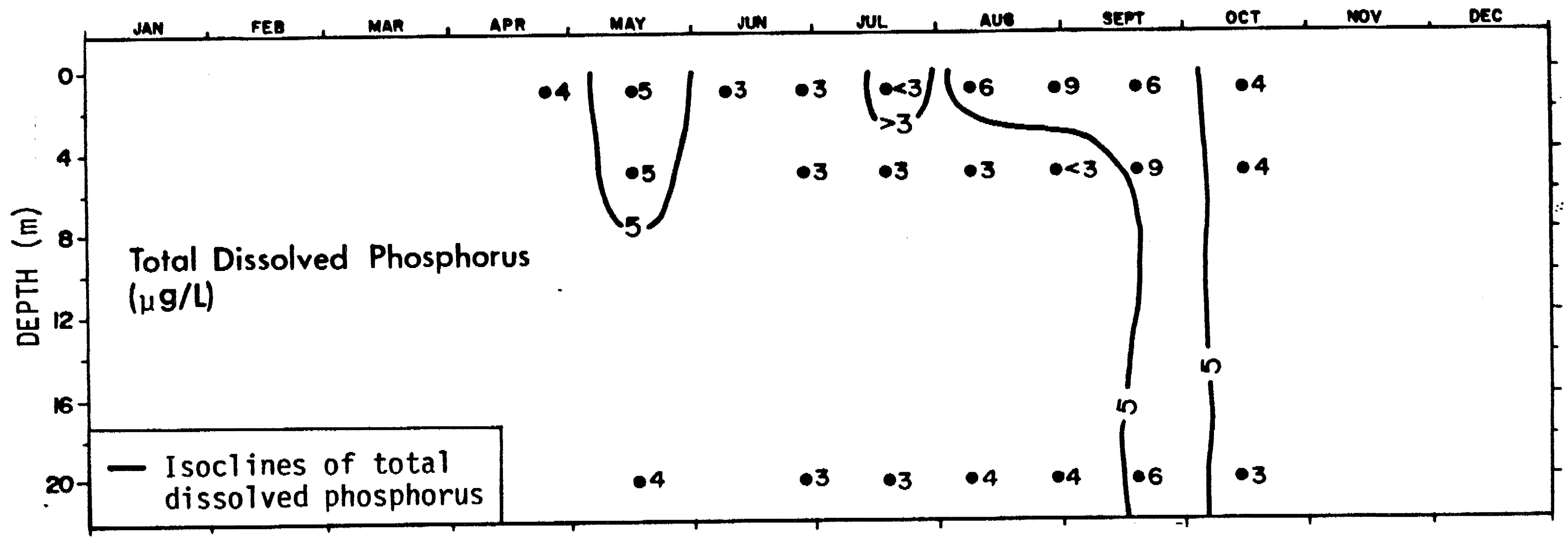

FIGURE 21: Total Dissolved Phosphorus Concentrations in the North Basin (0300204) of Green Lake in 1979

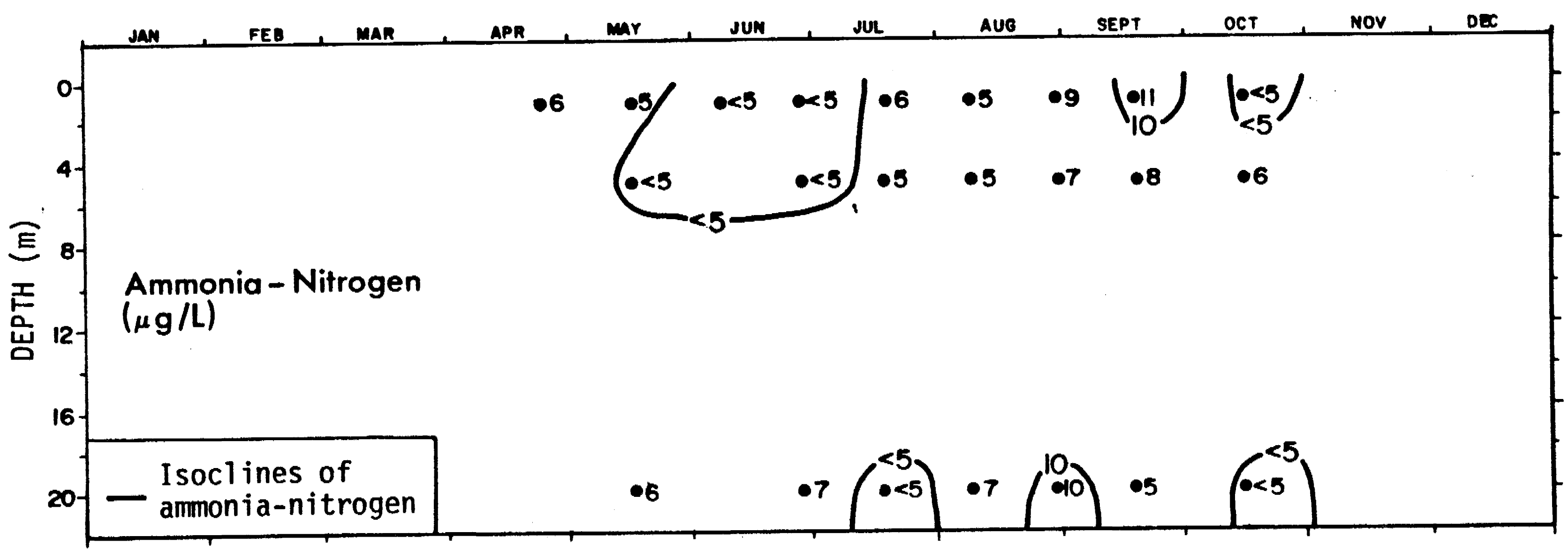

FIGURE 22: Ammonia-Nitrogen Concentrations for the North Basin (0300204) of Green Lake in 1979

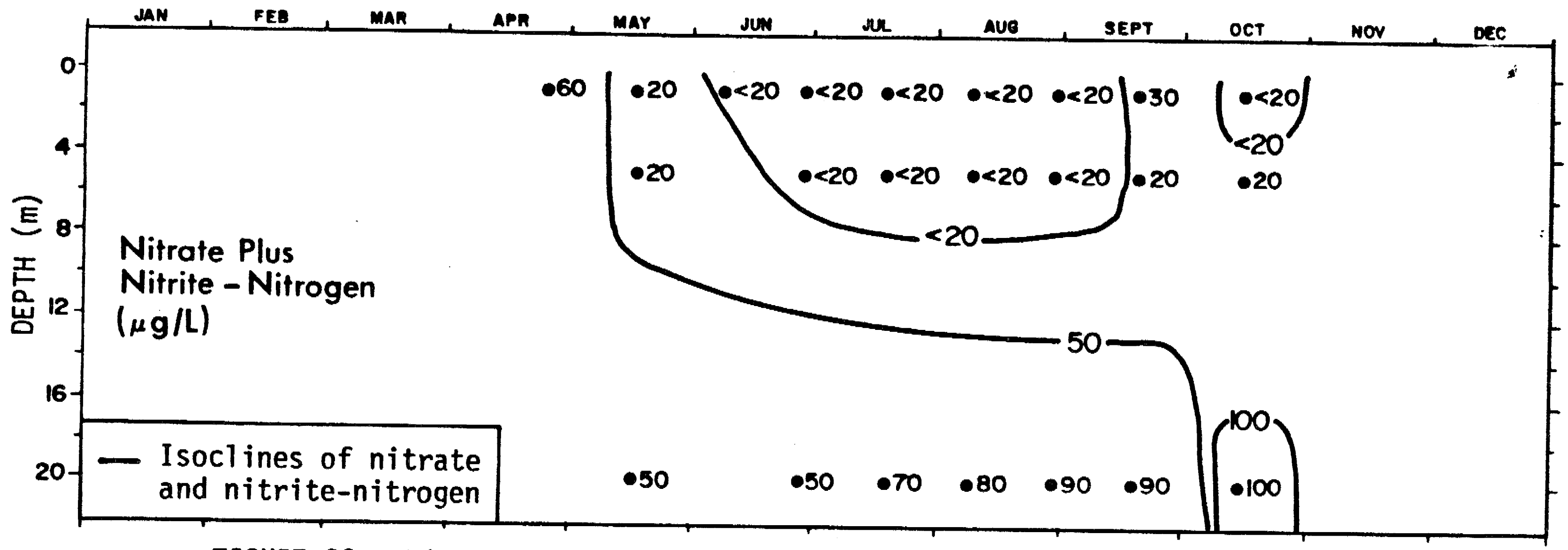

FIGURE 23: Nitrate and Nitrite-Nitrogen Concentrations for the North Basin (0300204) of Green Lake in 1979

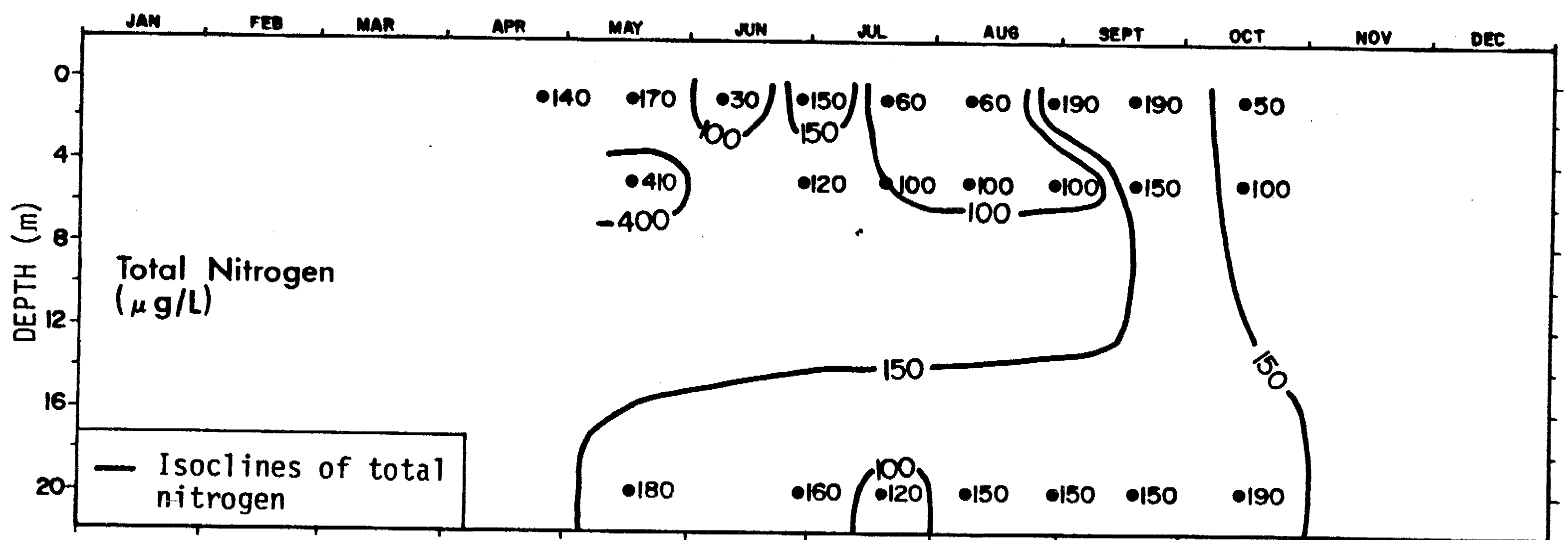

FIGURE 24: Total Nitrogen Concentrations for the North Basin (0300204) of Green Lake in 1979

3.6 NUTRIENT LOADING

Two models were used to estimate the lake's annual phosphorus loading rate (Table 10).

The two models estimated the phosphorus loading rate at approximately 1.0 $g/m^2/yr$. Using the modified Vollenweider model (Rast and Lee, 1978), the permissible annual phosphorus loading rate for Green Lake was estimated at 1.9 $g/m^2/yr$ (Figure 25). If Green Lake were at the theoretically 'permissible loading rate', the lake would be considered midway between the oligotrophic and eutrophic status (mesotrophy). Both the Reckhow and Simpson, and Dillon and Rigler equations establish that the 1979 loading rate was far below the permissible levels recommended by Vollenweider. From these calculations, Green Lake would be able to withstand as much as a 40 percent increase in the present phosphorus loading rate without noticeable change from its present oligotrophic status.

TABLE 10

Calculation of Phosphorus Loading Rate for Green Lake

Model	Equation	Estimated Loading Rate ($g/m^2/yr$)	Estimated Annual Loading (kg.)
Dillon and Rigler (1975)	$P = \frac{L}{q_s}(1-R_{exp})$	0.97	1989
Reckhow and Simpson (1981)	$P = \frac{L}{11.6 + 1.2 q_s}$	1.04	2132

Notes:

R_{exp} = Expected phosphorus sedimentation rate calculated from Larsen and Mercier (1976) = 0.166

q_s = surface overflow rate

$q_s = Z/\tau$ $\qquad q_s$ = 128 m/yr

Z = mean depth (14.23 m)
τ = hydraulic detention time (0.111 yr)
L = annual areal phosphorus loading ($g/m^2/yr$)
P = lake phosphorus concentration (mg/L) at spring overturn

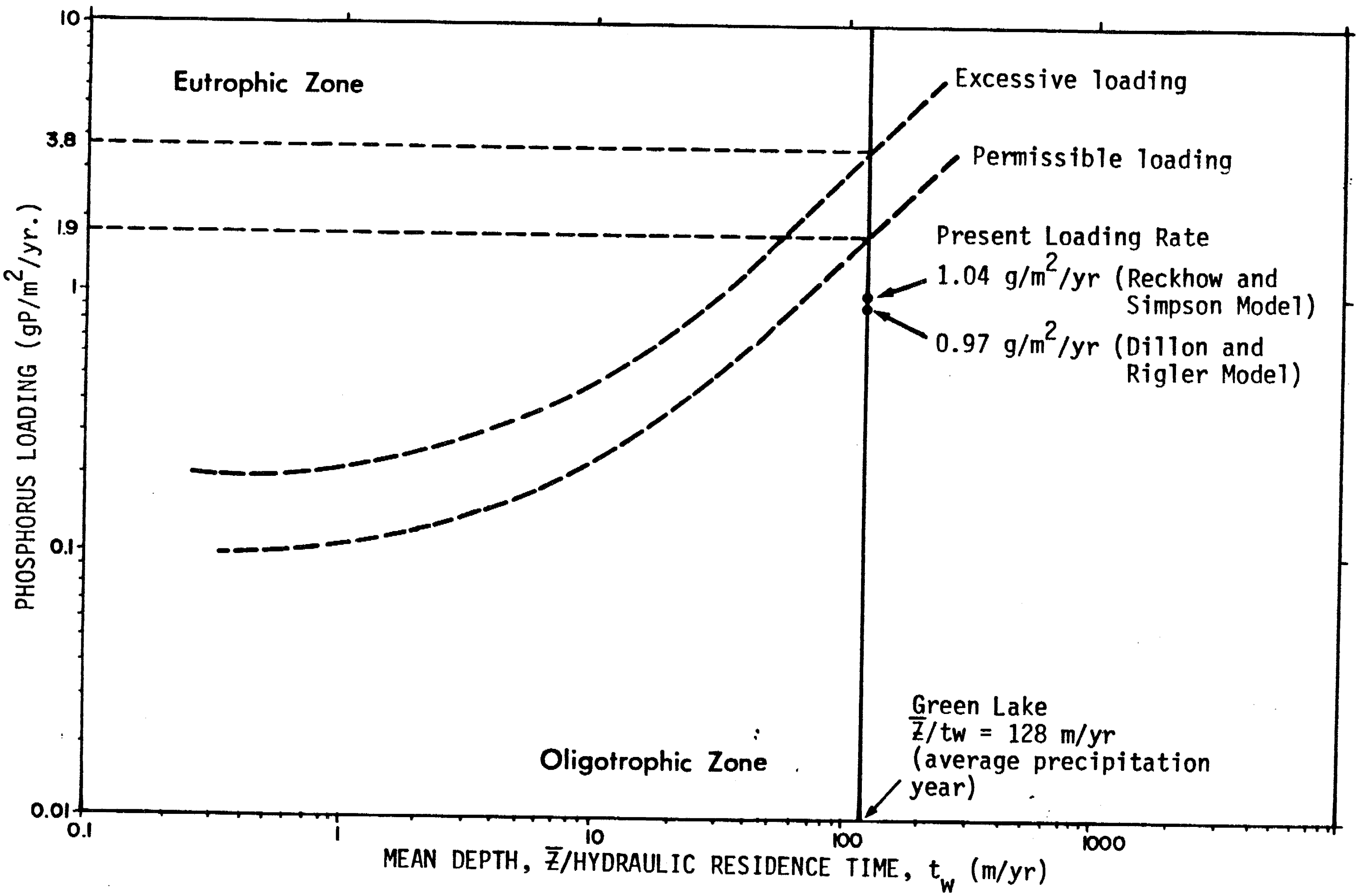

FIGURE 25: Modified Vollenweider Phosphorus Loading and Mean Depth/ Hydraulic Residence Time Relationship for Green Lake in 1979

The major source of phosphorus originates from Fitzsimmons Glacier. Other sources and their proportion of the total annual loading can not be accurately calculated from the present data base. Stream flow calculations for the three major inflows are required before the total stream loading can be calculated.

Other sources of phosphorus include dust fall, precipitation, septic tanks, and the land disturbance associated with the ski operations.

3.6.1 SEPTIC TANKS

To calculate the annual input of nutrients from sewage disposal a series of calculations and assumptions are required. The method of the loading calculations, and the basis for all assumptions were defined by Dr. J.H. Wiens of the Terrestrial Studies Branch, Ministry of Environment.

Table 11 lists the number of houses in each soil type and the distance the lot is from the lake shore.

TABLE 11

Number of Developed and Undeveloped Lots Around Green Lake in 1981 as a Function of Distance From the Lake

Distance From Lake (m)	Soil Group 1		Soil Group 2		Totals
	Number of Developed Lots	Number of Undeveloped Lots	Number of Developed Lots	Number of Undeveloped Lots	
0-60	25	21	0	0	46
60-120	62	11	3	4	80
>120	88	46	39	38	211
Totals	175	78	42	42	337

The parent material of soil group 1 is gravelly alluvial fan, and minor glacial outwash (soil type 1, Figure 5). It is classified as an orthic humo-ferric podzol with good to rapid drainage. Soil group 2 is shallow (50 cm) stoney, gravelly colluvium, and glacial till over bedrock, with some exposed bedrock and minor basal till (soil types 8, 9, 10, Figure 5). It is classified as a orthic humo-ferric podzol with some bedrock or lithic folisol and rapid to moderately good drainage.

Nutrient loading assumptions were:

1) 5 g total phosphorus per person per day
2) 17 g total nitrogen per person per day

Both the nitrogen and phosphorus loading rates are within the ranges quoted by several researchers. The range of phosphorus loading is 3-5 grams (g) per person per day, and nitrogen is 6-17 g per person per day. The maximum values quoted were used to estimate the maximum possible effect of septic discharge on the lake.

Not all of the nitrogen and phosphorus discharged by a septic tank will reach the lake. Soils and plants can intercept the nutrients as they travel toward the lake. Phosphorus transfer coefficients are highly dependent on both the type of soil and the distance the septic tank is located from the lake. Nitrogen transfer coefficients are constant as they are not affected by the soil type or the distance zone.

The transfer coefficients used to calculate the nutrient loading to Green Lake are summarized in Table 13.

Based on the number of houses in each distance zone, and the occupancy assumptions listed below, the annual phosphorus and nitrogen loadings from septic tanks to groundwater are listed in Table 12.

Present loading rates are calculated from lots that are developed. Potential loadings assume all the lots in each soil group are developed.

Occupancy assumptions were:

1) 50 percent of the developed lots occupied full time with 3 persons/household.
2) 50 percent of the developed lots occupied 4 months/yr with 4 persons/household.

TABLE 12

Nutrient Loading from Septic Tanks to Groundwater

Soil Group 1

Distance Zone (m)	Present Phosphorus Loading (kg/yr)	Present Nitrogen Loading (kg/yr)	Potential Phosphorus Loading (kg/yr)	Potential Nitrogen Loading (kg/yr)
0-60	98	335	181	615
60-120	244	830	287	977
>120	347	1178	527	1794
Total	689	2343	995	3386

Soil Group 2

Distance Zone (m)	Present Phosphorus Loading (kg/yr)	Present Nitrogen Loading (kg/yr)	Potential Phosphorus Loading (kg/yr)	Potential Nitrogen Loading (kg/yr)
0-60	0	0	0	0
60-120	12	40	28	94
>120	153	522	303	1030
Total	165	562	331	1124

TABLE 13

Nutrient Transmission Coefficients as a Function of Soil Group and Distance of the Discharge from the Lake

Distance From Lake (m)	Soil Group 1		Soil Group 2	
	Phosphorus Transmission Coefficient	Nitrogen Transmission Coefficient	Phosphorus Transmission Coefficient	Nitrogen Transmission Coefficient
0-60	0.30	0.72	0.45	0.72
60-120	0.20	0.72	0.30	0.72
>120	0.10	0.72	0.15	0.72

By multiplying the transfer coefficient by the loading values in Table 12, the mass of nutrients reaching Green Lake can be estimated. These estimates are presented in Table 14.

For the purpose of this report, the nutrient loadings from septic tanks will be assumed to cause the maximum possible effect on the lake. The phosphorus loading in 1981 was 130 kg. This value will increase to 200 kg per year when all the lots are developed. Nitrogen loading was much higher at 2090 kg in 1981 with a maximum potential of 3250 kg per annum.

The impact of these additional nutrient loadings are discussed on pages 49 and 53.

TABLE 14

Estimated Nutrient Loading from Septic Tanks Entering Green Lake

Soil Group 1 Distance Zone (m)	Estimated Phosphorus Loading to Lake in 1981 (kg)	Estimated Nitrogen Loading to Lake in 1981 (kg)	Potential Phosphorus Loading to Lake (kg)	Potential Nitrogen Loading to Lake (kg)
0-60	29	241	54	443
60-120	49	598	57	703
>120	35	848	53	1291
Subtotal	113	1687	164	2437

Soil Group 2 Distance Zone (m)	Estimated Phosphorus Loading to Lake in 1981 (kg)	Estimated Nitrogen Loading to Lake in 1981 (kg)	Potential Phosphorus Loading to Lake (kg)	Potential Nitrogen Loading to Lake (kg)
0-60	0	0	0	0
60-120	2	29	6	68
>120	15	376	30	742
Subtotal	17	405	36	813

Column Total (Soil Group 1 Plus Soil Group 2)	130	2092	200	3250

3.6.2 SKI OPERATIONS

Although effects of ski operations on the water quality of Fitzsimmons Creek were not assessed, previous work by Gosz (1977) indicates ski operations, including sewage disposal, have little effect on the nitrogen loading to streams. Phosphorus was not included in the study. The only major factor affecting water quality was application of road salt.

3.6.3 DUSTFALL AND PRECIPITATION

Preliminary work done by the Aquatic Studies Branch and others (e.g. Murphy and Doskey, 1975; Kuntz, 1978) on the nutrient loading from dustfall and precipitation indicates that the loadings can be significant on an annual basis, particularly if the area is in the airshed of an industrial operation (e.g. the Howe Sound pulp mills).

Snowfall for Green Lake averages 5.43 m (B.C. Ministry of Agriculture, 1970) which is equivalent to 54.3 cm of precipitation. Based on a lake area of 205 ha, approximately 1 118 000 m^3 of precipitation (as snowfall) will fall in an average winter. Assuming a phosphorus concentration in snowfall of 0.003 mg/L (Table 8), the average phosphorus input from snow would be 3.4 kg/yr. In general, 0.6 kg of phosphorus will be added to the lake for every metre of snow that falls during the winter.

Summer loading in the form of dustfall and direct precipitation is estimated from aerial phosphorus input (12.9 kg/km^2/month) at Brannen Lake (McKean _et al_., in prep.). Based on this input, 185 kg of phosphorus was added to Green Lake during April through October.

In total, the direct aerial input of phosphorus to Green Lake was approximately 190 kg/year.

3.6.4 SUMMARY OF PHOSPHORUS SOURCES

In the previous sections of this report, certain sources of nutrients were examined. The annual phosphorus load from these sources is summarized in Table 15.

Stream transport is believed to be the largest remaining source of phosphorus to the lake. The stream input of phosphorus was calculated by subtracting the volumes of phosphorus added from dustfall and septic tanks from the total phosphorus load estimated by the Dillon and Rigler and Reckhow and Simpson models. Based on the work of Gosz (1977), the phosphorus loading from ski associated activities was assumed to be negligible.

TABLE 15

Summary of Phosphorus Sources Entering Green Lake

Source	Amount of Phosphorus in kg/yr	Percent of Total
Stream Input (by difference)	1680	84
Dustfall	190	9.5
Sewage disposal	130	6.5
Total	2000	100

The largest source of phosphorus was stream input (84 percent). The high phosphorus concentrations recorded in Fitzsimmons Creek in July and August (Table 9) are associated with runoff from Fitzsimmons Glacier.

3.7 CHLOROPHYLL

Chlorophyll 'a' is a measure of the biomass of phytoplanktonic algae present in the lake. The chlorophyll concentrations in the main basin of Green Lake in 1979 are listed in Figure 26. Maximum concentrations of 3.9 µg/L were recorded in late August at the surface of the lake. In general, however, concentrations ranged from 1.0 µg/L to 3 µg/L. These concentrations are typical of oligotrophic lakes.

The algal populations in most lakes are limited by the nutrient concentrations in the water. In most lakes, phosphorus is the macronutrient most likely to be limiting the growth of algae during the summer months. For lakes with a nitrogen to phosphorus weight ratio greater than 15:1, phosphorus is the nutrient limiting algal growth. Algae growing in water with a nitrogen-phosphorus ratio less than 5:1 will be limited by the availability of nitrogen. Because Green Lake had a nitrogen-phosphorus ratio greater than 15:1 throughout most of the summer months (Table 16), the growth of algae was assumed to be limited by the availability of assimilable phosphorus.

The late summer nitrogen-phosphorus ratios dropped below 5:1 (Table 16). Consequently, the growth of the phytoplanktonic community was then theoretically limited by the availability of assimilable nitrogen. The presence of dissolved inorganic phosphorus (orthophosphorus) during this period supported the possibility of nitrogen limitation. However, the presence of high turbidity in the lake may also have limited phytoplankton growth, or may have been a factor interacting with nutrients to limit algal growth.

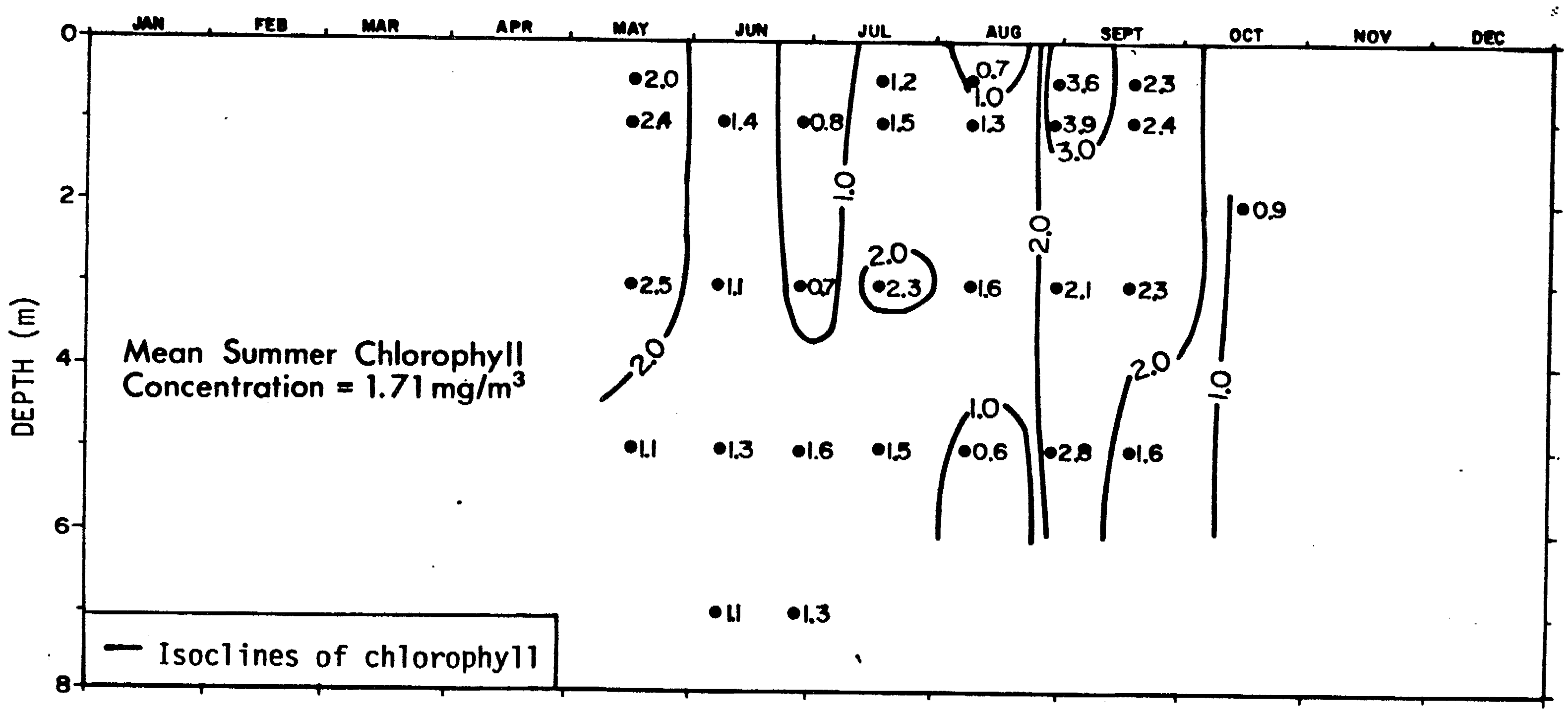

FIGURE 26: Chlorophyll Concentrations (mg/m^3) for the Main Basin (0300203) in 1979

TABLE 16

Nitrogen - Phosphorus Weight Ratios for Green Lake in 1979

Date	Nitrogen - Phosphorus Ratio at 0 m	Nitrogen - Phosphorus Ratio at 5 m
April 24, 1979	23:1	25:1
May 16, 1979	13:1	14:1
June 7, 1979	6:1	13:1
June 27, 1979	22:1	20:1
July 18, 1979	24:1	8:1
August 8, 1979	5:1	3:1
August 29, 1979	3:1	5:1
September 18, 1979	5:1	1:1
October 15, 1979	27:1	35:1

Several workers have established a direct positive relationship between the spring overturn phosphorus concentration and the mean summer chlorophyll 'a' concentration for phosphorus limited lakes. Nordin (in prep.) has developed a model for lakes within British Columbia (Figure 27). Based on the 1979 chlorophyll data, the general phosphorus-chlorophyll relationship slightly underestimates the actual chlorophyll 'a' in Green Lake. This may be due to the periods of nitrogen limitation of algal growth.

Using the slope of the general phosphorus-chlorophyll relationship and applying it to Green Lake, the chlorophyll 'a' concentrations can be predicted for different spring overturn phosphorus concentrations (assuming phosphorus limitation). According to Dillon and Rigler (1975) an optimum mean summer chlorophyll concentration ranges from 1.5 μg/L to 2.5 μg/L.

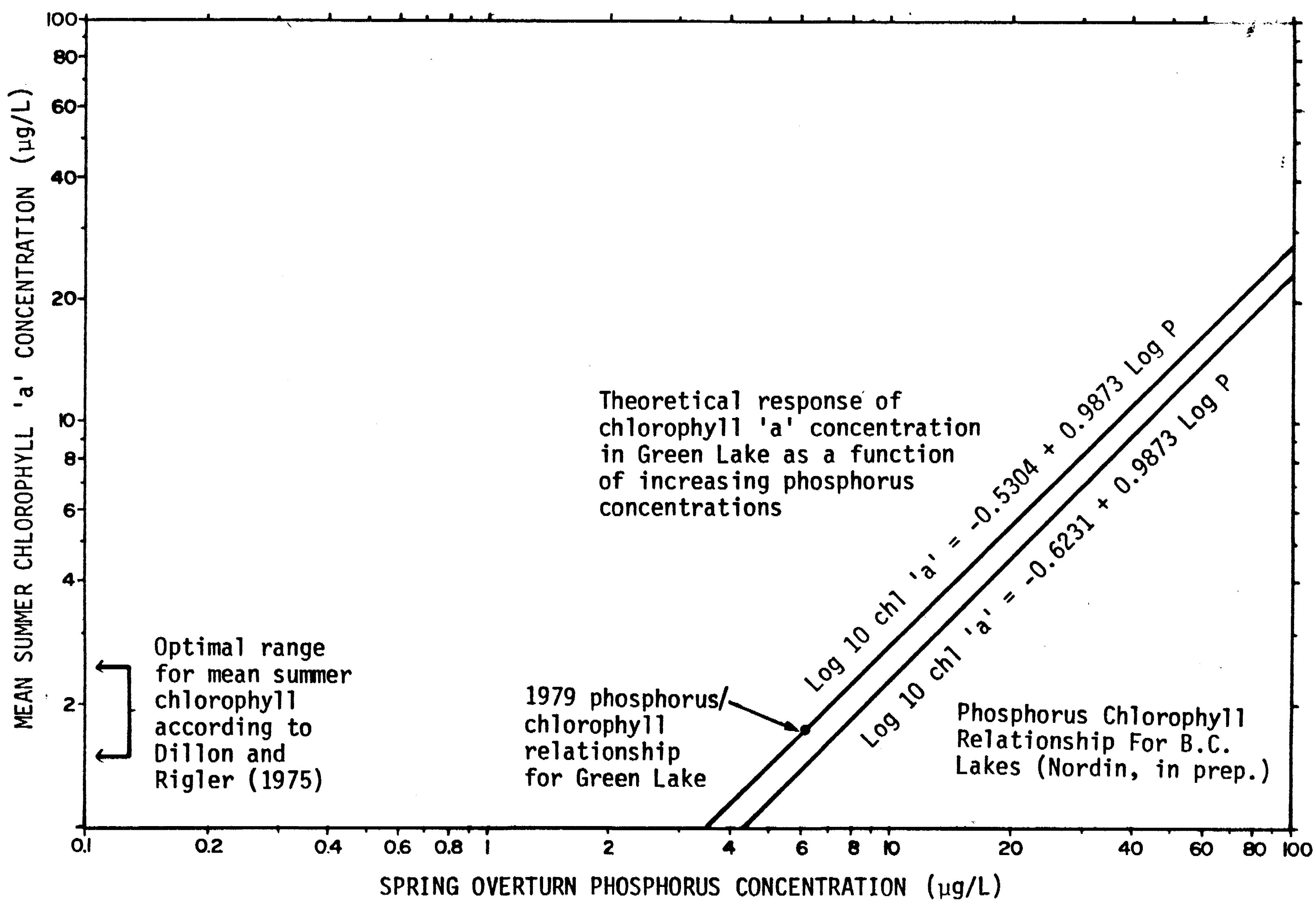

FIGURE 27: Relationship Between Mean Summer Chlorophyll Concentration and Spring Overturn Phosphorus Concentration for Green Lake

In order to maintain the chlorophyll 'a' concentrations within the optimum range, the spring overturn phosphorus concentration should not exceed 9 µg/L. Using the Dillon and Rigler model discussed in the previous section, the annual phosphorus loading can increase by 850 kg/yr before the spring overturn phosphorus concentration would theoretically exceed 9 µg/L.

4. PLANKTON AND AQUATIC MACROPHYTES

Samples were taken through 1979 to identify the major species of the phytoplankton and zooplankton communities, the successional pattern, and the numbers.

4.1 PHYTOPLANKTON

The phytoplankton are of interest since many species are indicative of certain water quality conditions and represent a record which can be used as a point of reference for future sampling. Examination of phytoplankton species is also useful to determine if any problems with regard to drinking water suitability or other consumptive use of the lake water might be encountered (e.g. taste and odours in domestic water).

Phytoplankton numbers were highest in April and May (300-700 cells/mL). During this period the highest chlorophyll values were obtained. The dominant species during April and May were Dinobryon (a chrysophyte) Rhizosolenia and Asterionella (diatoms) and Chlamydomonas (a green flagellate).

During the summer, phytoplankton numbers were low (18-48 cells per mL) with Asterionella and Dinobryon dominating. An increase in July (295 cells per mL) was composed almost entirely of three species of Dinobryon. Samples in August, September and October indicated very low numbers of phytoplankton (8-35 cells/mL) dominated by Asterionella (early August), Chroomonas, (a cryptomonad flagellate) and Oscillatoria (a blue-green) (Table 17).

TABLE 17

Dominant Phytoplankton Species of Green Lake in 1979

Date	Total number cells/mL	Dominant Species	Percent of Total
April 24, 1979	695	Dinobyron sertularia	24%
		Rhizosolenia eriensis	23%
		Chlamydomonas sp.	20%
		Chroomonas	17%
		Asterionella formosa	10%
		Phormidium sp.	4%
		15 species total	
May 16, 1979	340	Rhizosolenia eriensis	58%
		Asterionella formosa	20%
		Chroomonas sp.	14%
		10 species total	
June 7, 1979	19	Asterionella formosa	58%
		Chroomonas	12%
		21 species total	
June 27, 1979	48	Dinobryon bavaricum	57%
		Asterionella formosa	36%
		21 species total	
July 18, 1979	295	Dinobryon bavaricum	74%
		D. sertularia	14%
		D. divergens	10%
		12 species total	
August 8, 1979	35	Asterionella formosa	66%
		20 species total	
August 29, 1979	25	Chroomonas	90%
		17 species total	
September 18, 1979	8	Oscillatoria	58%
		Chroomonas	25%
		18 species total	
October 15, 1979	8	Chroomonas	65%

The phytoplankton are in very low numbers and would not be expected to cause any problems with drinking water or aesthetics. The low numbers indicate a very unproductive condition (oligotrophy), and are in basic agreement with chlorophyll 'a' results. The community is composed of a very diverse group of algae, many species of which reflect the very low nutrient concentrations in the lake.

The succession pattern, with highest numbers of phytoplankton only in April and May is typical of oligotrophic lakes, where algal growth is high only as long as nutrients are available. With the exhaustion of nutrient supply, phytoplankton are present only in low numbers, and species which can take up nutrients at very low concentrations are present. Another factor limiting phytoplankton growth is the input of colloidal suspended sediment ("glacial flour"). These finely divided particles impart the "milky blue" colour to the lake during July through October and may be a major factor in limiting algal growth during the summer.

4.2 ZOOPLANKTON

The zooplankton are important as a food source for juvenile fish and as an intermediate in the aquatic food chain. Only three samples were taken during 1979 (May, June and August). Rotifers (Kellicottia and Keratella were present in all three samples. The copepod Cyclops was present in both June and August in small numbers (19-26 organisms per m^3). In August the highest numbers of zooplankters were present, with two species of Daphnia (longiremus and rosea) being present in appreciable numbers (370/m^3). However, because of the limited sampling, very little is known of either the patterns of growth or the maximum or minimum numbers during the year.

Additional detail with regard to identification and number of both zooplankton and phytoplankton can be obtained by requesting a retrieval from site 0300203 from the B.C. Ministry of Environment EQUIS biological data file.

4.3 MACROPHYTES

The aquatic macrophyte community was surveyed in 1978 by Dr. P. Warrington, Ministry of Environment. A species list of the macrophyte community is summarized in Table 18.

TABLE 18

Species List of Macrophytes Collected from Green Lake

Callitriche hermaphroditic
Callitriche heterophylla
Equisetum fluviatile
Hipporis vulgaris
Myrica gale
Myriophyllum exalbenscens
Myriophyllum verticillatum
Potamogeton amplifolius
Potamogeton gramineus
Potamogeton pectinatus
Ranunculus aquatilus
Ranunculus sceleratus
Sparganium emersum
Utricularia vulgaris

The macrophytes are located sparsely throughout the lake, with the largest populations on the sill separating the north and south basins.

Macrophytes have been noted to release phosphorus and nitrogen to the water column (Tilley *et al*., 1977). Muztar *et al*., (1978) reported elevated nitrogen and phosphorus lake water concentrations in macrophyte beds.

In accordance with the findings of Tilley et al., (1977) and Muztar et al., (1978), the aquatic macrophytes in Green Lake are expected to release some nitrogen and phosphorus into the water column. Consequently, a higher biomass of periphyton and phytoplankton are expected in and around macrophyte beds.

The impact of macrophytes on the lake's periphyton, phytoplankton and overall general water quality is expected to be low, however, because of the sparse macrophyte community. If large increases in the macrophyte community occur, the impact on the lake's water quality will increase.

4.4 PERIPHYTON

No lake periphyton were sampled, but some noticeable growth was observed during the summer below the lake outlet in the Green River. George Gough (pers. comm.) made collections and noted that the dominant genera were *Zygnema*, *Ulothrix*, *Oedogonium* and *Melosira*. The visible growth covered (at maximum) about 10% of the stream bed with clusters and long strands of green filaments. The predominant species (*Zygnema*, *Ulothrix*) are typical of cold, low productivity streams, consistent with the other biological indicators of the lake system.

5. DISCUSSION

Green Lake has had some development in its watershed and more development will occur in the near future, particularly in the Emerald Estates subdivision. Such developments might cause deterioration of water quality in Green Lake by input of nutrients from septic tank-tile field sewage disposal systems. Any lake with low nutrient content is particularly susceptible to increased nutrient input, since small incremental increases tend to have disproportionately larger effects. This is partially a consequence of a logarithmic relationship between loading and algal growth (see Figure 27). Consequently, minimization of nutrients should be a priority at Green Lake.

There are two inherent characteristics of Green Lake which tend to protect the water quality, and at present perhaps reduce the amount of algal growth from what might be expected under normal conditions. The input of large amounts of fine suspended particulate matter, largely of glacial origin, may cause light limitation, or partial light limitation of algal growth in the July through September period. It may be a co-limiting factor with nitrogen during this period since there are concentrations of available phosphorus in the water. A second important factor is the large volume of water passing through the lake (an equivalent of nine times the lake volume per year). It is difficult to separate all of the factors which control algal growth (nitrogen, phosphorus, water residence time, light penetration, mixing depth, zooplankton grazing) and indicate, in any one year, which factors appear to be the dominant ones. The 1979 sampling year is certainly not definitive.

It may be reasonable in this case to assume that nutrients are the limiting factor. They certainly are for part of the year (April, May and June). On this basis some consideration can be made of the effect of additional nutrient loading on algal growth and water clarity of the lake with the use of the general relationship outlined in Figure 27.

The present nutrient loading to the lake (Table 15) is very high, largely as a consequence of the high inflow volume and high concentration of suspended sediments from Fitzsimmons Creek. However, the two major factors controlling algal growth (nutrient loading and flushing rate) tend to counteract each other. This is reflected in the Vollenweider curve shown in Figure 25. Lakes with very high flushing rates tend to be able to accept very high nutrient loads without displaying symptoms of eutrophy. Thus Green Lake has some protection against developments in the watershed which would increase the nutrient loading to the lake. As added protection, for at least part of the growing season, algal growth would be limited by low light penetration into the water. This would preclude any nuisance algal growth during part of the summer, even if other factors were favourable for growth.

Green Lake would be maintained within the permissible phosphorus loading rate outlined on pages 36-38, so long as no more than an additional 850 kg of phosphorus were added per year.

Based on the domestic nutrient loading assumptions outlined on pages 38-43, a house within the 0-60 m distance zone of soil group 1 (page 39) will add an estimated 1.2 kg of phosphorus per year. Because of the greater distance from the lake, developed lots 60-120 m and >120 m from the lake will add 0.8 kg/yr, and 0.4 kg/yr respectively. In summary, the expected phosphorus loading from individual houses in soil type 1 are as follows:

0-60 m - 1.2 kg/yr
60-120 m - 0.8 kg/yr
>120 m - 0.4 ky/yr

So far, only the developments with soil type 1 have been addressed. Soil type 2 is less suitable for septic tanks. Housing units within this soil will have the following estimated loading values:

0-60 m - 1.75 kg/yr
60-120 m - 1.2 kg/yr
>120 m - 0.6 kg/yr

Consequently, if planners within the municipality keep a record of the potential loading from new developments in order that the maximum loading of 850 kg/yr of phosphorus is not exceeded, the lake in general would not be expected to experience eutrophication problems. However, it is difficult to guarantee that minor local problems might not occur. Such problems could be, for example, attached algal growth in shore areas which are subjected to higher loadings because of converging ground water flows, or other situations which might compound several small factors.

This estimate is based on the number of developed lots in Table 11. Additional development within Emerald Estates must be considered as new development.

An additional study of the lake should be initiated when the phosphorus loading from new developments approaches 850 kg/yr.

Finally, any apparent evidence which indicates that the expected effect of development in the watershed would be minor should be tempered with the fact that scientific understanding of lake processes governing productivity is in a very early stage of development. Green Lake is a lake type (alpine) on which a relatively small amount of information exists, and this report, being based on one complete year of sampling, is minimal for this level of understanding. In spite of these limitations, the interpretation of the data collected leads to the conclusion that a reasonable amount of development should not adversely affect the water quality of Green Lake if prudent precautions, as outlined by Wiens and Epp, (1982), are taken during the development of the watershed, and lake foreshore.

6. REFERENCES CITED

American Public Health Association. 1971. Standard Methods for the Examination of Water and Wastewater. 13th edition. American Public Health Association, Washington, D.C. 20036.

British Columbia Department of Agriculture. 1970. Climatic Normals, Tables of Temperatures and Precipitation 1941-1970. Department of Agriculture, Province of British Columbia.

British Columbia Ministry of Health. 1969. Recommended Water Quality Standards. Department of Health Services and Hospital Insurance. Province of British Columbia, Victoria, B.C. 1969.

Dillon, P.J. and Rigler, F.H. 1975. A simple method for predicting the capacity of a lake for development based on lake trophic status. J. Fish. Res. Bd. Can. 32:1519-1531.

Gosz, J.R. 1977. Effects of ski area development and use on stream water quality of the Santa Fe Basin, New Mexico. Forest Science 23(2):167-179.

Gough, G. pers. comm. 1982. Regional Biologist, Waste Management Branch, Surrey, B.C.

Kuntz, K.W. 1978. Atmospheric bulk precipitation in the Lake Erie basin. Water Quality Branch, Burlington, Ontario. Inland Waters Directorate, Ontario Region, Environment Canada Report Series No. 56.

Larsen, D.P. and Mercier, H.T. 1976. Phosphorus Retention Capacity of Lakes. J. Fish. Res. Bd. Can. 33:1742-1750.

Luttmerding, H.A. 1971. Soils Survey of the Alta Lake Area. Soils Discussion, B.C. Ministry of Agriculture.

McKean, C.J.P., R.N. Nordin and I.T. Boyd. (in prep.). Water Quality of Brannen Lake. B.C. Ministry of Environment, Aquatic Studies Branch, Victoria.

Murphy, T.J. and Doskey, P.V. 1975. Inputs of Phosphorus from Precipitation to Lake Michigan. Environmental Research Laboratory, Office of Research and Development, Environmental Protection Agency, Duluth, Minnesota 55804. EPA-600/3-75-005.

Muztar, A.J., S.J. Slinger, and J.H. Burton. 1978. Chemical Composition of Aquatic Macrophytes III. Mineral Composition of Freshwater Macrophytes and their Potential for Mineral Nutrient Removed from Lake Water. Can. J. Plant Sci. 58: 851-862.

Nordin, R.N. (in prep). Limnology and Water Quality of Shawnigan Lake. Aquatic Studies Branch, B.C. Ministry of Environment.

Rast, W. and G.F. Lee. 1978. Summary Analysis of the North American (U.S. Portion) OECD Eutrophication Project: Nutrient Loading - Lake Response Relationships and Trophic State Indicies. Office of Research and Development, E.P.A. Corvallis, Oregon 97330. Report Number EPA-600/3-78-088.

Reckhow, K.H. and Simpson, J.T. 1980. A procedure using modelling and error analysis for the prediction of lake phosphorus concentration from land use information. Can. J. Fish. Aquat. Sci. 37:1439-1448.

Squamish River Estuary Management Study, Air and Water Quality Final Report. 1981. Co-published by Government of Canada and Province of British Columbia. ISBN 0-7719-8536-3.

Tilley, R.R., M.M. Brinson and G.J. Davis. 1977. Phosphorus absorption, translocation and secretion in *Nuphar luteum*. Limnol. and Oceanogr. 22(6):1022-1032.

Wiens, J.H. 1981. Soils Specialist, Terrestrial Studies Branch, Ministry of Environment, Province of British Columbia.

Wiens, J.H. and Epp. P.F. 1982. A Review of Soils and Lot Conditions for Onsite Waste Water Disposal at Emerald Lake Estates, Whistler, B.C. Terrestrial Studies Branch, Ministry of Environment, Province of British Columbia. Victoria, B.C.