MINISTRY OF ENVIRONMENT
PROVINCE OF BRITISH COLUMBIA

SKEENA, NASS AREA

KATHLYN, SEYMOUR, ROUND AND TYHEE LAKES: WATER QUALITY ASSESSMENT AND OBJECTIVES

TECHNICAL APPENDIX

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February 1985

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ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the personnel of the Regional District of Bulkley-Nechako, and the Regional Waste Management Branch office in Smithers for their assistance with the field work; Dr. J. Wiens (Waste Management Branch, Victoria) for his interpetations of the soils data; and R.J. Rocchini (Water Management Branch, Victoria) for his editorial commments.

1. INTRODUCTION

1.1 BACKGROUND

In October of 1981, Mr. W. Gilgan, the Planning Director for the Regional District of Bulkley-Nechako, requested that the Ministry of Environment study existing (baseline) water quality of certain lakes, and develop a monitoring program to determine changes in water quality. Also required were land-use studies around the lakes to establish soil types, drainage features, development density, and other relevant information needed to establish lake-shore management guidelines. This report attempts to answer these needs and suggest methods of improving and maintaining water quality to levels suitable for its designated use.

The major problem arising from a watershed development is an increased supply of nutrients, in the form of nitrogen and phosphorus, to the lake. This is a consequence of sewage disposal, soil disturbance, road building and vegetation removal. Increased nutrients generally lead to increased growth of algae, causing decreased water clarity. The most important parameter involved is phosphorus since it is usually the limiting nutrient for algal growth in a lake. Fortunately, the amount of phosphorus entering a lake can be controlled to a certain extent with the implementation of lake management techniques.

The studies of Kathlyn, Seymour, Round and Tyhee Lakes quantify the inputs of phosphorus from various sources (precipitation, septic tanks, and inflow streams), and determine the extent to which additional phosphorus (originating from new watershed development) could be tolerated by each lake without a serious decrease in water quality. Based on this information, appropriate land uses and population densities can be developed by the Regional District.

In addition to this analysis, the report considers the data collected from these lakes, and recommends water quality objectives for the four lakes to protect water uses.

1.2 METHODS

On January 25, 1982, sampling began on each of the four lakes. During the first trip, it was necessary to sample through the lake ice. Subsequent sampling trips were in ice-free conditions, and used either a float plane or boat. Sampling continued until November 1982.

Data collection was shared among personnel from the Water Management Branch of Victoria, the Waste Management Branch of Smithers, and the Regional District of Bulkley-Nechako based in Burns Lake.

Samples from the water column were obtained using an eight litre Van Dorn water sampler. Temperature and dissolved oxygen were measured using a YSI model 57 meter. The dissolved oxygen readings were calibrated on each lake with Winkler titrations. Chlorophyll samples were filtered and frozen shortly after collection. Phytoplankton samples were taken as unconcentrated surface samples at each lake on each sampling trip. All data collected in 1982 are presently stored on the EQUIS data storage system. All chemical and biological analyses were carried out by the Ministry of Environment's Environmental Laboratory located in Vancouver, B.C.

1.3 GENERAL LAKE CHARACTERISTICS

Figure 1 shows the location of each of the four lakes involved in this study. Kathlyn and Seymour Lakes are similar morphometrically. Both are small, shallow lakes with comparable volume (Figures 2 and 3). They have a relatively large surface area to depth ratio which facilitates increased wind mixing, and productivity (Rawson, 1956; Hutchinson, 1967; Koshinsky, 1970; Fee, 1979). Round and Tyhee Lakes are larger, and deeper (Figures 4 and 5). Morphometry of all lakes is summarized in Table 1.

All lakes drain into the Bulkley River which in turn joins the Skeena River at Hazelton. Bathymetric maps for each lake are provided in Figures 2 through 5.

2. HYDROLOGY

The Surface Water Section of the Water Management Branch, Ministry of Environment, calculated the average and 1981-1982 water input to the four lakes. The following is an excerpt from the analysis of the area's hydrology (Weiss, 1982).

2.1 AVAILABLE DATA

Of the four basins for which mean annual runoff estimates were required, only the Kathlyn Lake basin has a good hydrometric record. Data are available for the period 1967-79, although some data are missing, primarily during the winter season. Estimates of some of the missing data were made, based on either partial records or other available hydrometeorologic data (Table 2). Kathlyn Creek is reported by Water Survey of Canada as a natural streamflow, although according to a report by Seymour (1976), some flows from the Upper Kathlyn Creek area are diverted to Simpson Creek. However, the quantity of flow diverted seems to be low in comparison with the natural flow.

During a 1977 low flow monitoring program, a few discharge measurements were obtained on Seymour Creek and Victor Creek which is an inflow channel to Tyhee Lake. Unfortunately, these measurements are of little help when trying to make estimates of the total annual runoff because summer runoff contributes only a small portion of the year round flow.

2.2 METHODS

Mean annual inflow estimates were required for Kathlyn, Seymour, Tyhee, and Round Lakes.

The mean annual inflow to Kathlyn Lake was computed directly from data that were available for Kathlyn Creek at the outlet of Kathlyn Lake. Some estimates for missing data were made based on partial records or other available hydrometeorologic data.

No useful outflow data were available for the other lakes. Therefore, an attempt was made to find a relationship between mean annual runoff and several physiographic variables using data from nearby gauging stations. No distinct relationship between mean annual runoff and median basin elevation or basin drainage area could be found. The poorly defined relationships yielded highly variable estimates for mean annual inflow for the 3 lakes. For example, based on median basin elevation, the mean annual inflow estimate to Tyhee Lake was approximately 2 000 dam^3. Based on drainage area, the mean annual inflow estimate was approximately 12 000 dam^3.

2.3 RECOMMENDATIONS

Because no distinct relationship between mean annual runoff and physiographic variables could be found, it is recommended that a monitoring program be undertaken. The following gauging program would help to provide more reliable estimates of mean annual inflow to Seymour, Tyhee, and Round Lakes.

1. An automatic recorder should be installed on Tyhee Creek near the outlet of Tyhee Lake and outflow data should be collected for a minimum of one year.
2. Outflows from Seymour and Round Lakes should be monitored during the freshet, coincident with collection of data on Tyhee Creek. Manual river stage readings and several discharge measurements would be required to establish a rating curve.

3. Lake level data on Seymour, Tyhee, and Round Lakes should be obtained coincident with the operation of the streamflow gauges. Weekly readings during the freshet and monthly readings during the summer and winter months will suffice.
4. It would also be useful to monitor the Water Survey of Canada gauges on Kathlyn Creek and Kathlyn Lake for this period of record, coincident with collection of data on Seymour, Tyhee, and Round Lakes.

Once these data are available, the runoff values obtained can be compared with runoff from nearby gauging stations which have a longer period of record, and estimates of mean annual inflow can be made.

2.4 RUNOFF ESTIMATES

Although more data would be desirable, a range of runoff estimates based on the present information was calculated and is presented in Table 3.

Until better information is available, the average of the two runoff estimates for Seymour, Tyhee and Round Lake will be used.

The water retention time and the flushing rate are also shown in Table 3 as a maximum, minimum and a mean. Even though there is a range of possible values, two distinct lake groups appear. Kathlyn and Seymour have flushing rates of approximately once per year and Tyhee and Round Lakes have flushing rates of at most once every three years or longer. From the preliminary data, it therefore appears that flushing rates are significantly longer in Tyhee and Round Lakes than in Kathlyn or Seymour Lakes.

3. WATER USE

3.1 KATHLYN LAKE

Kathlyn Lake has the most water volume licenced of the four lakes studied. All licences on the lake are summarized in Table 4 and located on Figure 2. Licences on inflow creeks and the lake outflow are not included because of the absence of water quality data on the specific water bodies.

The Kathlyn Lake water licences are mainly domestic water licences concentrated on the north and south shores. Two minor irrigation and industrial licences also exist on the lake.

The licenced withdrawal of water totals 45.5 m^3/d for domestic use, and 475 m^3/d for industrial use. Irrigation licences total 1.7 dam^3/yr.

The Ministry of Forests holds the largest industrial licence (455 m^3/d) for firefighting. This licence is undoubtedly only used during the summer, and the actual daily consumption will vary depending on the forest fire activity. The other industrial licence is for domestic use by a motel. Again most of the daily consumption (23 m^3/d) would be during the summer recreation season. The irrigations licences are small. Both are used for lawn and garden watering.

Fisheries use of Kathlyn Lake is low. The regional Fish and Wildlife Branch reports light fishing pressure. Species present are rainbow and cutthroat trout, and several species of coarse fish (long nose sucker, pea mouth chubb, squaw fish, sculpin etc.). The lake was stocked in 1958 and 1959 with 4000 rainbow trout. There are no plans to rehabilitate the lake by removing the coarse fish and restocking the lake with sports fish.

Kathlyn Lake has a high recreation use by the residents of the Smithers area. The Ministry of Lands, Parks and Housing reported heavy use of the municipal beach area at the north east end of the lake (Dalziel, pers. comm.).

3.2 SEYMOUR LAKE

Seymour Lake has the largest number of water licences of the lakes studied. All licences are summarized by priority date in Table 5, and are located in Figure 3. All of the 26 licences are for the domestic use of 2.3 m^3/d. The maximum licenced withdrawal is 59 m^3/d.

Twenty of the water licences have a common point of withdrawal (AA on Figure 3). Of the remaining water licences, one is located at the south end of the lake, the rest are grouped at the northwest and east end.

The Fish and Wildlife regional office reports light fishing pressure in Seymour Lake. The lake contains rainbow and cutthroat trout, and coarse fish. Rainbow trout have been stocked from 1956 and 1959. Rehabilitation (removal of coarse fish) of the lake was planned for 1983, but it has been cancelled because of public opposition.

Seymour Lake is very close to the town of Smithers. Consequently, the lake receives heavy recreational use from the local residents. Recreational use is expected to increase as the population of the area increases. At present there are no developed beach areas. Access to the lake is from the road along the north end of the lake.

3.3 TYHEE LAKE

Tyhee Lake has 7 domestic, 1 waterworks and 1 industrial licence (Table 6). Total domestic (including waterworks) consumption is 43 m^3/d

and industrial consumption is 27 m^3/d. The industrial water licence (C 44560) supplies a trailer park with domestic water. The majority of the water licences are located on the east side of the lake (Figure 4).

Tyhee Lake receives moderate fishing pressure for pygmy whitefish, burbot, rainbow and cutthroat trout. The lake has been stocked intermittently from 1955. There were 40 000 and 50 000 rainbow trout fingerlings added in 1981 and 1983 respectively. The lake contains the same coarse fish as found in Kathlyn Lake. There are no plans at present by the Fish and Wildlife Branch to remove the coarse fish.

Tyhee Lake is used intensively for recreation by the local residents of the Smithers area. There is a Provincial Park beach area on the south west shore which is used for swimming and boating.

3.4 ROUND LAKE

Only two domestic licences and one waterworks licence are situated on Round Lake (Table 7; Figure 5). The maximum licenced withdrawal is 43 m^3/d. The water withdrawals are located on the south east shore, the north west shore, and the north end of the lake.

The Fish and Wildlife regional office reports a moderate fishing pressure on Round Lake. The lake contains rainbow and cutthroat trout, burbot, and coarse fish. The lake has been stocked with rainbow trout fingerlings since 1956. Recent stocking include 45 000 in 1981, 55 000 in 1982, and 50 000 in 1983. There are no plans for the removal of the coarse fish and restocking with rainbow trout.

Round Lake is used extensively for swimming and boating by the residents of the local community. Residents from the Smithers area are inclined to use the other lakes outlined in this report for recreation, because of the longer travelling distances to Round Lake (Dalziel, pers. comm.).

4. WASTE DISCHARGES

Around the four lakes, non-point nutrient discharges from agriculture and domestic septic tank tile fields are the only waste discharges. The impact of livestock on the nutrient concentrations of the inflow streams is considered in Section 5.9.2. The nutrient loading from the Smithers airport to Kathlyn Lake is also considered in Section 5.9.2. Nutrient loading from septic tanks is considered in detail in this section.

4.1 PHOSPHORUS LOADING FROM SEPTIC TANKS

Phosphorus input to each lake via septic tanks can be estimated using the procedures outlined by Wiens (1983b). Septic plumes can also be detected by the use of a fluorometer specially equipped to detect detergents in septic effluent. A fluorometer of this type was used on all four lakes. The results of the surveys are contained in a report by Suttie and Wiens (in prep.).

The phosphorus input from septic tanks for each watershed was estimated by counting the number of houses present, and applying an average discharge value of 5.5 kg/yr of phosphorus per home (Appendix 1). Phosphorus loading to Seymour, Tyhee, and Round Lakes from septic tanks was estimated by this method to be below 2 percent of the annual phosphorus budget. As a result, only Kathlyn Lake is considered further in this section.

Air photographs from 1980 were used to count the homes within the Kathlyn Lake watershed. A total of 56 houses were noted. Assuming year round occupancy, and a phosphorus loading rate of 5.5 kg/home/yr (1.83 kg/person/yr; 3 persons/house), residential development contributed 300 kg/yr of phosphorus into the Kathlyn Lake watershed. Not all the phosphorus discharged by septic tanks into the watershed will reach the lake since a good portion will be retained by soils in which the drainfields are located.

Dr. J. H. Wiens, of the Surveys and Resource Mapping Branch, estimated the percentage of the 300 kg/yr discharged by septic tanks that will be absorbed by soils, and the percentage that will reach the lake.

Table 8 summarizes the phosphorus loading data. The three soil types found around Kathlyn Lake were further divided into three distance zones around the lake. Listed in the table are the number of houses, the phosphorus transmission coefficients, and the estimated phosphorus input from septic tanks to the lake. In total, an estimated 28 kg/yr enters Kathlyn Lake via septic effluent. The impact of this loading on the water quality, and the lake's present eutrophic state is outlined in Section 7.2.1.

4.2 DETECTION OF SEPTIC TANK EFFLUENT

The littoral zones of each lake were analysed for septic inflows using a fluorometer modified to detect the whiteners and brighteners contained in washing detergents. The technique is described by Suttie and Wiens (1982), and is used to detect septic plumes in the lake. The results for each lake will be described in Suttie and Wiens (in prep.), but are briefly described below.

4.2.1 KATHLYN LAKE

Along the shoreline of Kathlyn Lake there were four areas of concern regarding possible septic effluent. The foreshore of four lots at the south west corner produced noticeably increased fluorescence. One additional lot at the south end was the site of a lesser increase.

The inflow from the airport area, on the southeast side of the lake produced an extreme increase in fluorescence.

The final noteworthy area was the developed shoreline on the east side of the lake, around the area of two stream inflows. In this area, foreshores of several lots showed high fluorescence, while the stream inflows once again produced high readings (sites 1131039, 1131040). This last area had weed growth along the shoreline, perhaps indicating enrichment of nutrients in the water and sediment. However, natural organics may have increased the readings as well.

4.2.2 SEYMOUR LAKE

The only noticeable increase in fluorescence on Seymour Lake was at the mouth of Upper Seymour Creek (site 1131041).

4.2.3 TYHEE LAKE

Unfortunately the results collected for Tyhee Lake are inconclusive. Consequently, no interpretation of septic tank effluent entering the lake is made.

4.2.4 ROUND LAKE

Natural organic substances in Round Lake had such an effect on fluorescence that the survey results are of questionable value for identifying septic tank inflows. However, the two stream inflows (Sites 1131044 and 1131045 Figure 4) caused large increases in fluorescence. One creek flowed through a cattle pen, the second flowed through farm fields. Runoff or leachate from these sources undoubtedly affected the fluorescence measurements.

4.3 SOIL SUITABILITY FOR SEPTIC TANKS

The suitability of the soils for septic tank tile fields was based on the soil's ability to adsorb phosphorus. The soils information presented in Appendix 1 has been condensed and ranked by the authors into four categories according to phosphorus adsorbing ability: excellent, good, moderate and poor. Figures 6 and 7 show the distribution of soils of each lake's watershed and the corresponding category for septic tank suitability.

The fluorescence surveys outlined in Section 4.2, indicate that the inflow creeks transport septic effluent to the lakes. Consequently, the recommended setbacks for developments (Section 7.3) should apply to not only the lake foreshores but the inflow creeks as well.

4.3.1 KATHLYN LAKE

The majority of soils around Kathlyn Lake are considered to have good capability for phosphorus adsorption. An area of minor concern is the Moricetown-Slug soils (M-SG) at the south and east shore of the lake (Figure 6). The 0-100 m zone is considered to have moderate suitability for septic tank drainfields. The moderate zone extends along the creek that runs through the area. The remaining area of the Morricetown-Slug soils is considered to have good suitability for septic tanks drainfields.

Around Kathlyn Lake there are several houses within the area designated as moderate suitability. Septic drainfields from new housing developments should be set back 100 m in this area.

4.3.2 SEYMOUR LAKE

Like Kathlyn Lake, the majority of soils around Seymour Lake are well-suited to adsorb phosphorus and renovate septic tank effluent (Figure 6). However, the areas containing the Barrett soils (BA) on the south shore, and the Ormond-Pinkut soils (OD-PT) on the west shore are considered to have poor suitability. It is recommended that new septic drainfield development be 300 m or more from the lake in these soil types.

4.3.3 TYHEE LAKE

The Tyhee Lake watershed has a more diverse range of soil conditions than the other lakes. The majority of the soil types are well suited to adsorb phosphorus from septic tank effluent (Figure 7). The north east and south west shoreline soils have moderate suitability to adsorb phosphorus. The soil types are the Slug-Barrett (SG-BA), Barrett-Alix (BA-AX), Barrett-Dahl (BA-DL), and Driftwood-Snodgrass (DD-SO) associations. Development of septic drainfields on these soil types should be restricted to a distance greater than 10 m from the lake.

The soil types considered to have poor suitability are the Stellako (SL) at the south end of the lake, and the Dahl-Barrett (DL-BA) soils in the upland area on the east side of the lake. Development in this area should be set back 300 m from the lake (this recommendation also holds for the unnamed lake in Dahl-Barrett soil type east of Tyhee Lake).

4.3.4 ROUND LAKE

Two soil types dominate the watershed of Round Lake, the Driftwood (DD) and the Barrett-Babine (BA-BE) associations (Figure 7). Both soil types are well suited for septic tank effluent. Consequently, no special building restrictions are recommended for the Round Lake watershed.

5. WATER QUALITY

5.1 TEMPERATURE

The ice usually left the lakes in late April. Following this, the sun began warming the surface waters, resulting in a decrease in density and a concomitant increase in thermal stratification. By late May or early June, the stratification was sufficient to physically isolate the epilimnion from the hypolimnion. The temperature gradient separating these two zones is termed the mesolimnion or thermocline. Figure 8 illustrates the stratified condition.

Maximum temperatures of between 17.0 and 18.4°C were achieved in mid-June (see Figures 9 through 11). Note that the shallower lakes (Kathlyn and Seymour) became the warmest. By mid-September cooling had eroded the thermocline and brought about the breakdown of stratification. At this point, the entire water column, was isothermal and free to mix. Wind can supply the required energy for this mixing which is called fall overturn.

By December the lakes were again frozen and thermally stratified under the ice. Water is most dense at 4°C. This water is found on the bottom during the winter with colder (yet less dense) water near the surface. Following break up of the ice in the spring, the surface waters were warmed until the density approximated that of the hypolimnion. At this point, spring overturn occurred and the period of summer stratification was repeated.

5.2 DISSOLVED OXYGEN

Ideally a lake should have sufficient dissolved oxygen throughout its water column to support various inhabitants (zooplankton, benthic invertebrates, fish, etc.). Within the epilimnion, the presence of oxygen-producing phytoplankton combined with the diffusion of oxygen across the air-water interface maintained dissolved oxygen concentrations at or above saturation levels.

The situation was different in the hypolimnion. During the period of summer stratification the concentration of epilimnetic phytoplankton was sufficiently high that almost all light was absorbed. Consequently, few phytoplankton exist in the hypolimnion. The lack of an oxygen source (i.e. photosynthesis), and the density gradient created by the thermocline which prevented mixing with well-oxygenated epilimnetic water, resulted in anoxic (no oxygen) conditions in the hypolimnion when organic matter suspended or dissolved in the water or on the bottom is decayed by oxygen-consuming microorganisms.

During the winter, the presence of ice and snow reduced the diffusion of oxygen across the air-water interface, and greatly attenuated the available light. As a result, the hypolimnion did not have any sources of oxygen during the winter. Consequently anoxic conditions persisted through the winter at the bottom of each lake.

Figures 12 through 14 illustrate the annual pattern of oxygen concentrations in the lakes. Note that the spring and fall overturns represent the only periods when oxygen was present throughout the entire water column.

5.3 SPECIFIC CONDUCTIVITY AND HARDNESS

Specific conductivity is a measure of the ability of water to conduct electricity. It is directly related to the dissolved solids content of the water. The specific conductance of Kathlyn and Seymour lakes was quite low (Table 9). The volcanic geology of the area, and the relatively high flushing rates would be the principal reasons for the low results. The hardness of water is expressed as the equivalent concentration of calcium carbonate. Usually calcium and magnesium represent the most prominent components of hardness. Calcium, which is usually in greater concentrations than magnesium, is dissolved (weathered or oxidized) very slowly from igneous and metamorphic rocks; thus water in contact with such rocks commonly carries low concentrations of calcium. Kathlyn and Seymour Lakes had sufficiently low concentrations of calcium and magnesium that their water should be considered soft (Table 9).

Tyhee and Round lakes had significantly higher specific conductivities, hardness and dissolved solids in the water (Table 10). Lower flushing rates and the influence of the calcareous Driftwood Soils on the east side of the lakes were likely responsible for the greater concentration of calcium which was, in turn, responsible for the moderately hard water in these two lakes.

5.4 TURBIDITY

Turbidity is an optical property of water expressed in nephelometric turbidity units (N.T.U.). All values except one (Tyhee Lake epilimnion) were low, which indicates relatively clear water (Tables 9 and 10).

Turbidity in lakes can be caused either by suspended inorganic solids entering the lake via the inflow streams, or by high concentrations of planktonic algae in the surface waters. In all the lakes, turbidity from inorganic solids (even during freshet) was low. Consequently the observed turbidity was caused by planktonic algae. Comparison of the data to the turbidity standard for domestic water supplies is contained in Section 7.1.

5.5 COLOUR

Colour in water results from the presence of dissolved organic matter or suspended solids. The breakdown of vegetative matter, particularly *Sphagnum* (peat moss), will release dissolved tannin and lignins into the water causing a brown colouration. High colour content will affect the suitability of the water for domestic drinking purposes (Section 7.1).

Seymour Lake had the highest colour results of the four lakes (50 T.C.U.) (Tables 9 and 10). The distinct brown colour of the lake was characteristic of dystrophic or bog lakes, although no *Sphagnum* was observed in the lake. The other lakes had much lower colour values (7-20 T.C.U.).

5.6 CARBON

Organic carbon is that which is incorporated into living (or once living) material. Kathlyn Lake exhibited an organic carbon concentration of 6 mg/L which is considered to be moderate. Seymour, Tyhee and Round lakes had organic carbon concentrations ranging from moderately high to high (7.33-14.0 mg/L) (Tables 9 and 10).

Inorganic carbon is that present as free carbon dioxide, bicarbonate and carbonate ions. Kathlyn and Seymour Lakes had concentrations of inorganic carbon which are considered to be low. Round and Tyhee Lakes contained high levels which are consistent with the hardness results outlined in Section 5.3. Based on the pH of the water, most of the inorganic carbon will be in the bicarbonate form (Wetzel, 1975).

5.7 TOTAL ALKALINITY

Alkalinity is a measure of the water's capacity to neutralize acid. This results from the ability of carbonate (CO_3) and bicarbonate (HCO_3) to absorb H+ ions (the product of acid dissociation in water). The greater the concentrations of carbonate and bicarbonate (high alkalinity) the greater the ability to neutralize acids. At the observed range of pH (6.5-8.7) the dominant forms of inorganic carbon would be the bicarbonate ion (HCO_3) and carbon dioxide (CO_2) (Wetzel, 1975).

The sensitivity of B.C. lakes to acid precipitation is being considered by Swain (pers. comm.). According to the classification system used by Swain, Kathlyn Lake with an alkalinity of 20 mg/L (Table 9) has a moderate sensitivity to acid precipitation. Seymour, Round and Tyhee Lakes have higher alkalinities (37, 120 and 140 mg/L respectivly) and are considered to have low sensitivity to acid precipitation.

5.8 METALS

Each lake was sampled for a limited number of metals in 1982 (Table 11). Most metals were below detectable limits. Lead was detected in small quantities, and was at or below the most sensitive criterion of 5 µg/L for aquatic life in soft water (Demayo et al., 1980).

5.9 NUTRIENTS

Eutrophication is the result of increased nutrient concentrations in a lake or reservoir, and the concomitant decrease in water quality. The main focus of this study was to evaluate the nutrients affecting water quality, temporal changes of nutrients, and the quantity and sources of nutrients entering the lake from the watershed. By understanding these processes, lake restoration methods can be designed to reduce the annual input of nutrients which will ultimately improve the overall quality of the water. Also, lake management guidelines (required for planning future lakeshore development) can be designed to minimize the effects of watershed development on water quality.

5.9.1 NUTRIENT LIMITATION

Other than light, nitrogen and phosphorus are usually the two key elements limiting plant growth. In the terrestrial and marine environments, nitrogen is usually limiting, while in freshwater systems phosphorus is usually limiting the growth of planktonic algae.

To confirm this assumption, investigations by Hutchinson (1957) and Forsberg and Ryding (1980), have compared the weight ratios of nitrogen and phosphorus present in the water. They have found that if the weight ratio of total nitrogen to total phosphorus in the lake or reservoir is 15:1 or greater, the plankton growth is limited by the availability of phosphorus.

However, if the ratio is 5:1 or less, the plankton are said to be in a nitrogen limiting environment. Table 12 summarizes the nitrogen-phosphorus weight ratios for all four lakes in 1982.

In all lakes, the weight ratio was usually greater than 15:1. In Round and Kathlyn Lakes some ratios below 15:1 were encountered, but during most of the summer and fall growing season, phosphorus was the nutrient limiting phytoplanktonic growth. Consequently, phosphorus will receive the main attention of this section.

5.9.2 PHOSPHORUS LOADING

The quantity (or loading) of phosphorus entering each lake can be approximated in two ways. The first involves the use of models which consider lake morphology, spring overturn phosphorus concentration and flushing rate. The second requires the identification of the sources of phosphorus and quantification of their annual input. This report considers both approaches.

5.9.2 a) Phosphorus Loading Models

There are two models commonly used for lake studies, the Reckhow and Simpson (1980) and the Dillon and Rigler (1975) models. The Dillon and Rigler model is not suited for shallow lakes with mean depths of less than 10 m (Kathlyn 4.6 m and Seymour 5.7 m). Secondly, the Dillon and Rigler model incorporates a phosphorus sedimentation coefficient which is not suited for lakes, like Round and Tyhee, that release phosphorus from the lake sediments. For these reasons, this report will use the Reckhow and Simpson model which does not have the limitations of the Dillon and Rigler model discussed above.

The Reckhow and Simpson (1980) formula is:

$$P = \frac{L}{11.6 + 1.2\, q_s}$$

where:

q_s = surface overflow rate, $q_s = Z/\tau$
Z = mean depth of the lake (m)
τ = hydraulic residence time(yr)
L = annual phosphorus loading ($g/m^2/yr$)
P = lake total phosphorus concentration (mg/L) at spring overturn.

The only unknown in the equation is L. To solve for L the formula is rewritten:

$L = P(11.6 + 1.2\, q_s)$

The Reckhow and Simpson model predicts that the annual phosphorus budget was approximately 560 kg for Kathlyn Lake, 885 kg for Seymour Lake, 890 kg for Tyhee Lake, and 1950 kg for Round Lake as shown in the table below.

PHOSPHORUS LOADING RATES
FOR THE STUDY LAKES IN 1982

	Spring Overturn Phosphorus Concentration (mg/L)	q_s (m/yr)	Estimated Areal Loading Rate ($g/m^2/yr$)	Estimated Total Annual Loading (kg)
Kathlyn Lake	0.020	4.0	0.33	560
Seymour Lake	0.052	6.2	0.99	885
Round Lake	0.070	3.1	1.07	1950
Tyhee Lake	0.020	2.2	0.28	890

These calculations are useful when comparing the importance of the individual phosphorus sources to the overall phosphorus budget of the lake. Section 4.1 compared the phosphorus input from septic tanks. This section estimates the magnitude of the other phosphorus sources (streams, agriculture and lake sediments) and compares them to the annual phosphorus budget calculated in the above table. Section 7.2 attempts to discuss the major phosphorus sources and outlines lake restoration methods designed to reduce the major sources of phosphorus.

5.9.2 b) Kathlyn Lake

Kathlyn Lake had low total phosphorus concentrations during the winter, spring, and fall with values ranging from 11 to 20 µg/L (Figure 15). The spring overturn total phosphorus concentration (early May) was 20 µg/L. During the summer, concentrations increased to maximum surface and bottom values of 43 and 66 µg/L, respectively, in late July. The constant increase in total phosphorus concentrations during the period when watershed runoff was occurring suggests that phosphorus loading resulted from the input of stream or surface water (Figure 15).

Ortho-phosphorus concentrations remained low in both the epilimnion and hypolimnion throughout the year. The low values observed at the sediment-water interface indicate that the release of phosphorus from anoxic sediments (common in eutrophic lakes; Vollenweider, 1976) was not occurring.

Nitrogen (Figure 16) can occur as nitrate, ammonia or organically bound nitrogen. Nitrate-nitrogen, was rarely detectable in both the surface and bottom waters from June through October (values for winter and spring are not available). Ammonia-nitrogen concentrations in the surface water were consistently below 25 µg/L, while bottom concentrations reached 300 µg/L during the summer anoxic period*. The high hypolimnion ammonia concentrations were oxidized to nitrate at fall overturn when oxygen was re-introduced into the bottom waters. Organic nitrogen was relatively stable, ranging from 250 to 370 µg/L in both the surface and bottom waters.

Normally, a great deal of stream flow and nutrient data are collected to understand the loading of phosphorus entering each lake. Unfortunately, poor hydrological records and insufficient sampling do not permit calculation in this case. There are sufficient data, however, to estimate the importance of phosphorus loading from streams for each watershed.

The nutrient data for all streams flowing into Kathlyn Lake are summarized in Table 13. The locations of the sampling sites are shown in Figure 2. Several obviously high phosphorus concentrations are observed in the data. The most obvious is the airport drainage area. This has been recognized in the past as a potential problem caused by the mixing of fire retardant on the runway (Hawthorn, 1976). The extent of the problem is severe as indicated by the extraordinarily high phosphorus concentrations occurring during freshet.

The area draining the airport is estimated at 500 000 m^2. Based on the hydrology data in Section 2, an estimated 0.25 m^3/m^2 of runoff will enter Kathlyn Lake in an average precipitation year from the airport area. Consequently, an estimated 125 000 m^3 of water will enter Kathlyn Lake from this area. If the average concentration of phosphorus of the airport runoff (site 1131037) is 2 mg/L (Table 13), then 250 kg of phosphorus is expected to enter Kathlyn Lake in an average precipitation year. This represent 45 percent of the annual phosphorus budget to the lake as determined by the Reckhow and Simpson (1980) model.

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* The 830 µg/L ammonia-nitrogen value recorded on September 8, 1982 is not regarded as representative. Contamination of the sample from lake sediments is suspected.

Soils surrounding the airport are relatively impervious. These nutrients therefore remain at or near the surface allowing for their eventual drainage into Kathlyn Lake. Hawthorn (1976) found nitrogen and phosphorus levels in airport drainage ditches to be in excess of 1000 times the concentrations found in the lake. The report recommended examination of the land drainage in the vicinity of the airport and, if possible, alteration of this drainage pattern to redirect runoff toward the Bulkley River.

Apparently, modification of the drainage for most of the runway was carried out, but this did not affect runoff from the B.C. Forest Service staging area (Hawthorn, pers. comm.), and north end of the runway.

5.9.2 c) Seymour Lake

Seymour Lake had total phosphorus concentrations of 30-33 µg/L during the winter (Figure 17). At spring overturn, the total surface concentrations increased to 52 µg/L (the highest recorded for the year), and then following a decrease to 19 µg/L (September 8, 1982) climbed back to 50 µg/L in the fall. Bottom concentrations of total phosphorus followed a similar pattern with overall concentrations a little higher.

This cycle of phosphorus suggests that the lake sediments released significant quantities of phosphorus during anoxic periods, and the surface water concentrations increased following spring or fall overturn. Other data, however, do not support this hypothesis. Lakes which do release phosphorus during anoxic conditions have high concentrations of dissolved ortho-phosphorus above the sediment-water interface during late winter and summer. The maximum ortho-phosphorus concentration recorded in the anoxic hypolimnion of Seymour Lake during late summer was 5 µg/L on September 8, 1982. This is not considered a significant concentration of inorganic phosphorus. Consequently, the release of phosphorus from the sediments of Seymour Lake, did not occur in sufficient quantities to cause the elevated phosphorus concentrations.

Surface concentrations of all forms of nitrogen were constant from June through October (no results for January through May). Ammonia-nitrogen ranged from 6 to 34 µg/L, with the higher concentrations occurring late in the summer (Figure 18). Nitrate-nitrogen was always below the 20 µg/L detection limit. Organic nitrogen (contained within algal cells), was the largest fraction of the total nitrogen content, ranging from 480 to 550 µg/L.

Hypolimnetic concentrations of nitrate and organic nitrogen were similar to those observed in the epilimnion. Ammonia-nitrogen was also stable and similar to the epilimnion values except for two values 181 µg/L and 875 µg/L (recorded on July 21 and September 8, 1982). These two samples were taken very close to sediment water interface, and some lake sediments were included with the sample. Consequently, these samples are not truly representative of the hypolimnetic conditions.

Table 14 lists data collected from inflow streams. The first samples of the north and northwest inflows were low in nutrients. The July 21 sample was extremely high in nutrients. Additional sampling is required to verify the results collected on July 21, 1982.

Until the phosphorus concentrations in the north west inflow are verified, the significance of the stream loading to the annual phosphorus input as determined by the Reckhow and Simpson (1980) model, can not be determined.

5.9.2 d) Tyhee Lake

The total phosphorus concentrations at the surface of Tyhee Lake were highest at spring and fall overturn (20 and 15 µg/L respectively), the result of entrainment of phosphorus rich hypolimnetic water (Figure 19). Surface concentrations decreased through the summer to a low of 11 µg/L in September 8, 1982. The decrease was the result of sedimentation from the epilimnion of organic phosphorus, incorporated in living or dead plankton.

The concentrations of phosphorus within the hypolimnion increased through the winter months because of the release of dissolved ortho-phosphorus from the anoxic lake sediments. Concentrations of ortho-phosphorus during the winter increased to 67 µg/L by May 15, 1982. With the introduction of oxygen throughout the lake bottom following spring overturn, concentrations dropped as ortho-phosphorus was absorbed by the oxidized lake sediments. Anoxic conditions recurred in July, and persisted through October, causing the release of ortho-phosphorus from the sediments. Concentrations increased to a maximum of 87 µg/L one meter above the lake sediments by October 20, 1982.

The volume of phosphorus released from the sediments during anoxic periods can be estimated by multiplying the volume of the hypolimnion (9 000 dam^3, based on a thermocline depth of 5-7 m), by the mean ortho-phosphorus concentration at overturn (0.050 mg/L at fall overturn and 0.030 mg/L at spring overturn). Based on these values, an estimated 450 kg and 270 kg of phosphorus (total of 720 kg) was released from the sediments into the hypolimnion, and mixed throughout the lake at fall and spring overturn.

The combined phosphorus loading (spring and fall) from the anoxic sediments represents 80 percent of the annual phosphorus budget for Tyhee Lake as calculated by the Reckhow and Simpson (1980) model.

Nitrogen concentrations followed closely the concentrations and patterns of Round Lake (which are discussed in the next section 5.9.2 e). Ammonia-nitrogen concentrations were very low in the surface water (Figure 20) while concentrations were high in the bottom water during the anoxic periods prior to spring and fall overturn. A maximum concentration of 446 µg/L was recorded on October 20, 1982 at 20 m depth.

Nitrate-nitrogen was undetectable at all depths from June through October (Figure 20). Oxidation of organic matter during the winter months in the surface and bottom waters elevated the nitrate levels to a maximum of

200 µg/L. Nitrate remained in the oxidized surface waters, but decreased in the bottom waters because of bacterial ammonification during the winter anoxic period.

Organic nitrogen was the largest component of the total nitrogen content of the water. Surface concentrations ranged from 450 µg/L to 600 µg/L; the maximum hypolimnetic concentration was 870 µg/L.

Nineteen inflow creeks were sampled around Tyhee Lake (Figure 4). Throughout May and June most streams had low concentrations of inorganic nitrogen and phosphorus (Table 15). This was unusual considering the agricultural activity occurring in the area. Freshet conditions undoubtedly caused some dilution which would reduce the concentrations. Values in July were consistently higher. High organic content was responsible for the high nitrogen concentrations in streams 1131065 and 1131066. It is not known if the organic content was a result of sample contamination, or whether it actually represented the nutrient content of the creek at the time of sampling.

Phosphorus loading from the inflow streams was roughly calculated by multiplying the mean and maximum watershed runoff values (7 065 and 12000 dam^3, Table 3), by the average stream phosphorus concentration (0.023 mg/L, Table 15). Using this method, an estimated 160-275 kg of phosphorus will enter Tyhee Lake per year. The actual amount should fall within the 160-275 kg range, and will depend on the hydrology and ranching practices of each specific year.

The contribution of phosphorus from the streams to Tyhee Lake is estimated to be between 10 and 18 percent of the lake's annual phosphorus budget (Section 5.9.2a). In contrast, the stream loading was higher than the input from septic tanks (Section 4.1), but secondary to the volumes of phosphorus released from the lake sediments during anoxic conditions.

5.9.2 e) Round Lake

Changes of ortho and total phosphorus during 1982 are illustrated in Figure 21. Total phosphorus concentrations in Round Lake were the highest of the study lakes. Concentrations ranged from a low of 18 µg/L at the surface on September 8, to a high of 394 µg/L at 18 m depth on October 20, 1982. The spring overturn phosphorus concentration was 70 µg/L in 1982.

Figure 21 shows the surface concentrations to be very high under the ice, and decreasing through the summer because of the sedimentation of organic phosphorus from the surface waters. A substantial increase occurred at fall overturn, the result of mixing with hypolimnetic water.

The hypolimnetic total phosphorus concentrations decreased slightly following spring overturn, followed by a rapid increase. Release of dissolved ortho-phosphorus from the lake sediments was the cause of the increase.

Normally, phosphorus contained in detrital material is bound by either calcium, iron, or aluminum in the sediments. When anoxic conditions exist inorganic phosphorus can become soluble, and move from the sediments back into the water. Round Lake was observed to release significant amounts of phosphorus from anoxic lake sediments during periods of thermal stratification

Ortho-phosphorus concentrations fluctuated considerably with time and depth (Figure 21). Winter concentrations were extremely high, as low plankton growth did not use all the available phosphorus at the surface. Anoxic conditions persisted below the winter thermocline which promoted further release of ortho-phosphorus from the lake's sediment. The result was a very high spring overturn ortho-phosphorus concentration (70 µg/L).

The volume of ortho-phosphorus released from the sediments was calculated by multiplying the volume of the anoxic zone of the hypolimnion (6 000 dam^3 in the summer and 4 000 dam^3 in the winter) by the average ortho-phosphorus concentration at the sample date closest to the spring and fall overturns (0.100 mg/L prior to spring overturn and 0.150 mg/L prior to fall overturn). The combined phosphorus loading from the sediments is estimated to be 1200 kg/yr. This represents 60 percent of the annual phosphorus budget for Round Lake.

At spring overturn, the surface concentrations decreased dramatically because of biological utilization by the phytoplankton community during the spring bloom. The surface concentrations of ortho-phosphorus remained low, but above detectable limits throughout the latter part of the summer.

Hypolimnetic ortho-phosphorus concentrations decreased briefly following spring overturn, probably the result of sedimentation during aerobic conditions. Once the sediments and the hypolimnion had become anoxic in July, the ortho-phosphorus concentrations increased rapidly, and reached a maximum concentration of 260 µg/L in late October (Figure 21).

Nitrogen concentrations throughout the study are given in Figure 22. Ammonia-nitrogen values followed closely the fluctuations in ortho-phosphorus concentrations. Under anoxic conditions, the hypolimnetic concentrations reached a maximum of 565 µg/L in the winter, and 1 380 µg/L in the fall. Low concentrations were observed in the oxygenated surface waters during the summer. There is a possibility of a winter or summer fish-kill because of the periodically high concentrations of ammonia, hydrogen sulphide, and low dissolved oxygen concentrations.

Nitrate nitrogen concentrations were much less variable with a high of 90 µg/L at the surface during the winter and 120 µg/L in the hypolimnion during June. Frequently, the nitrate-nitrogen concentrations were undetectable because of biological utilization at the surface, and because of denitrification in the anoxic hypolimnion (anoxic conditions promote microbial ammonification rather than nitrification; Wetzel, 1975).

Organic nitrogen was the most abundant form of nitrogen in Round Lake comprising 50 percent or more of the total nitrogen present. The values fluctuated from 570 µg/L to 1 000 µg/L , with the larger values occurring in late summer in the hypolimnion, as a result of sedimentation of particulate matter.

Despite elevated nutrient concentrations in the creeks (Table 16), the levels observed were lower than expected considering the amount of agriculture in the watershed. Other similar studies (Suttie et al., 1982; McKean, 1982) report high nutrient loading from agricultural activities.

The combined phosphorus loading from the two inflow streams was estimated at 200 kg/yr. This represents 10 percent of the annual phosphorus budget (1950 kg, Section 5.9.2a) as determined by the Reckhow and Simpson (1980) model.

The stream loading was calculated by multiplying the stream's annual flow by the average phosphorus concentration in the stream (Table 16). The annual streamflow was calculated by multiplying the average annual water input (5 500 dam^3, Table 3) by the area (as a percent) of the stream's individual drainage area (north flow: 70%; north east inflow: 10%).

The annual water input to Round Lake is discussed in Section 2. Because the hydrological record is unclear, the annual watershed runoff could be as much as 9 000 dam^3 (Table 3) which is 60 percent higher than the value used in the stream phosphorus loading rates above. Should the higher stream runoff occur, the phosphorus loading rate estimated above would increase by 60% to 16% of the annual phosphorus budget.

Regardless of possible inaccuracies in the hydrology estimates, the stream phosphorus input to Round Lake is considered to be of modest importance. The largest source of phosphorus appears to be release from the lake's sediments during the summer and winter anoxic conditions in the hypolimnion.

5.10 PHYTOPLANKTON AND CHLOROPHYLL a

A number of problems are apparent when lakes become too productive. Algal growth causes problems with water supply (clogging of filters, colour, taste and odour), oxygen depletion (when algae are decomposing, or during the night when respiration is the predominant metabolic process), and general aesthetic deterioration (reduced water clarity, increased turbidity, odour, etc).

Samples were taken in 1982 to determine how much algal growth was present in each lake at different times of the year. This information can be used to gauge the problems which can be expected in various types of water use, and to determine the level of improvement required for satisfactory water quality.

Planktonic algae were sampled to determine species composition and numbers; separate samples were obtained for chlorophyll a analysis. Numbers of algae and chlorophyll a quantify algal biomass (standing crop) at points in time through the study. Numbers of algae are discussed in the text. The mean summer chlorophyll a concentrations are plotted in Figure 23 against spring overturn phosphorus concentration.

Several authors have established a direct correlation between mean summer chlorophyll a concentrations and spring overturn phosphorus concentrations. Nordin and McKean (1984) developed a similar relationship for British Columbia lakes. Figure 23 outlines the general relationship for

B.C. lakes, and the relative positions of the four study lakes. Each section below will discuss the algae collected and the individual lake's position on Figure 23.

5.10.1 KATHLYN LAKE

Kathlyn and Tyhee are the least productive of the four lakes, but still would be considered eutrophic.

Kathlyn Lake in January had a low standing crop (260 cells/mL). The dominant genera were Anabaena and Cryptomonas. In May, the standing crop had increased to 1 300 cells/mL with the dominant genera being Dinobryon, Asterionella, Anabaena and Chroomonas. Another sample a few days later had a lower standing crop (550 cells/mL) and the dominant organism was Stephanodiscus sp., which is a significant change from the earlier sample. The June sample had a fairly high cell density (6 000 cells/mL) with the dominant genera being Anabaena and Asterionella. In July, the standing crop was lower (1200 cells/mL) and the dominant algae were blue-green genera (Gomphosphaeria, Chroococcus, Anabaena) plus one chlorophytic species (Quadrigula). In September, the standing crop was 700 cells/mL with two blue-green algae being the most numerous genera (Gomphosphaeria and Coelosphaerium).

The corresponding chlorophyll a measurements show a maximum of 9.5 µg/L (May), and a May to October mean concentration of 5.0 µg/L (Figure 23). The mean summer chlorophyll concentration may have been higher if June chlorophyll samples had been analysed (this was a period of higher phosphorus concentration, the result of runoff from the airport). Unfortunately, the June chlorophyll samples were accidentally destroyed in transit to the laboratory.

5.10.2 SEYMOUR LAKE

Seymour Lake was, on the basis of the phytoplankton data, the second most productive of the lakes examined. In January, low numbers of algae were present (<200 cells/mL). This would be expected considering the time of year, low light and low temperature. The dominant species were Synura uvella and Cryptomonas ovata. Both are flagellates and probably reflect the physical conditions (low light and lack of any vertical water movement). In May, relatively low numbers were present (1 500 cells/mL). The dominant species was Cryptomonas sp. The June sample had 11 000 cells/mL (considered high) and the dominant alga was a species of Coelosphaerium (a blue-green alga). In July, only a moderate standing crop was present (3 600 cells/mL), but the dominant genera were Anabaena and Aphanizomenon, both blue-green algae and typical of relatively high nutrients and moderately productive to eutrophic lakes. Many of the other genera present (Eudorina, Ceratium, Ankistrodesmus) would generally be considered to be part of the flora of eutrophic lakes.

The chlorophyll a concentrations for Seymour Lake were relatively high through the growing season. The May to October mean chlorophyll a was 8.4 µg/L. Based on Figure 23, the chlorophyll concentration was below that expected from the general relationship for B.C. lakes. One possible reason is that the highly coloured water reduced the light intensities in the water column sufficiently to lower the algal biomass.

5.10.3 TYHEE LAKE

Only three samples were taken from Tyhee Lake, so less information is available than for the other lakes. The January sample had 100 cells/mL and was predominantly Coelosphaerium sp. and Chroomonas sp. The June sample also had a low standing crop (500 cells/mL) composed primarily of Dinobryon sp., Asterionella sp., and Fragilaria sp. The July sample also had relatively low biomass (1 200 cells/mL), but the predominant taxa were Anabaena flos-aquae (a blue-green usually considered indicative of warm, productive lakes) and Chroomonas sp.

The chlorophyll a results show a consistent level of biomass through the summer with some reduction in September and October. The May to October mean chlorophyll a value was 4.0 µg/L, which was slightly below the expected concentration predicted from Figure 23.

5.10.4 ROUND LAKE

Round Lake was the most productive of the four lakes in terms of algal standing crop. On January 26, a very high standing crop was present (7 000 cells/mL). This is surprising considering the heavy ice cover and generally low biological production at this time of year. The dominant genera present were Coelosphaerium and Gomphosphaeria, both of which are coccoid blue-green algae. On May 15, unconcentrated discrete samples (normal method of collection) and a vertical net tow were taken. The regular samples showed a reasonably high standing crop (8 500 cells/ml) dominated by Coelosphaerium sp. and Microcystis sp. Microcystis is a blue-green alga generally considered an indicator of eutrophic conditions. The net tow (which cannot be used for quantitative samples) showed a very biased species composition (reflecting the use of the net as a sampling device). The dominants in this case were the genera Coelosphaerium, Phormidium (a filamentous blue-green) and Asterionella (a large colonial diatom). No Microcystis was present.

The June sample had a standing crop of 5 200 cells/mL. Dominant genera were Chroomonas (a flagellated cryptomonad), Stephanodiscus (a diatom) and Anabaena (a filamentous blue-green). The July sample had a very high standing crop (65 000 cells/mL) with the dominant genera all being blue-green algae (Aphanizomenon Anabaena, Coelosphaerium), the former being indicators of eutrophy.

The chlorophyll a results showed high values in May through July. Maximum values were in May (water column mean of 45 µg/L), and the growing season mean (May-October) was 15.5 µg/L.

5.10.5 GENERAL OBSERVATIONS

From the phytoplankton data on the four lakes, a number of general conclusions can be made. The lakes contained different levels of phytoplankton biomass with Round Lake being the most productive, followed by Seymour, Kathlyn and Tyhee in order of decreasing productivity. There are a number of methods of relating phytoplankton biomass to trophic status. Stockner and Northcote (1974) examined the Okanagan lakes, and suggested that Kalamalka Lake with a mean phytoplankton standing crop of 700 cells/mL represented oligotrophy, Skaha Lake (mean value 3 700 cells/mL) represented mesotrophy and Wood Lake (7 900 cells/mL) was eutrophic. Number of cells/mL can be a poor indicator when a variety of cell sizes are present. The number of cells converted to biomass is a better indicator. Wetzel (1975) gives ranges of values for phytoplankton biomass and chlorophyll a which can be used to characterize different trophic states (Table 17), as do Rast and Lee (1978), and Carlson (1977).

From the range of trophic indices outlined in Table 17, Round and Seymour Lakes would appear to be clearly eutrophic, and Kathlyn and Tyhee Lakes would be either eutrophic or mesotrophic, depending on the criteria used.

It is also evident that all of the lakes have algal communities which are dominated by blue-green algae. This group of algae is characteristic of eutrophic lakes, and is particularly undesirable when the water is used for recreation or drinking.

Blue green algae contain gas vacuoles causing them to float near the surface. These algae can form large floating colonies or a surface scum, which is easily moved around the lake by wind. Water contact recreation can be severely impaired if a large algal mass is blown onto a beach or into swimming areas. The genera *Aphanizomenon*, *Anabaena*, *Microcystis* are present in the lakes, and are capable of causing nuisance algal blooms that reduce the recreation suitability. At present, the algal concentrations in Round Lake could be considered a nuisance for recreation. Because eutrophication in the other three lakes is not as advanced, the algae are not considered to be a nuisance to recreation.

Algae (particulary blue-green algae) can impart taste and odours to drinking water or clog water filters. Palmer (1962) and Taylor *et al*. (1981), give excellent reviews of problems caused by algae. Those algae found in lakes and noted by Taylor *et al*. (1981) to cause problems in drinking water supplies, are listed in Table 18.

Three minor problems exist with the 1982 water monitoring data. The first is that the spring overturn samples were collected one to two weeks late. Secondly, Round and Tyhee Lakes did not appear to mix completely at overturn. These two factors caused the spring overturn phosphorus concentrations to be underestimated. Thirdly, the chlorophyll sampling should have been more frequent (a common problem in many lake studies).

Because of these problems, the relationship between phytoplankton, chlorophyll, and phosphorus varied from the general relationships for lakes in British Columbia (Nardin and McKean, 1984). However, the variability was quite small, indicating that the relationship was valid for the study lakes.

Consequently, the relationship can be used to predict the impact of changing phosphorus concentrations on the phytoplankton community. Lake restoration and management guidelines based on the phosphorus chlorophyll relationship and the Reckhow and Simpson model are discussed in Section 7.

6. WATER QUALITY OBJECTIVES

Water quality objectives are desirable to ensure that present and future water uses of the lake are protected. This report has shown that each lake is important for:

- domestic water supply
- industrial water supply
- irrigation water supply
- primary-contact recreation
- fisheries

It is proposed that these be adopted as the designated water uses to be protected in the lakes.

The provisional water quality objectives outlined below are set to protect the most sensitive use. If the objectives are met for the most sensitive use, then all of the other uses of the lake will be protected.

6.1 FECAL CONTAMINATION

The most sensitive uses are for drinking water supply and primary-contact recreation such as swimming. The objective for drinking water supplies is designed to ensure that no water treatment apart from disinfection is required.

The provisional objective for domestic water supply is: the fecal coliform density shall not exceed 10 MPN per 100 mL in 90 percent of lake water samples taken in any consecutive 30-day period. The objective is based on the Ministry of Health's guidelines for the treatment of raw water supplies (B.C. Ministry of Health, 1982).

The objective for primary-contact recreation is based on the recommendations by Richards (1983). The provisional objective is: the fecal coliform density shall not exceed a running log mean of 200 MPN/100 mL, calculated from at least five weekly samples taken during the recreation season, nor shall more than 10 percent of samples during any 30-day period exceed 400 MPN/100 mL.

Fecal coliform densities have not been measured in the lakes, and monitoring is necessary to determine if these objectives are being met.

The objective for domestic water supply should apply to grab samples taken within 10 m of a domestic intake. The objective for recreation applies to bathing beaches. Section 8.1 outlines the frequency at which coliform bacteria should be sampled.

6.2 ALGAL GROWTH AND NUTRIENTS

Nuisance algal growth is the result of excessive phosphorus in the lakes. Excess algae can cause taste and odours in drinking water, clog filters, cause aesthetic problems for recreation, reduce water clarity, create high hypolimnetic oxygen depletion rates which result in loss of fisheries habitat, and create possible winter or summer fish-kill situations.

Because the lakes do not have high fishing pressure, and there are no rehabilitation plans to remove coarse fish, the cold water fishery is not the major use to protect. Water quality objectives were therefore designed to meet the recreational requirements. The maximum algal biomass acceptable for recreation (and providing some protection for cold water fisheries) is a mean summer chlorophyll a concentration between 3-5 µg/L (Dillon and Rigler, 1975). At this biomass level, domestic water supplies (the principal consumptive use) will not be compromised. For the purpose of this study the mean summer chlorophyll concentration in the lakes should not exceed 4 µg/L (the mid point of the levels recommended by Dillon and Rigler).

As mentioned earlier, the biomass of algae is controlled by the availability of phosphorus. To achieve a mean summer chlorophyll a concentration of 4 µg/L, the spring overturn total phosphorus concentration should not exceed 15 μg/L (Figure 23). Consequently, the provisional water quality objective for all the lakes is a total phosphorus concentration of 15 μg/L or less at spring overturn. The objective applies to the average of three samples taken 1 m below the surface, at mid depth and 1 m above the bottom at the deepest point of the lake. The monitoring program for the objective is outlined in Section 8.

All the lakes were above the recommended water quality objective for phosphorus. Consequently, the water quality objective for phosphorus is considered to be a long term objective. It will not be attainable until the remedial measures recommended in this report can be implemented. Water management techniques designed for Kathlyn, Tyhee and Round Lakes (discussed in Section 7.2), are capable of reducing the spring overturn phosphorus concentrations, to levels near the water quality objective.

Seymour Lake is a more difficult case. The present causes of eutrophication are not known. Additional sampling in 1984 (Section 8.2) by the Waste Management Branch in Smithers will try to assess the source(s) of phosphorus. Should the results show that the causes of eutrophication are natural and irreversible then the water quality objective should be revised to 50 μg/L of total phosphorus at spring overturn to prevent any further deterioration in water quality. The revised objective is based on the 1982 spring overturn phosphorus concentration.

Should the higher phosphorus objective be used in Seymour Lake the principal water users should be notified that the water is poorly suited for water contact recreation or domestic consumption, and no improvements in the future water quality can be expected.

6.3 TURBIDITY

The use most sensitive to turbidity is drinking water supply with disinfection only (i.e., no removal of turbidity/suspended residues).

The proposed provisional water quality objective is a maximum of 5 NTU and a average of ≦ 1 NTU. These objectives are based on B.C. Ministry of Health, (1982), Drinking Water Quality Standards. The maximum shall apply to any grab sample taken within 10 m of a domestic intake, and the average is calculated from at least 5 weekly samples in a period of 30 days. The proposed monitoring for turbidity is outlined in Section 8.2.

Turbidity can be induced by algal growth or soil erosion within the watershed. Sampling of inflow creeks around all lakes indicates low soil erosion. The turbidity in the lakes caused by inorganic solids during freshet was also low.

The measured turbidity of the lakes was caused by algal growth. Only Tyhee Lake epilimnion met the average objective of 1 NTU. The remainder of the lakes exceeded the average objective, but were within the maximum of 5 NTU. The lake restoration methods outlined in Section 7.2 are the recommended techniques of reducing turbidity. If the objectives for spring overturn phosphorus are met in the long term, the turbidity water quality objective of 1 NTU will also be met.

6.4 COLOUR

The water use most sensitive to colour is drinking water supply.

The colour of water is caused by dissolved organics and possibly iron, present in the water. Colour induced by turbidity is not included in the colour test. The provisional water quality objective for colour is a maximum of 15 True Colour Units, measured in any grab sample of lake water taken within 10 m of a domestic water intake. This is a long term objective based on the B.C. Ministry of Health (1982) Drinking Water Quality Standards.

On average, the colour values in Kathlyn, Round and Tyhee Lakes were slightly above the colour objective, but Seymour Lake exceeded the objective. Dissolved organics that cause the colouration are produced by vegetative material either within the lake or from the watershed. Other than Seymour Lake, the colour appears to be derived from within the lakes. Reduction of the phosphorus concentrations and algal biomass following implementation of the lake management techniques (Section 7.2), may reduce the colour values. However, it can not be predicted that the colour will be reduced to the level of the water quality objectives.

Seymour Lake has a more distinct colour than the other lakes. It is a colour typical of bogs, although not as brown. It is not known if the colour originates from within the lake or from the watershed.

7. LAKE RESTORATION AND MANAGEMENT TECHNIQUES

All four study lakes were classified as eutrophic in 1982. Water quality problems associated with the eutrophic conditions reduce the value of the resource to the many domestic, industrial and recreational users of the lakes. This section will outline lake restoration methods, and develop lake management guidelines to ensure that eutrophication caused by watershed development is controlled.

7.1 DRINKING WATER SUITABILITY

The recommended drinking water objectives and standards adopted by the B.C. Ministry of Health are listed in Table 19. In all lakes, domestic water intakes that are located near the surface draw water which, during the summer, exceeded the recommended temperature maximum of 15°C. The colour standard of 15 true colour units (TCU) was greatly surpassed by the water of Seymour Lake (mean = 50.0, standard deviation ± 10.0). The maximum epilimnetic concentration of ortho-phosphorus in Round Lake was 73 µg/L, which occurred just before spring overturn. This value exceeds the drinking water objective (B.C. Ministry of Health, 1969).

Surface water of the study lakes contained high concentrations of phytoplankton during the spring summer and fall. Table 18 outlines the species of algae that are capable of causing taste and odour problems in drinking water supplies. If eutrophication increases, the concentrations of algae, and the occurrence of taste and odour problems, will also increase.

Water drawn by domestic intakes located below the thermocline would generally be of lower quality. Hypolimnetic water temperatures in both Kathlyn and Seymour Lakes exceeded the designated standard (15°C) during the summer. Dissolved oxygen concentrations in all lakes fell below the 3.0 mg/L standard recommended by Nemerow (1974) and the Ontario Ministry of Environment (1979). Hypolimnetic colour values for Kathlyn and Seymour

Lakes were higher than the surface waters, with values exceeding the 15 TCU standard (16.7 and 45 respectively). Colour values from Round and Tyhee were also higher in the hypolimnion, but were at or just below the B.C. Ministry of Health (1969) water quality standard (15 and 13.3 respectively). Hypolimnetic ammonia nitrogen concentrations in Kathlyn and Seymour Lakes peaked in September (830 and 875 µg/L respectively). Round Lake had two periods during which ammonia nitrogen exceeded the recommended standard of 0.5 mg/L (B.C. Ministry of Health, 1969). During the winter ammonia nitrogen was measured at 570 µg/L. Following a brief drop during spring overturn the concentration rose to 1100 µg/L. Although Tyhee Lake did not exceed the recommended standard (B.C. Ministry of Health, 1969), ammonia concentrations were high (44 µg/L). Both Round and Tyhee lakes had high concentrations of ortho-phosphorus through the winter (103 and 67 µg/L respectively); maximum concentrations occurred in late summer (259 and 87 µg/L respectively). Hydrogen sulphide (not measured) was noted by field crews in late summer and winter, and may have contributed objectionable taste and odour to the water.

In summary, the surface water of all lakes appeared to be less objectionable as a source for domestic drinking water than the bottom (hypolimnetic) water. Residents may find significant improvements in water quality with the use of in-line water filters.

7.2 LAKE RESTORATION TECHNIQUES

7.2.1 KATHLYN LAKE

Sufficient evidence exists to show that large amounts of nutrients are entering the lake from the airport area. The collection and containment system currently used to handle spilled fire retardant was inspected in June 1983. Subsequently the Waste Management Branch (Ministry of Environment) permit to the Ministry of Forests was amended to redirect release of excess waste water from the storage lagoon. The water is now discharged on the east side of the airport runway. Most of the phosphorus should be adsorbed by soils or taken up by grasses on the runway apron, the remainder, if any, will drain into the riparian forest on the Bulkley River. It will be necessary to sample for nitrogen and phosphorus in ditch water between the hangar and the lake, and in the lake itself during spring runoff, to determine if further controls are necessary.

Once this source is curtailed, improvements in water quality in Kathlyn Lake would be expected. Reduced productivity would be reflected by a less severe spring phytoplankton bloom. The subsequent lower concentration of ammonia and reduced biological oxygen demand would create a more hospitable environment for fish, as well as water more suitable for domestic use.

A proposal was made to divert Glacier Gulch Creek into Kathlyn Lake (Buchanan and Baillie, 1974) in order to improve water quality, but it is not recommended at this time. Solving the airport runoff problem should bring about the necessary reduction in spring phosphorus, and consequently improvements in water clarity. Two or three years are probably required to monitor the lake's response. Meanwhile, the value of the minor increment in flushing rate achieved by diverting Glacier Creek has to be weighed against losses of fish habitat in Toboggan Creek. Diversion schemes should only be considered if the lake does not respond as predicted to improvements in airport drainage.

The cost of these diversions have been estimated (Bergman, 1980) to be $45 000 for Glacier Gulch Creek and $26 000 for Simpson Creek. These figures are in 1976 dollars.

The effects of building and agricultural development on aquatic plants is of concern in Kathlyn Lake. Although there were no data collected, there is evidence in the literature that rooted aquatic plants are not limited by nutrients. Rather their distribution is limited by light availability and substrate suitability (Feedman and Canale, 1977).

McKean and Nordin (in prep.) studied the aquatic plant Nuphar polysepalum (the common lily pad) in Brannen Lake. Tissue nutrient concentrations did not vary between an undeveloped foreshore, and an area receiving agricultural runoff. Solander (1978) could not detect any significant change in macrophyte growth following artificial enrichment of a Swedish Lake.

According to these findings, increased development and subsurface disposal of household effluent should not influence the distribution and abundance of aquatic macrophytes. Buchanan and Baillie (1974), and Bergman (1980) outlined the possibility of lowering the water level of Kathlyn Lake in the fall and freezing the roots of the plants. To reduce the water level of the lake by 3.7 m, Bergman estimated the cost at $80 000.

7.2.2 SEYMOUR LAKE

Data collected in 1982 for Seymour Lake were difficult to interpret. Relatively low nitrogen and phosphorus values in the inflow streams in May were followed by very high stream concentrations in July. Aerial photographs of the watershed indicated no apparent source of nutrients. Since only a single sample (July 21, 1982) gave a high stream loading, the possibility of sample contamination must be considered. A more intensive stream sampling program is necessary to assess adequately the effect of the inflow streams.

The fact remains that a source of nitrogen and phosphorus still exists causing the eutrophic conditions. Internal recycling of nutrients has been eliminated as a source of phosphorus because of the low phosphorus concentration at the sediment-water interface. Loading from septic tanks was minimal. Significant aerial input is unlikely. One possibility involves wind mixing. Turbulence on a lee shore caused by wave action can resuspend a significant amount of phosphorus in shallow lakes. McKean (1982) showed that the major input of phosphorus to Dragon Lake (Quesnel) resulted from the resuspension of bottom sediments during wind events. Prevailing winds (as recorded at the Smithers Airport) are predominantly from the southeast quadrant (Environment Canada, 1981). Since Seymour Lake is oriented southeast- northwest it is subject to this wind activity along the long axis. As fetch increases so does wave size and, therefore, turbulence on the lee shore. Despite the susceptibility of the lake to wind mixing, no data have been collected to support the hypothesis that the resuspension of phosphorus by wind activity was a major source of nutrients to the lake. Consequently, the major source of phosphorus to Seymour Lake remains unknown. Until the sources of phosphorus can be identified, no lake restoration strategies can be developed.

7.2.3 ROUND AND TYHEE LAKES

These two lakes are similar in many ways. They have similar mean depths, water chemistry, nutrient concentrations, and phosphorus sources. The release of ortho-phosphorus from the lake sediments was the largest contributing factor to the eutrophication process in both lakes. The large hypolimnetic oxygen demand (typical of eutrophic lakes) caused anoxic conditions to persist through most of the summer, fall and winter. The result was a loss of fisheries habitat, and a build-up of ammonia and hydrogen sulphide that may cause summer and winter fish-kills.

The absence of nutrients in the streams at Round and Tyhee Lakes was probably due to the suitability of the soil for phosphorus adsorption. The soils around Round Lake are exclusively Driftwood soils (Figure 7), which are characterized as moderately fine textured unsorted glacial till. The dominant soils around Tyhee Lake are the Barrett and Driftwood soils. Like the Driftwood soils, the Barrett soils are moderately fine textured unsorted glacial till. Both these soil types are moderately to well drained. Combined with the soils' moderately fine texture, these soils are well suited to adsorb nutrients (particularly ortho-phosphorus). The observation of low nutrient concentrations in the creeks draining the agricultural areas supports these assumptions about the soils (Section 5.9.2d and 5.9.2e).

The stream input of phosphorus was estimated to be between 10 and 25 percent of the annual phosphorus budget for both lakes (Section 5.9.2d and 2e). Septic tanks were of minor importance (Section 4.1). Internal recycling of phosphorus from anoxic sediments was observed to be the largest source of phosphorus. Even though the nutrient originates from within the lakes, it is considered a source because it is biologically available, and the major cause of the lakes' eutrophication problems.

To prevent the release of phosphorus from the sediments a hypolimnetic aeration system is recommended. The benefits of an aeration system would include a significant reduction in spring overturn phosphorus concentration, elimination of the possibility of winter or summer fish-kill situations, a reduction in algal biomass, and a shift in the species community from blue-green algae to less obnoxious green algae (Nordin and McKean, 1982).

Aeration should be initiated in the fall to maximize the benefits in the first year of operation.

The advantage of the hypolimnetic aeration design is it does not significantly elevate the bottom water and sediment temperatures. A lower temperature in the bottom waters is advantageous for the cold water fishery and limits the biological oxygen demand of the sediments. Destratification aeration on Langford Lake (near Victoria) increased the oxygen demand of the sediments above the oxygenation capacity of the aerator. The result was anoxic conditions at the sediment water interface, phosphorus release from the sediments, and a large algal bloom throughout the lake (McKean, pers. obs.).

7.3 WATERSHED MANAGEMENT GUIDELINES

In order to limit the impact of watershed development on the water quality of the lakes, several recommendations are outlined.

The first is a freeze on watershed development until the present eutrophic conditions are controlled by the lake management programs outlined in Section 7.2. Secondly, when additional development is permitted by the Regional District, the emphasis must be on restricting the movement of phosphorus from new developments, to the lake.

After the lakes are successfully restored to acceptable levels (spring overturn phosphorus concentrations of 15 µg/L or less), development in the watershed can proceed using sewers or septic tanks. A sewer system connecting existing and new homes will remove the household wastes from the watershed. However, if high density housing is required around the lake to provide the tax base to fund the system, then any benefits offered by the collection and disposal system may be offset by changes within the watershed. For example, storm runoff from new roads, lawns, and houses will be an additional source of nutrients to the lake. Because of ditching, diversions, and land disturbance associated with high density development the hydrology of the watershed may also change. The inflow creeks may flood more often, and dry up in the summer.

Maintenance of water quality will require low to moderate density housing located on soils suitable for the adsorption of phosphorus. Section 4.1 noted the soils around each lake that have good, moderate or poor suitability. Septic drainfields serving housing on the soil types determined to have good phosphorus adsorption suitability should have a 50 m setback. On soils of moderate suitability, housing should have a minimum of 100 m setback, while on poor soils it should have a 300 m setback.

These setback distances for septic drainfields are designed to minimize the amount of phosphorus entering the lake from homes using septic tanks.

They would, of course not be relevant for developments served by sewers which carry the domestic wastes out of the watershed. However, precautions would still be necessary to control adverse effects from storm drainage and leaching from residential gardens. These matters are elaborated on in the following section.

7.3.1 WATERSHED DEVELOPMENT

The setback guidelines (around the study lakes and their inflow streams) outlined in Section 4.3 were designed to limit the input from septic tanks to an estimated maximum of 10 percent of the 5.5 kg of phosphorus discharged by an average home. Consequently the phosphorus loading reaching the lakes from new developments using septic tanks should never exceed 0.55 kg/yr per house if the setback guidelines are followed.

Two methods were used to determine the phosphorus loading from residential runoff in the Smithers area. In the first method Dr. J.H. Wiens (pers. comm.), of the Surveys and Resource Mapping Branch estimated the phosphorus loading from residential areas (non-septic tank related activity). He concluded that fertilization of lawns and gardens would be the largest source of phosphorus. Assuming 50% of the homes will fertilize in any one year, that the fertilization application rate will be 44 kg P/ha, and that the average lot size is 0.08 ha, each house will contribute the equivalent of 1.75 kg P/yr into the watershed.

The phosphorus transmission coefficients for applied fertilizers should be lower than for septic tanks (Section 4.1), because septic tanks discharge large volumes of water below ground. Reduced soil thickness and greater volumes of water would reduce the soil's capacity to adsorb phosphorus. Fertilizers are applied to the root zone of the soil which has a higher phosphorus adsorption ability. Consequently the phosphorus transmission coefficient was estimated at 5 percent of 1.75 kg (see above) or 0.1 kg P/yr per house.

The second method used residential runoff concentrations of phosphorus recorded in Vancouver in 1980-1981 by Swain (1983). He reported an average phosphorus concentration in runoff of 160 µg/L from a residential complex of 200 homes. The volume of runoff measured was 76 000 m^3 which produced a phosphorus loading of 12 kg P/yr from the 200 home complex or 0.06 kg P/yr per house.

The method used by Wiens overestimates the phosphorus loading from sewered residential homes in Vancouver. Because of the differences in rainfall, soil type, slope and climate between Smithers and Vancouver, the liberal loading estimates by Wiens are preferred. They are used to estimate the impact of new watershed development on the water quality of the lakes.

In summary each home on septic tanks (proper setbacks assumed), contributes about 0.65 kg (0.55 plus 0.10) of phosphorus to the lake per year, and each new home on a sewer system contributes about 0.10 kg P/yr.

Watershed development should only be permitted when the lake restoration methods outlined in Section 7.2 are implemented, and the water quality objective for phosphorus (15 µg/L at spring overturn) is attained. After restoration, the phosphorus loading can be increased by as much as 35 kg/yr in Kathlyn and Round Lakes, and 30 kg/yr in Tyhee Lake (according to the Reckhow and Simpson(1980) model) without any notable change being expected in phosphorus levels or water quality.

Based on the phosphorus loading rates for septic tanks (0.65 mg/yr), and sewered homes (0.1 kg/yr), Table 20 summarizes a range of additional development that could be allowed around each lake (except Seymour). The estimates assume that the setback recommendations outlined in Section 4.3 are met. The range of additional houses serviced by septic tanks or sewers gives the Regional District flexibility in determining the density of development.

Because there are no lake management proposals outlined in this report for Seymour Lake, no watershed development estimates are possible. The best recommendation that can be offered, is that no further development be allowed until the causes of eutrophication are known, corrected, and a watershed development strategy designed.

Kathlyn and Round Lakes can withstand similar amounts of watershed development. A maximum of 55 new housing units on septic tanks or 350 units on sewers is recommended in these watersheds. Tyhee Lake was considered more sensitive. A maximum of 45 new homes on septic tank, or 300 units on sewers is recommended.

The phosphorus loading from livestock was addressed in Section 5.9.2 for Tyhee and Round Lakes. Small 'hobby' farms are a possible concern around Kathlyn and Seymour Lakes. The following discussion attempts to assess the impact this type of farm would have on water quality.

Two assumptions are made: 1) the farms will be small (2-3 ha), and 2) the set back regulations outlined for septic tanks apply equally to livestock.

The phosphorus contribution from livestock was assessed at 16 kg/year for every animal unit (450 kg=1 animal unit) (Wiens, pers. comm.). The deposition of animal manure is on the soil surface, in comparison to the subsurface discharge of septic tanks. Surface deposition can allow mineralization and adsorption or uptake within the root zone. Offsetting this advantage over septic tanks is the possibility of direct discharge of manure into the lake or inflow streams during freshet or storm events. Based on this assessment, 10 percent of the phosphorus deposited on a 'hobby' farm will reach the lake. This is the same loading factor used for septic tanks.

The Ministry of Agriculture and Food (1983), noted that the livestock density on grazing pasture (no additional feed) is 1 000 kg/ha (2.2 animal units/ha). If feed is supplemented then densities can increase to 20 000 kg/ha (44 animal units/ha) without being classified as a feed lot. For the purpose of this report the livestock density of the typical 'hobby' farm is assumed to be 1 000 kg/ha. The phosphorus deposit rate of 16 kg/yr for every 450 kg of livestock yields a loading of 35 kg/ha. If every 'hobby' farm has 2 ha of grazing land the phosphorus deposition from each farm is 70 kg/yr. The volume of phosphorus entering a stream or lake is 10 percent of the volume deposited or 7 kg/yr.

The phosphorus loading from a house on septic tank was estimated at 0.65 kg/yr. Therefore, each 'hobby' farm of 2 ha size is equivalent to the impact of 10 houses using septic tanks.

8. MONITORING

8.1 FECAL COLIFORM BACTERIA

The sampling program outlined below is designed to determine the degree of attainment of the fecal coliform water quality objectives for domestic water supplies and contact recreation for each of the lakes. Because the laboratory is in Vancouver, samples must be collected on Monday or Tuesday, and transported by air.

Considering these restrictions, the domestic fecal monitoring should be five weekly samples over 30 days at two locations on each lake. The sites, are left to the discretion of the sampler but should be associated with a domestic or waterworks licence. Location of the site should, however, be consistent to assure comparability of data.

The sample can be collected within 10 m of the intake or at a tap (or outside location) that comes directly from the lake (no chlorination or filtering). The line should be thoroughly flushed before filling the sample bottle from the tap.

Monitoring for primary contact water recreation should be during the summer months (June through August). The beaches at the north end of Kathlyn Lake and the Tyhee Lake Provincial Park should be sampled weekly. Five weekly samples over 30 days should be taken at different locations along each beach. Samples should be taken 2 m from shore at the surface. The presence of swimmers must be noted at the time of sampling.

8.2 GENERAL WATER QUALITY

Regular water quality monitoring is a key element in determining the effectiveness of watershed management initiatives. In the present case, phosphorus concentration at spring overturn, together with mean summer chlorphyll a concentrations, are the basic variables expected to change if the lake and watershed management recommendations are followed. Monitoring programs however, may be limited by available manpower and budgets.

Because Round and Tyhee Lakes have similar characteristics, it is not necessary to monitor both lakes to the same extent. Only spring overturn nutrients should be collected from Round Lake (site 1131008). The more extensive monitoring of Tyhee Lake (site 1131009) is outlined below. The monitoring of Kathlyn Lake (site 1131007) will be the same as Tyhee Lake

The recommended monitoring for Tyhee and Kathlyn is as follows:

	Late Winter	Spring Overturn	Mid July	End of August
Dissolved oxygen profile	x	x	x	x
Temperature profile	x	x	x	x
Ammonia-nitrogen		x	x	x
Nitrate-nitrogen		x	x	x
Organic nitrogen		x	x	x
Total nitrogen		x	x	x
Ortho phosphorus		x	x	x
Total phosphorus		x	x	x
Total metals (package F)		x		
Chlorophyll a		x	x	x
Phytoplankton		x	x	x
Zooplankton			x	x
Turbidity		x	x	x
Secchi disc		x	x	x
Colour		x	x	x

Further inverstigations on Seymour Lake are needed to clarify the source of nutrients and colour. The special investigation of Seymour Lake should follow the same routine, but nutrients, chlorophyll a, colour and turbidity should be added for the late winter sampling event. In addition, nutrients, colour, total carbon, organic carbon and turbidity should be measured monthly in inlet and outlet streams. This should provide the basis for assessing nutrient loading and a management prescription for Seymour Lake.

If lake restoration projects are undertaken at Round Lake, then it will be necessary to monitor that lake, in order to evaluate the project's impact on water quality.

In addition to the annual monitoring outlined above, Section 2.3 outlines four recommendations that would provide more reliable runoff and flushling rate estimates for all the lakes.

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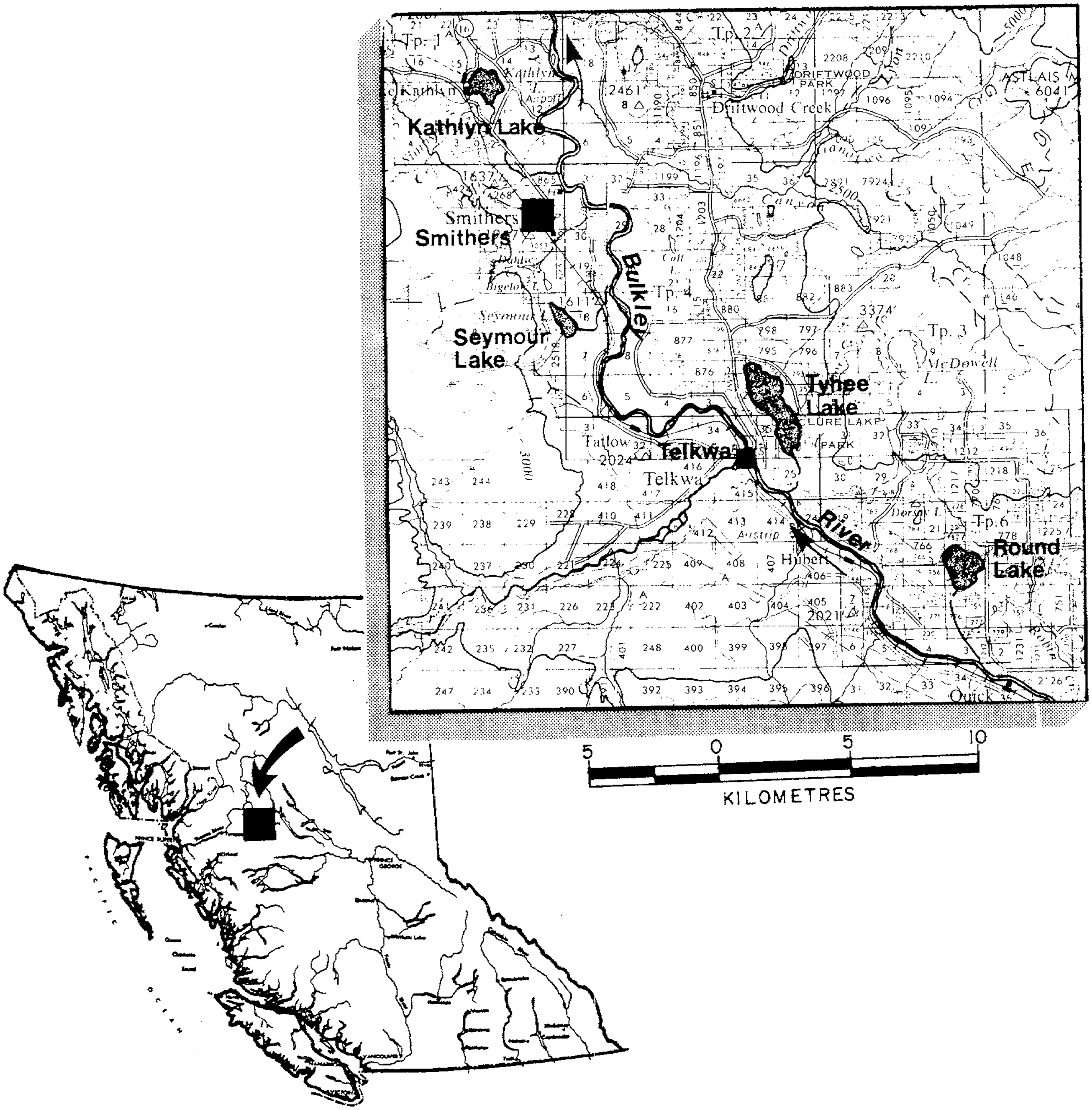


FIGURE 1 Location of Kathlyn, Seymour, Round and Tyhee Lakes

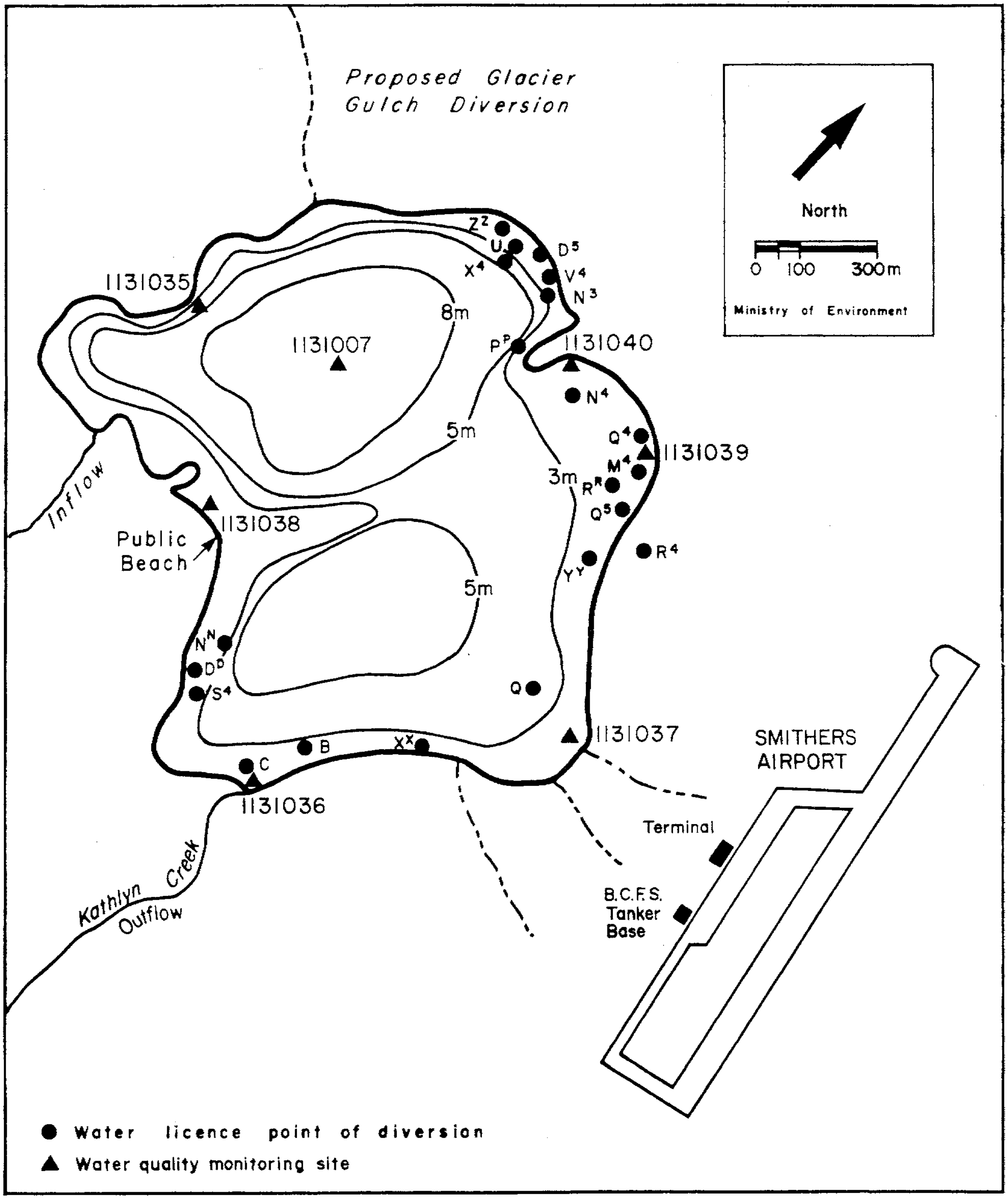


FIGURE 2: BATHYMETRY, WATER LICENCE POINT OF DIVERSION, AND WATER QUALITY SITES FOR KATHLYN LAKE

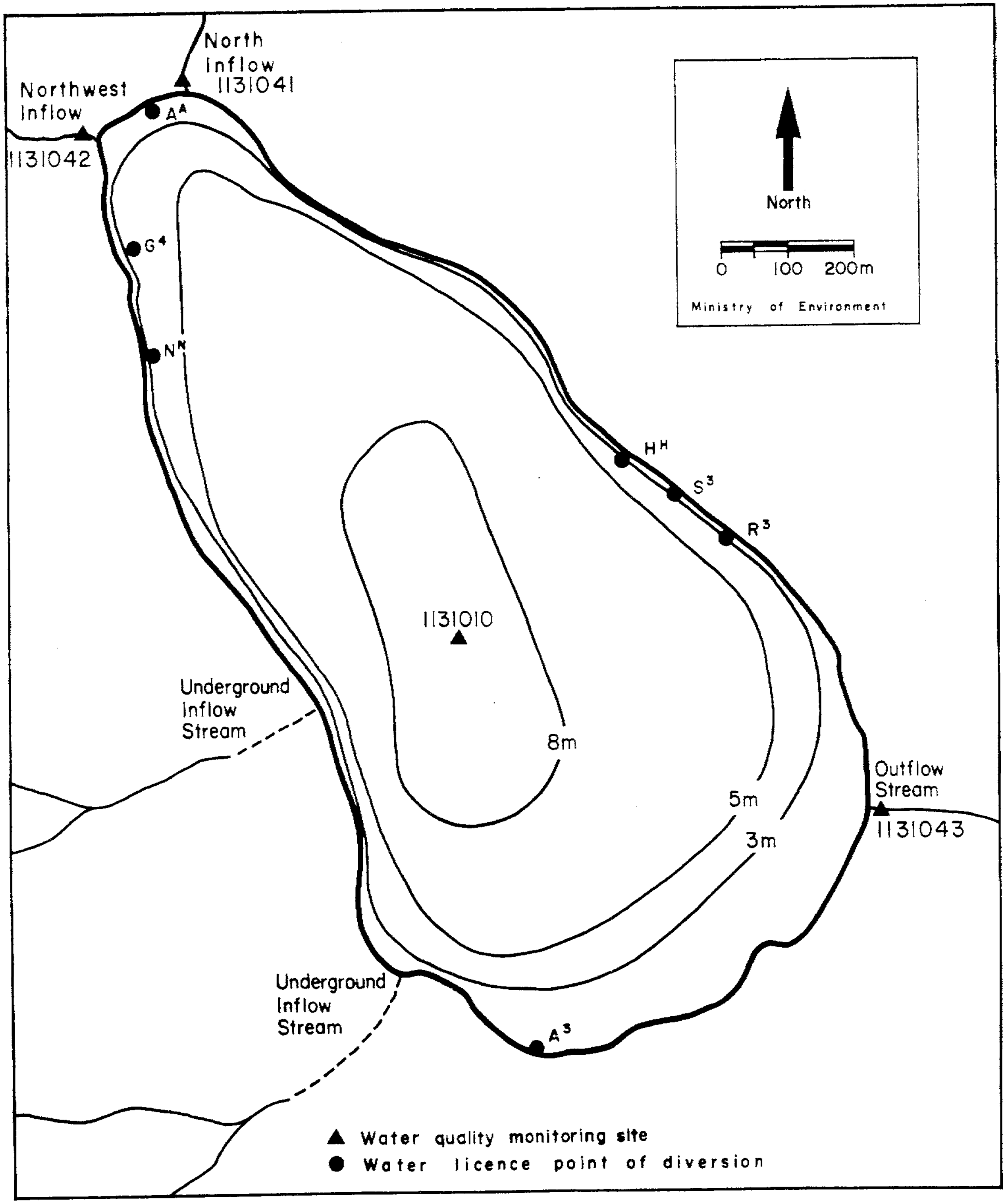


FIGURE 3: BATHYMETRY, WATER LICENCE POINT OF DIVERSION, AND WATER QUALITY SITES FOR SEYMOUR LAKE

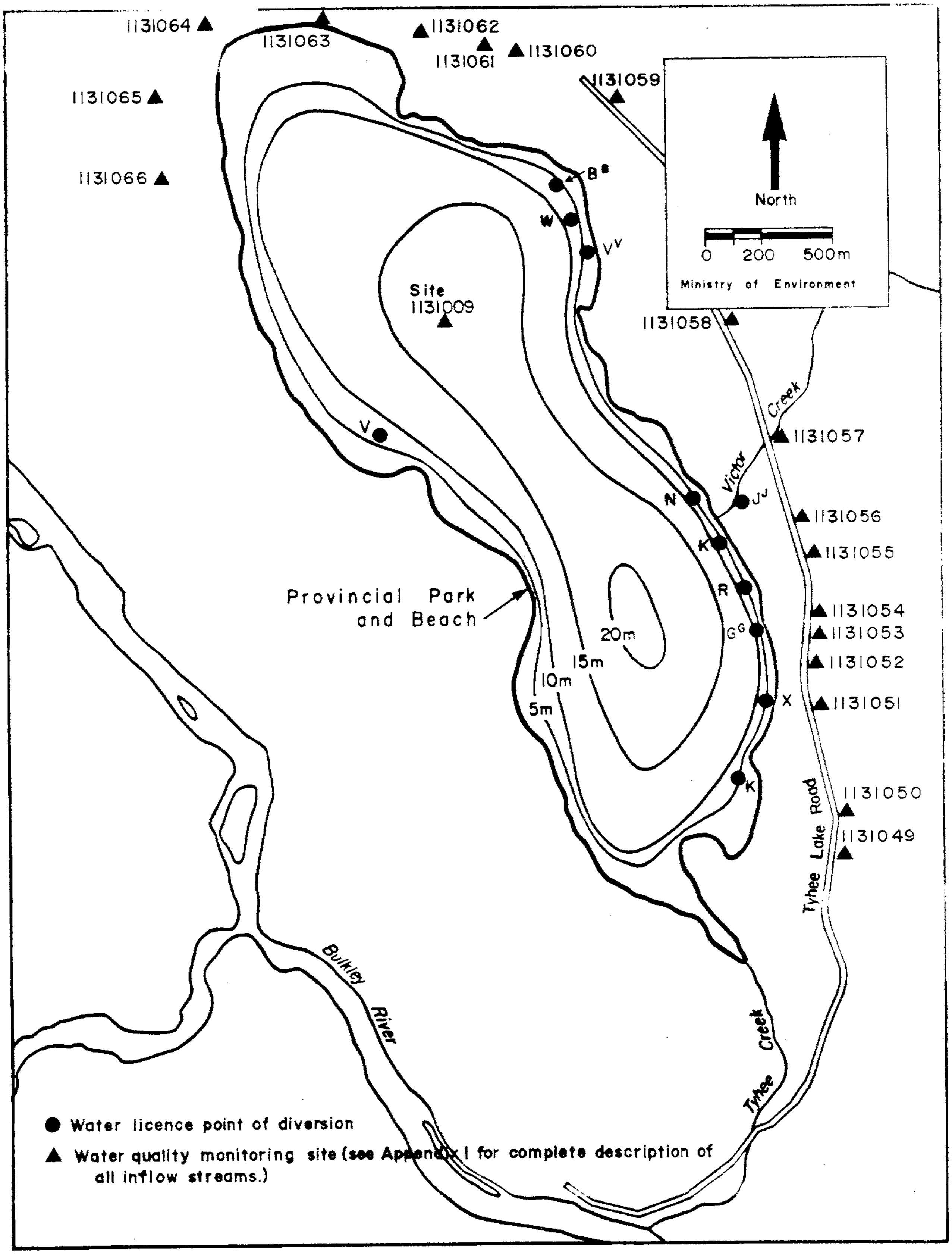


FIGURE 4: BATHYMETRY, WATER LICENCE POINT OF DIVERSION AND WATER QUALITY SITES FOR TYHEE LAKE

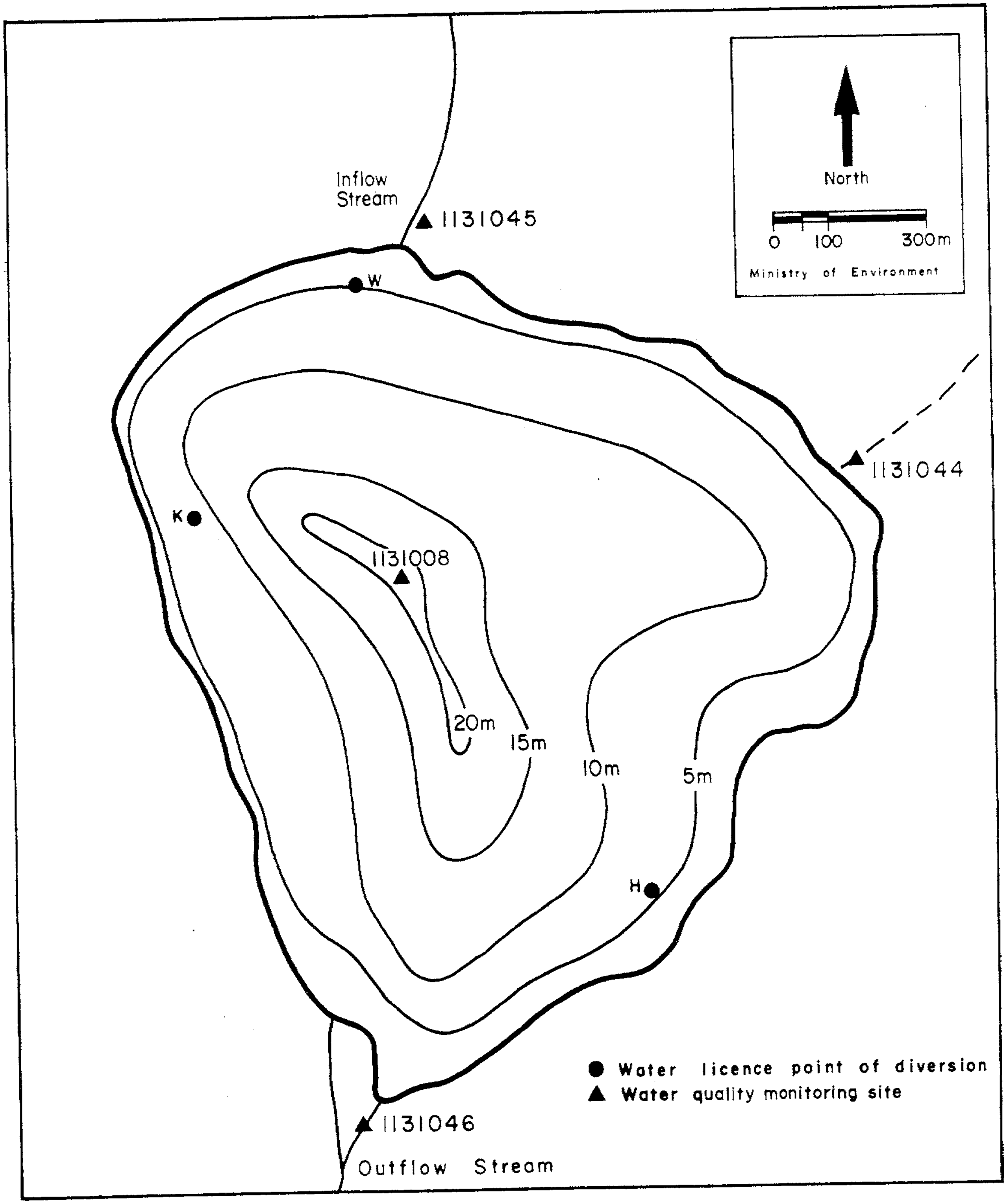


FIGURE 5: BATHYMETRY, WATER LICENCE POINT OF DIVERSION AND WATER QUALITY SITES FOR ROUND LAKE

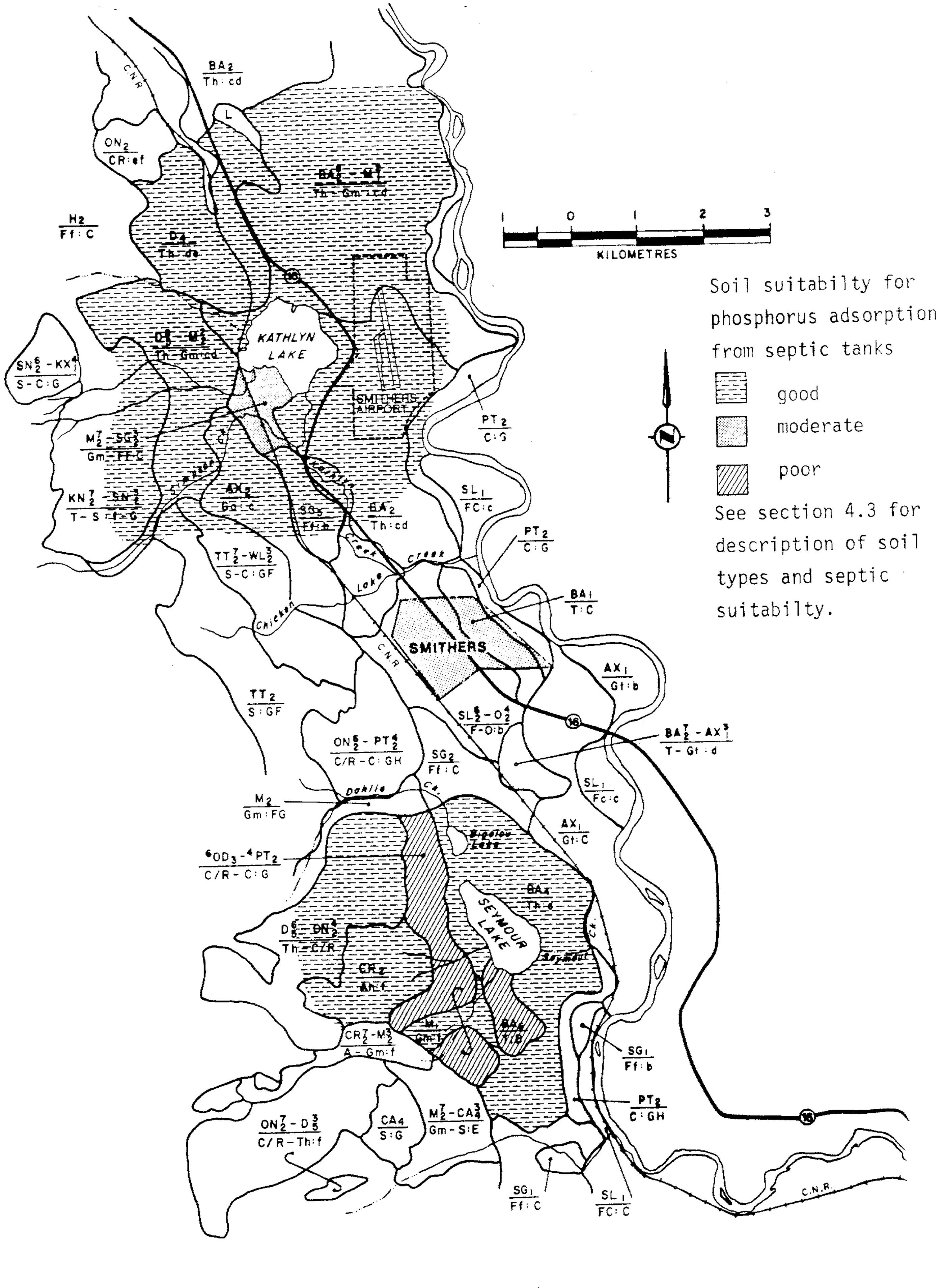


FIGURE 6: SOIL TYPES AND SEPTIC TANK SUITABILITY FOR KATHLYN AND SEYMOUR LAKES

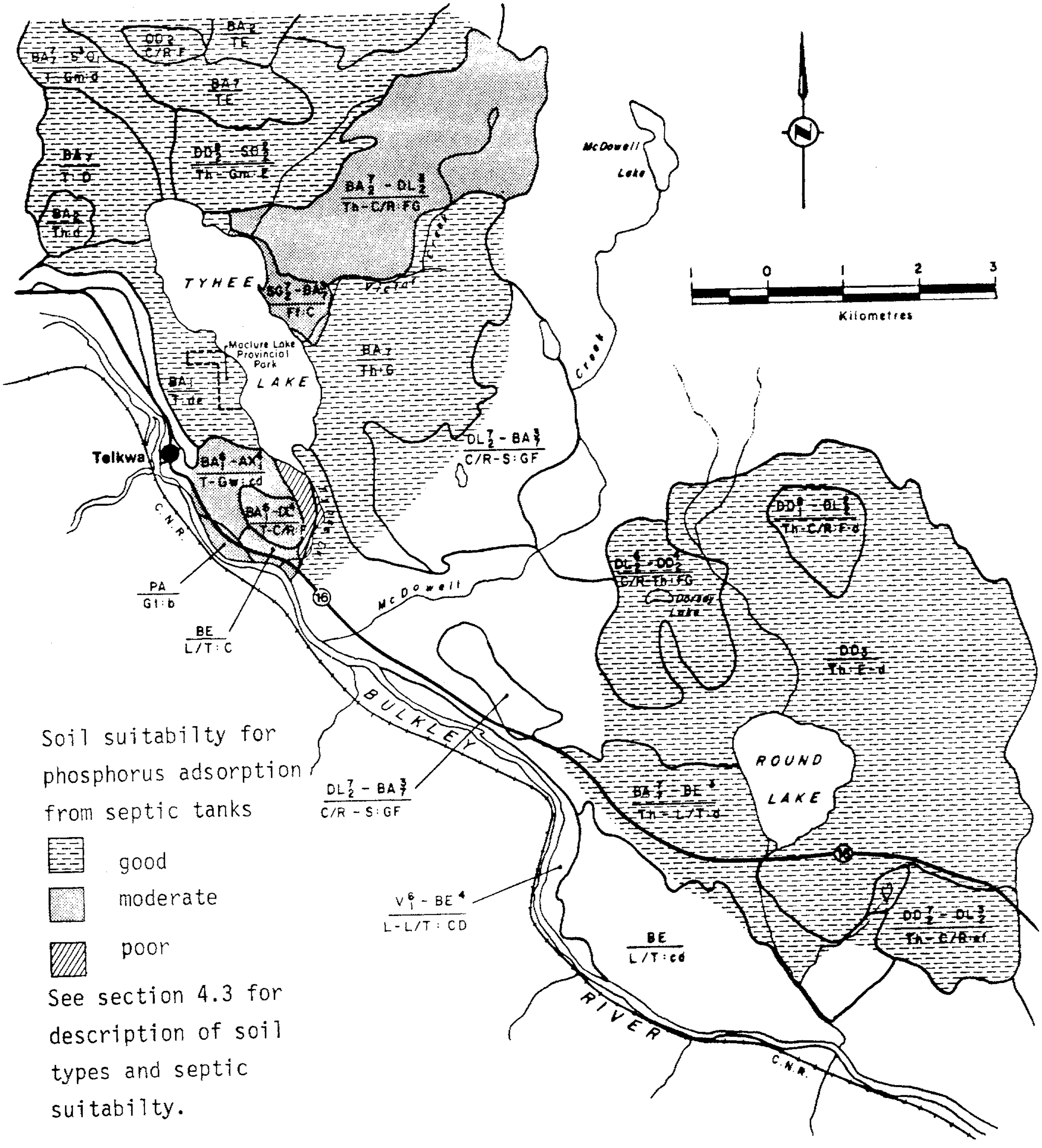


FIGURE 7: SOIL TYPES AND SEPTIC SUITABILITY FOR TYHEE AND ROUND LAKES

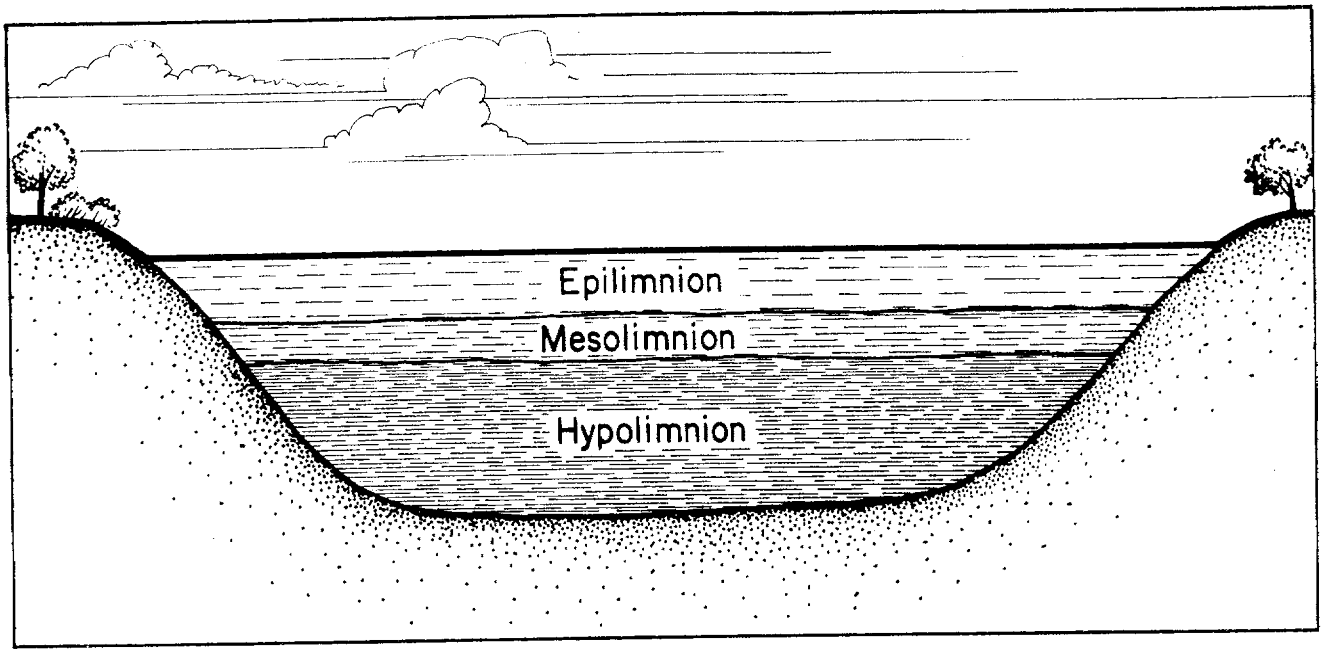


FIGURE 8: A GENERAL STRATIFICATION REGIME IN A TYPICAL LAKE

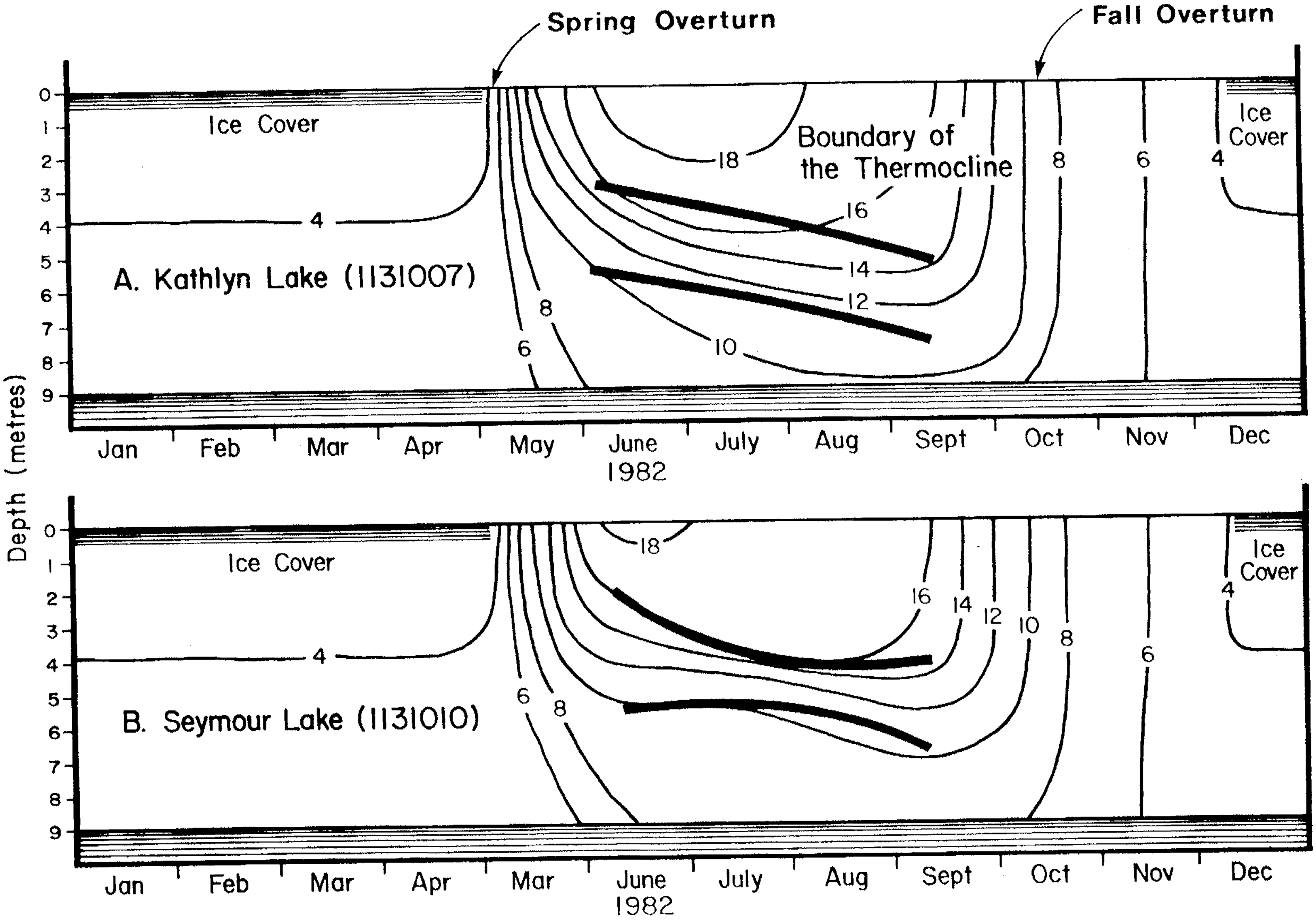


FIGURE 9: TEMPERATURE CONDITIONS IN KATHLYN AND SEYMOUR LAKES IN 1982

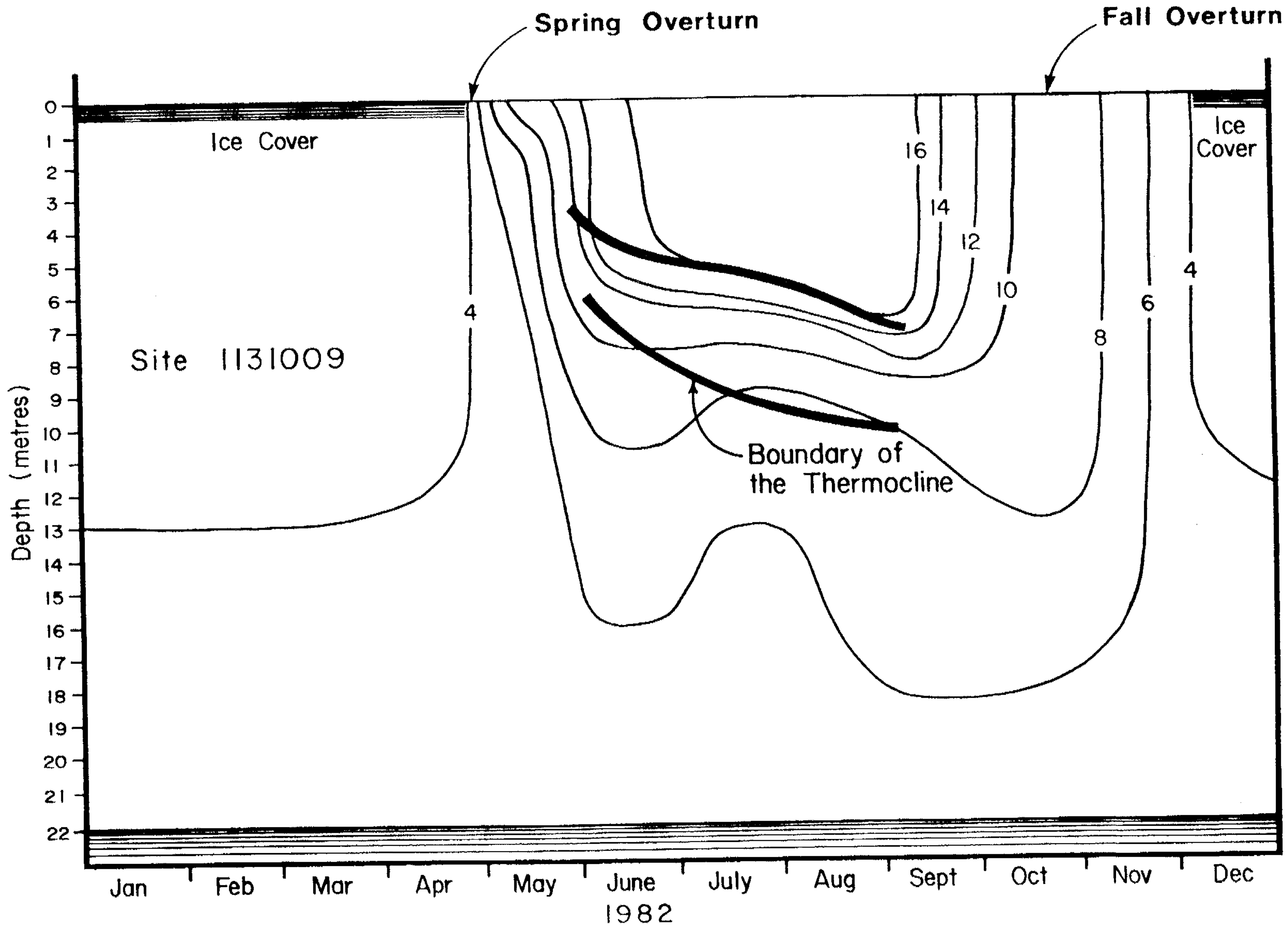


FIGURE 10: TEMPERATURE CONDITIONS IN TYHEE LAKE IN 1982

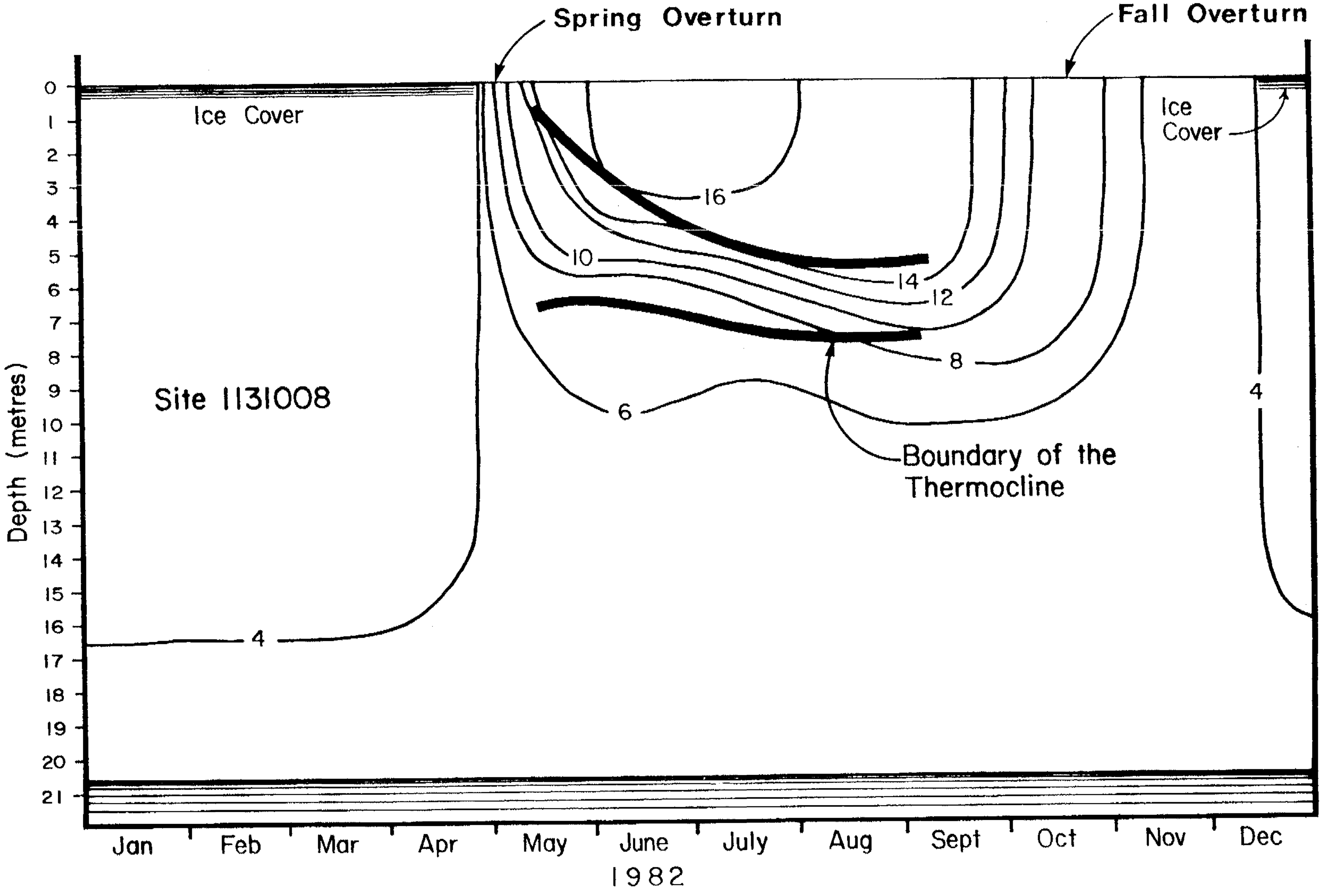


FIGURE 11: TEMPERATURE CONDITIONS IN ROUND LAKE IN 1982

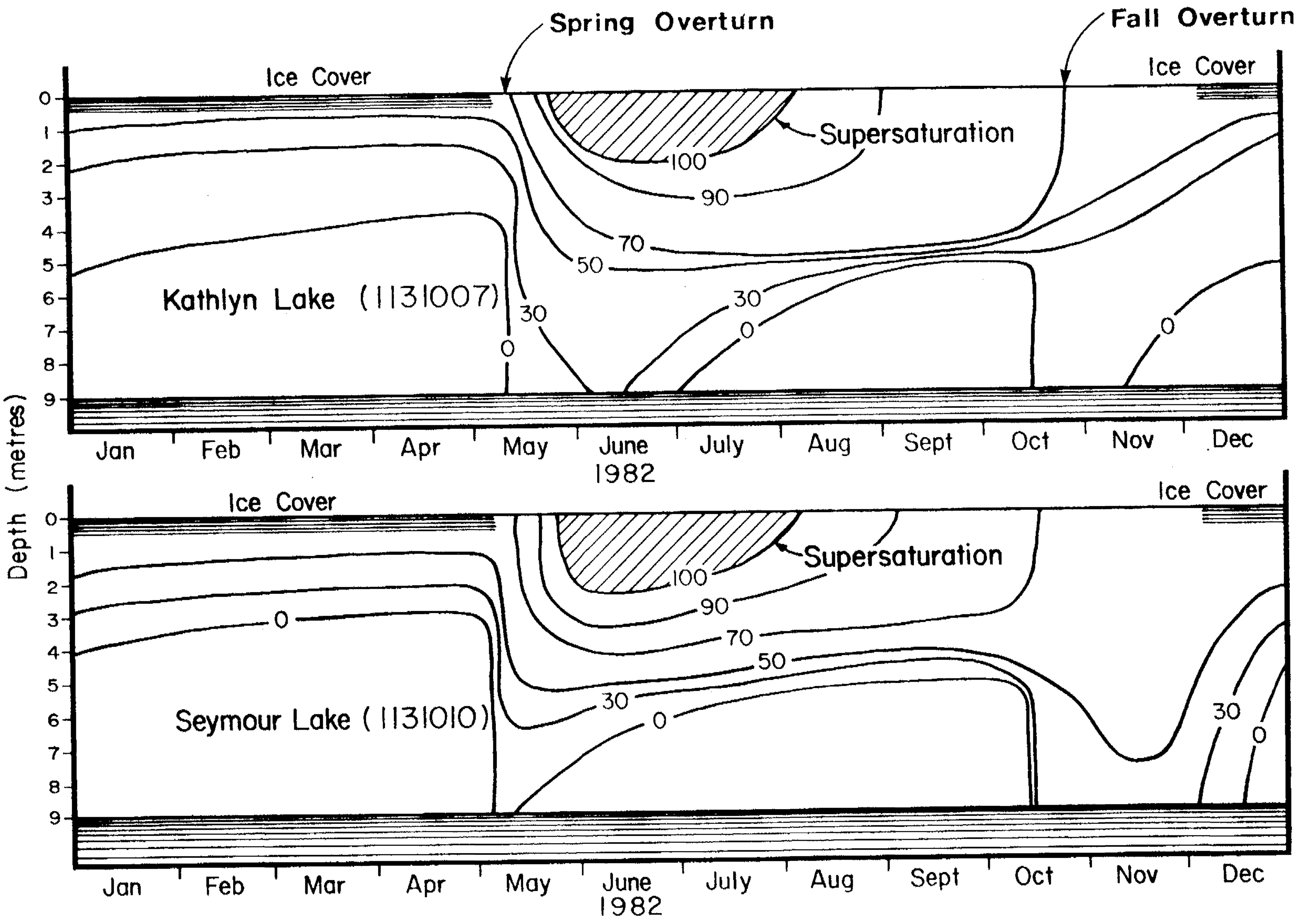


FIGURE 12: DISSOLVED OXYGEN (as percent saturation) FOR KATHLYN AND SEYMOUR LAKES IN 1982

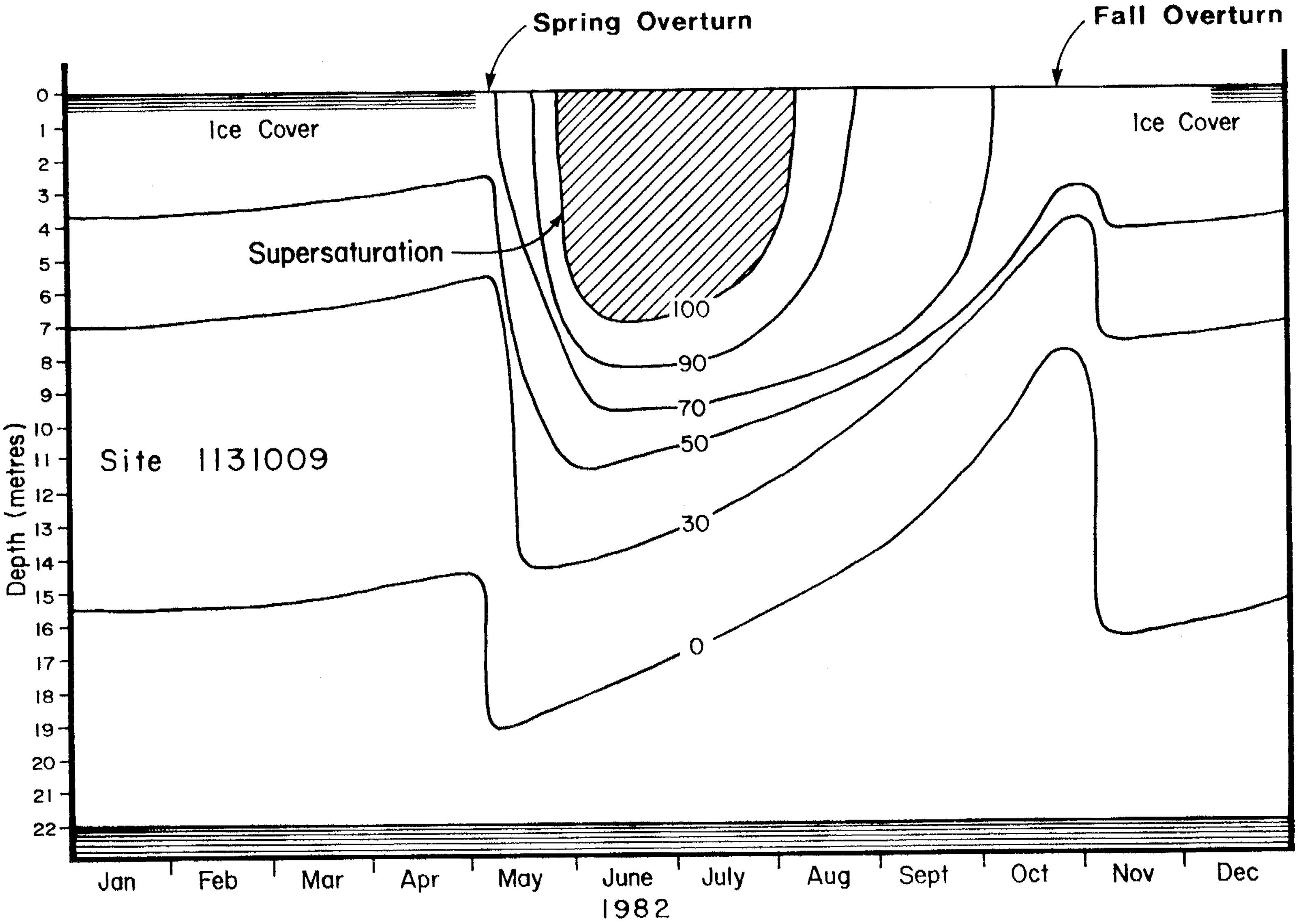


FIGURE 13: DISSOLVED OXYGEN (as percent saturation) FOR TYHEE LAKE IN 1982

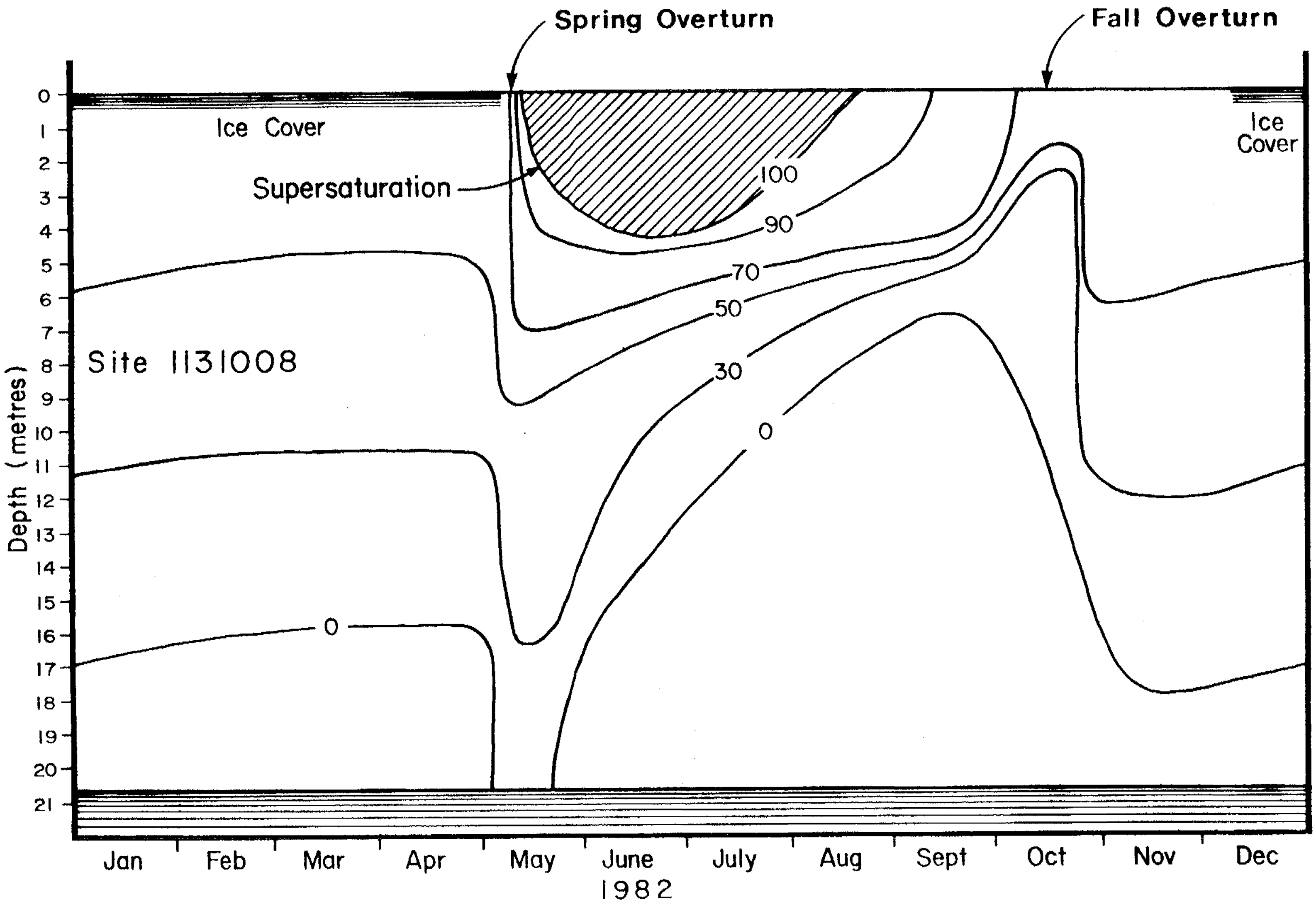


FIGURE 14: DISSOLVED OXYGEN (as percent saturation) FOR ROUND LAKE IN 1982

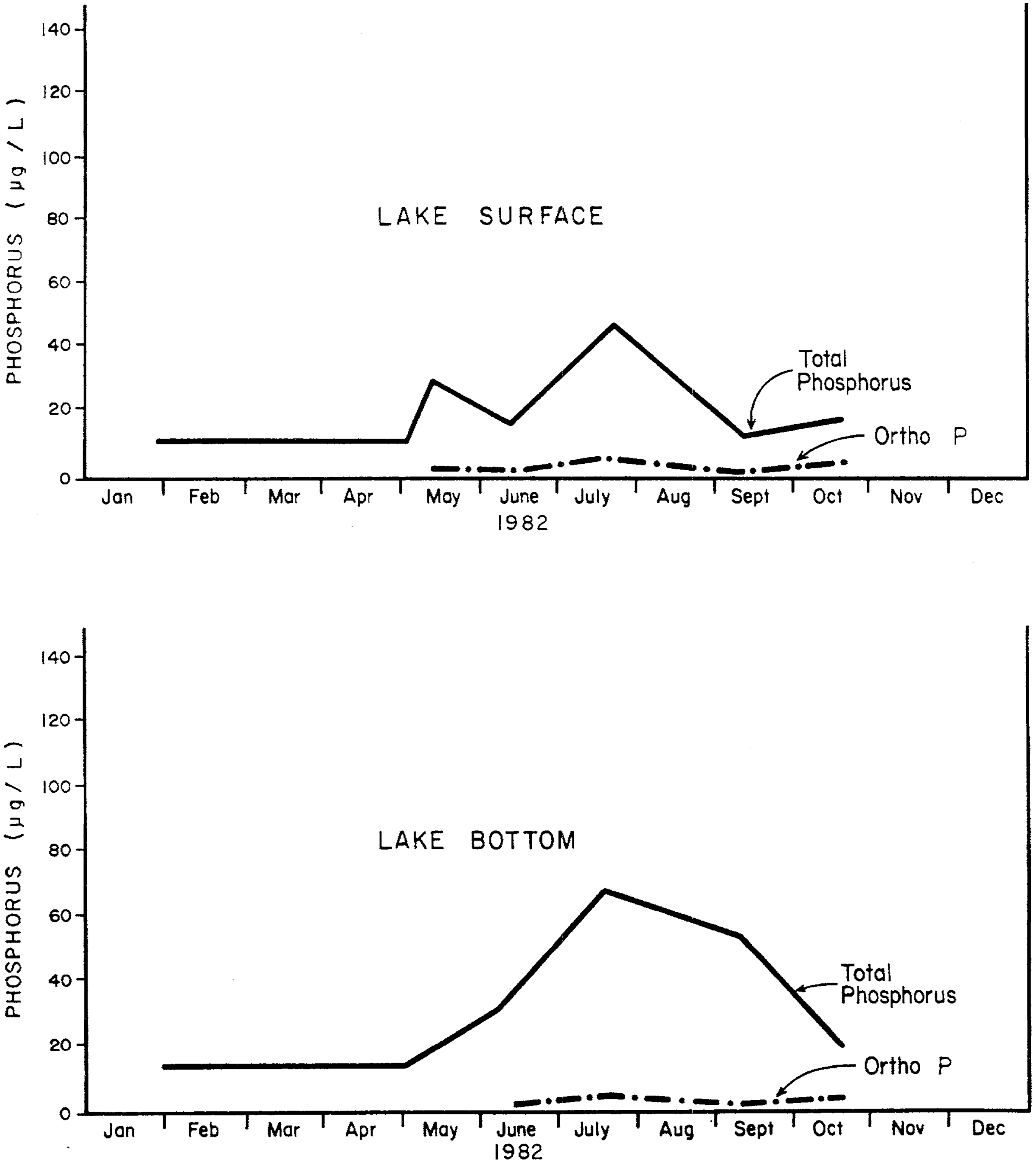


FIGURE 15: PHOSPHORUS CONCENTRATIONS IN THE SURFACE AND BOTTOM WATERS OF KATHLYN LAKE

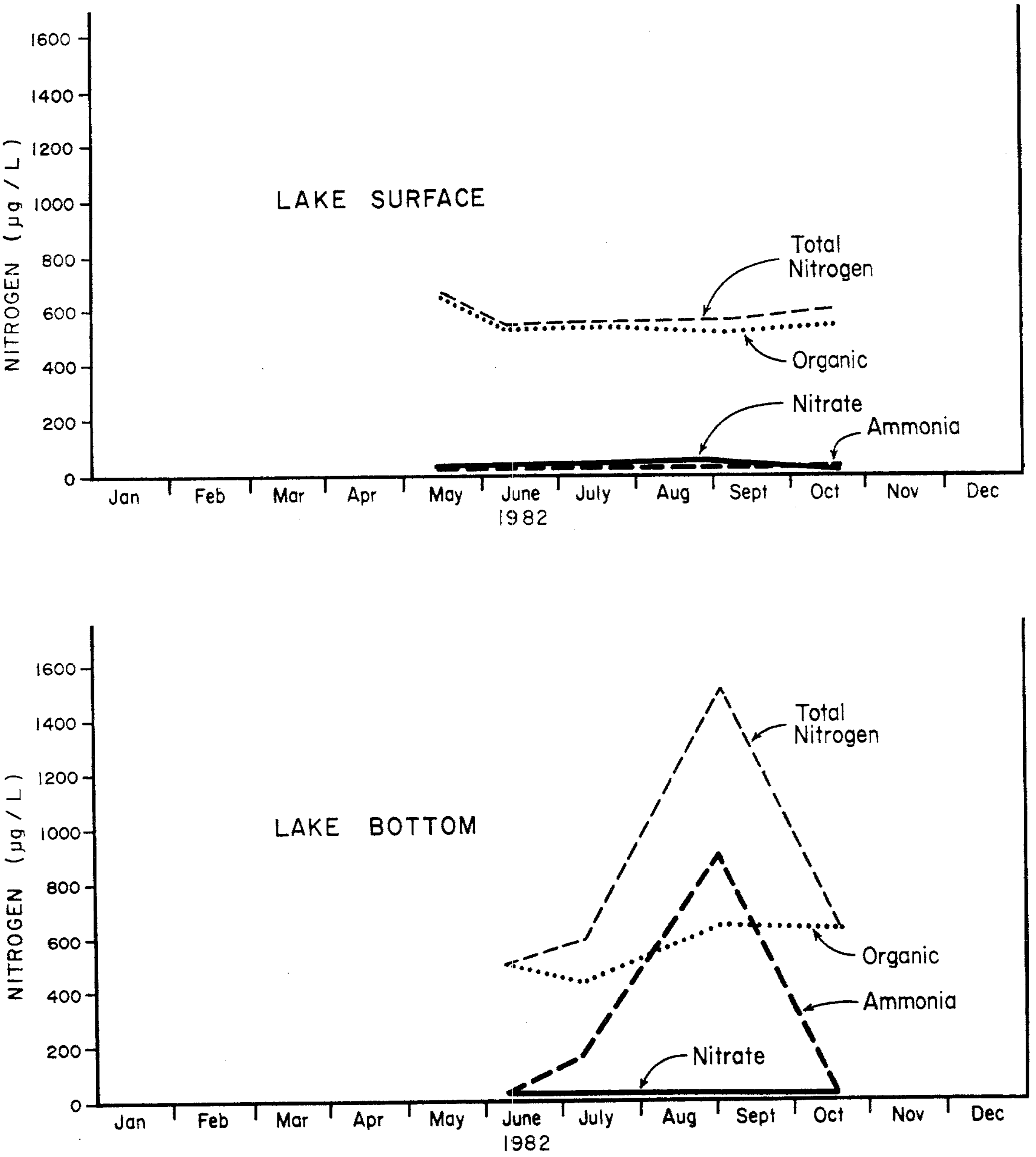


FIGURE 16: NITROGEN CONCENTRATIONS IN THE SURFACE AND BOTTOM WATERS OF KATHLYN LAKE

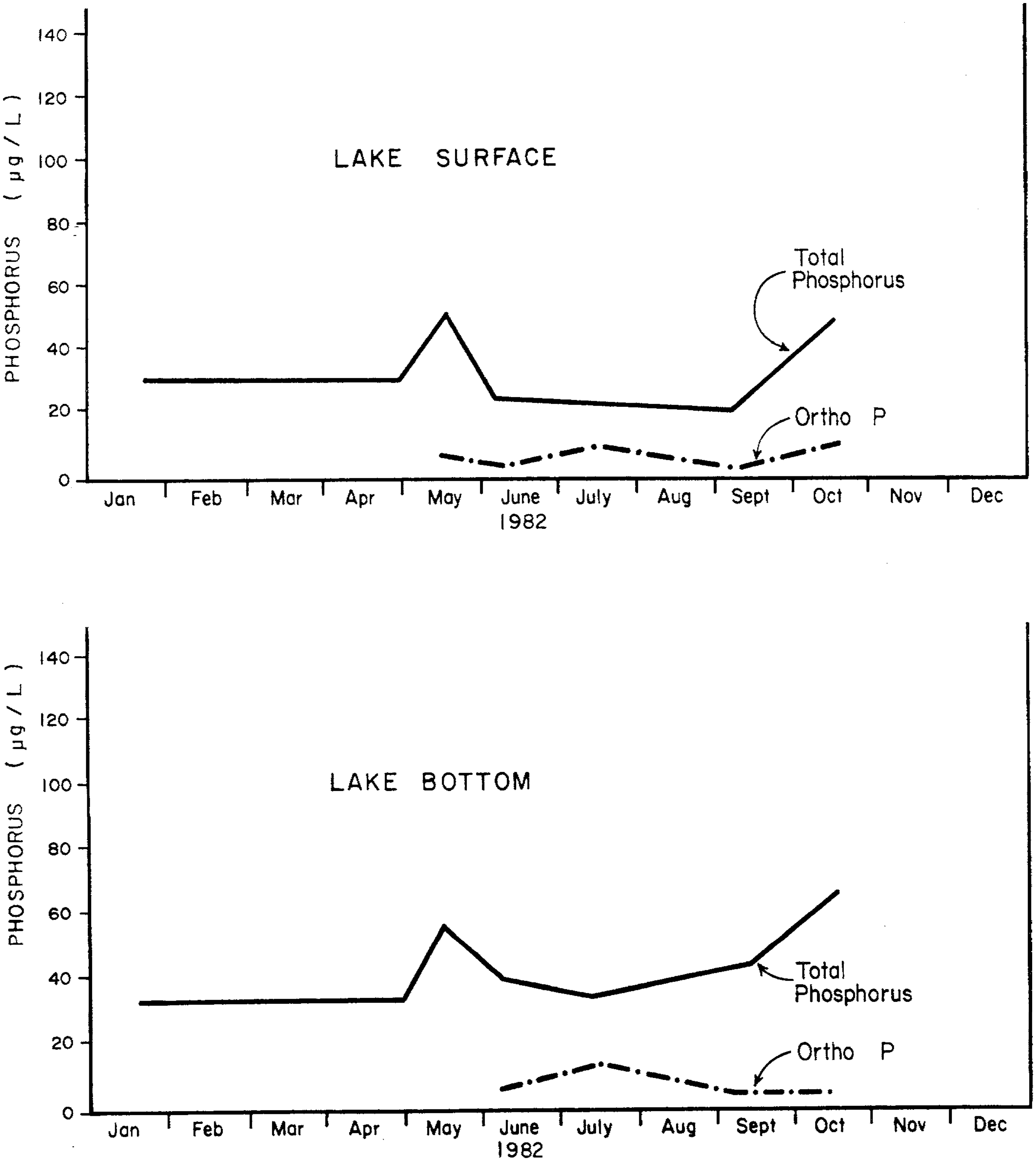
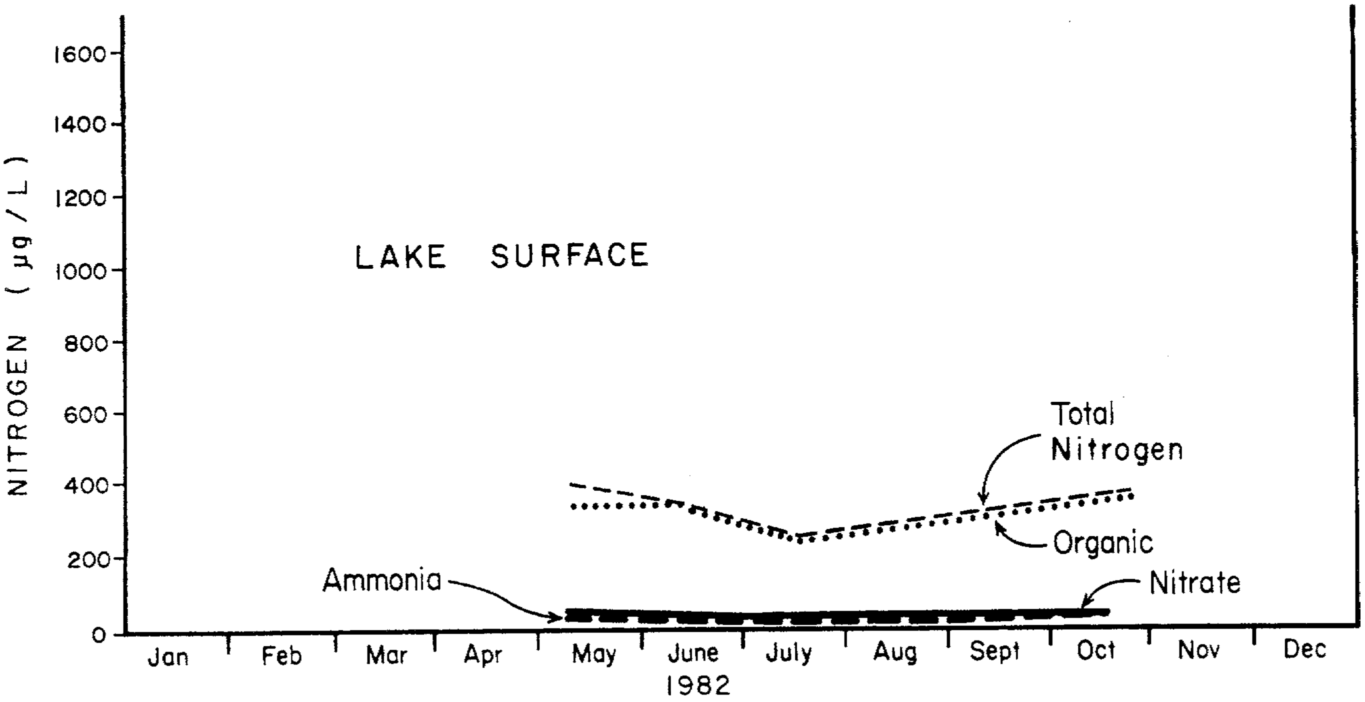


FIGURE 17: PHOSPHORUS CONCENTRATIONS IN THE SURFACE AND BOTTOM WATERS OF SEYMOUR LAKE



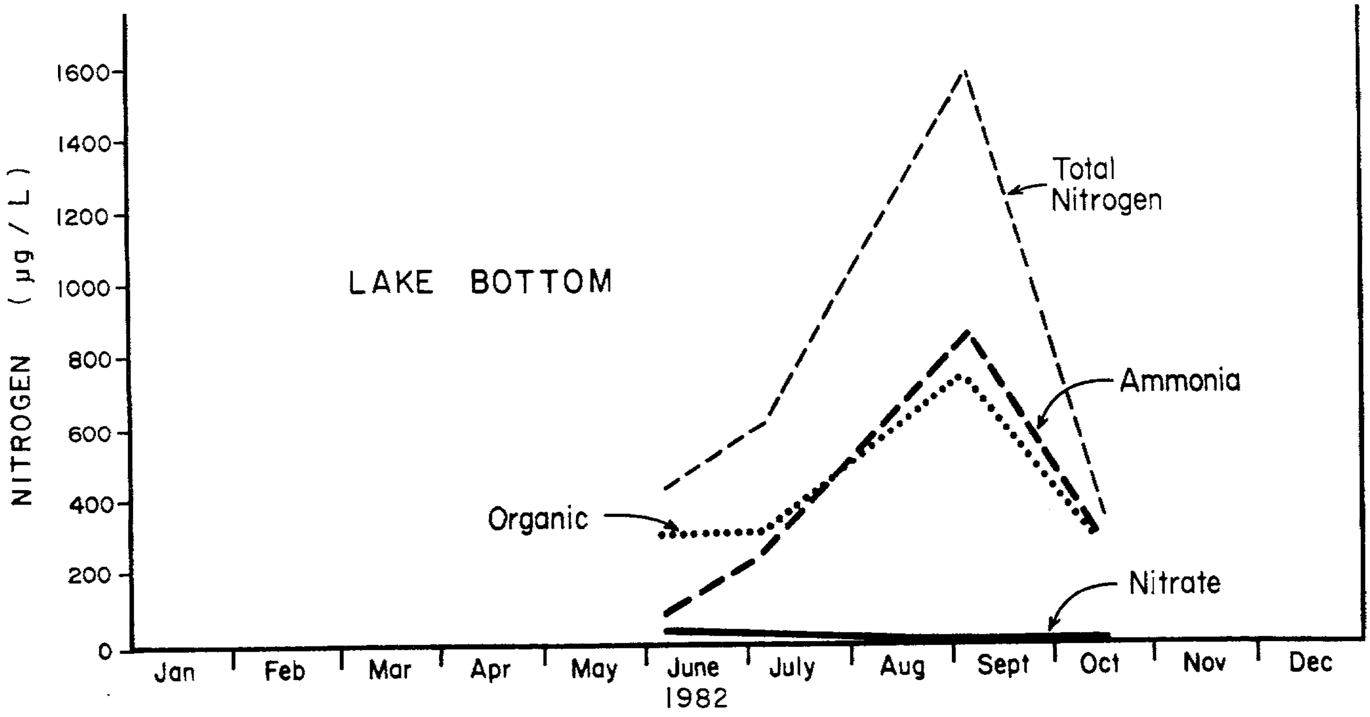
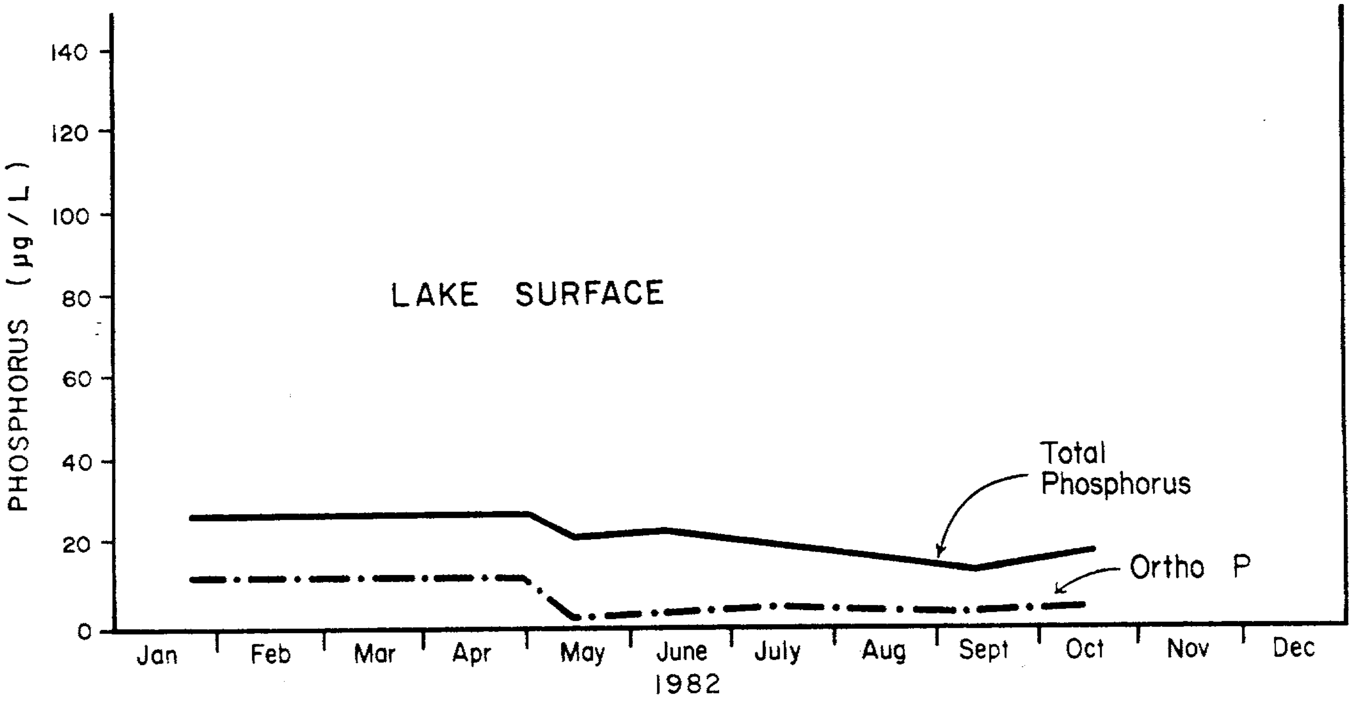


FIGURE 18: NITROGEN CONCENTRATIONS IN THE SURFACE AND BOTTOM WATERS OF SEYMOUR LAKE



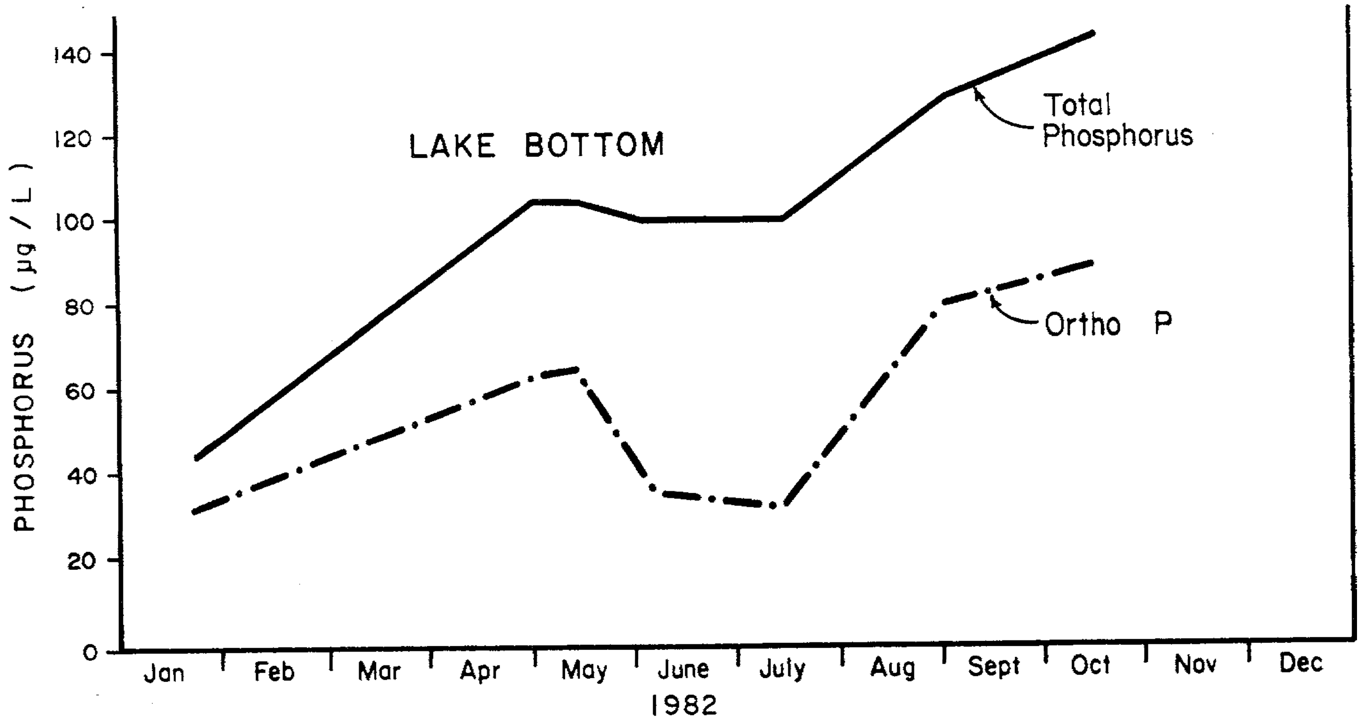
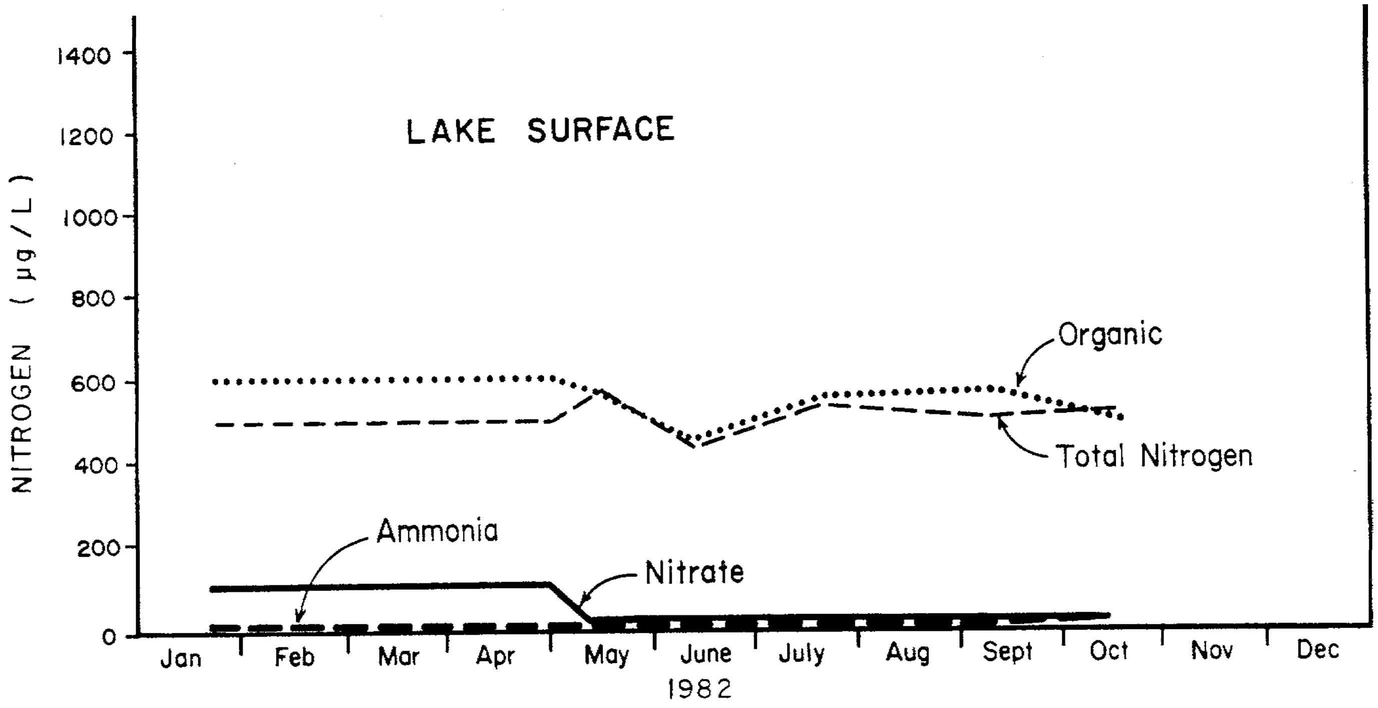


FIGURE 19: PHOSPHORUS CONCENTRATIONS IN THE SURFACE AND BOTTOM WATERS OF TYHEE LAKE



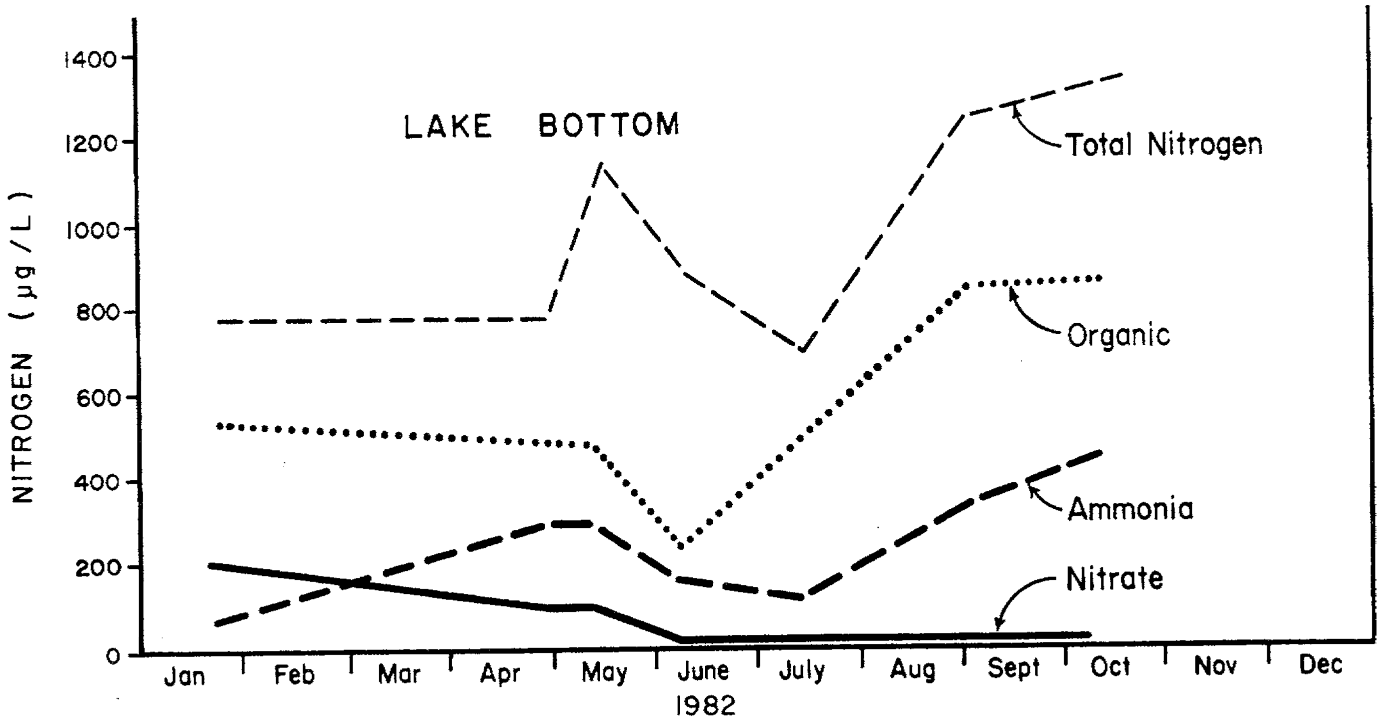


FIGURE 20: NITROGEN CONCENTRATIONS IN THE SURFACE AND BOTTOM WATERS OF TYHEE LAKE

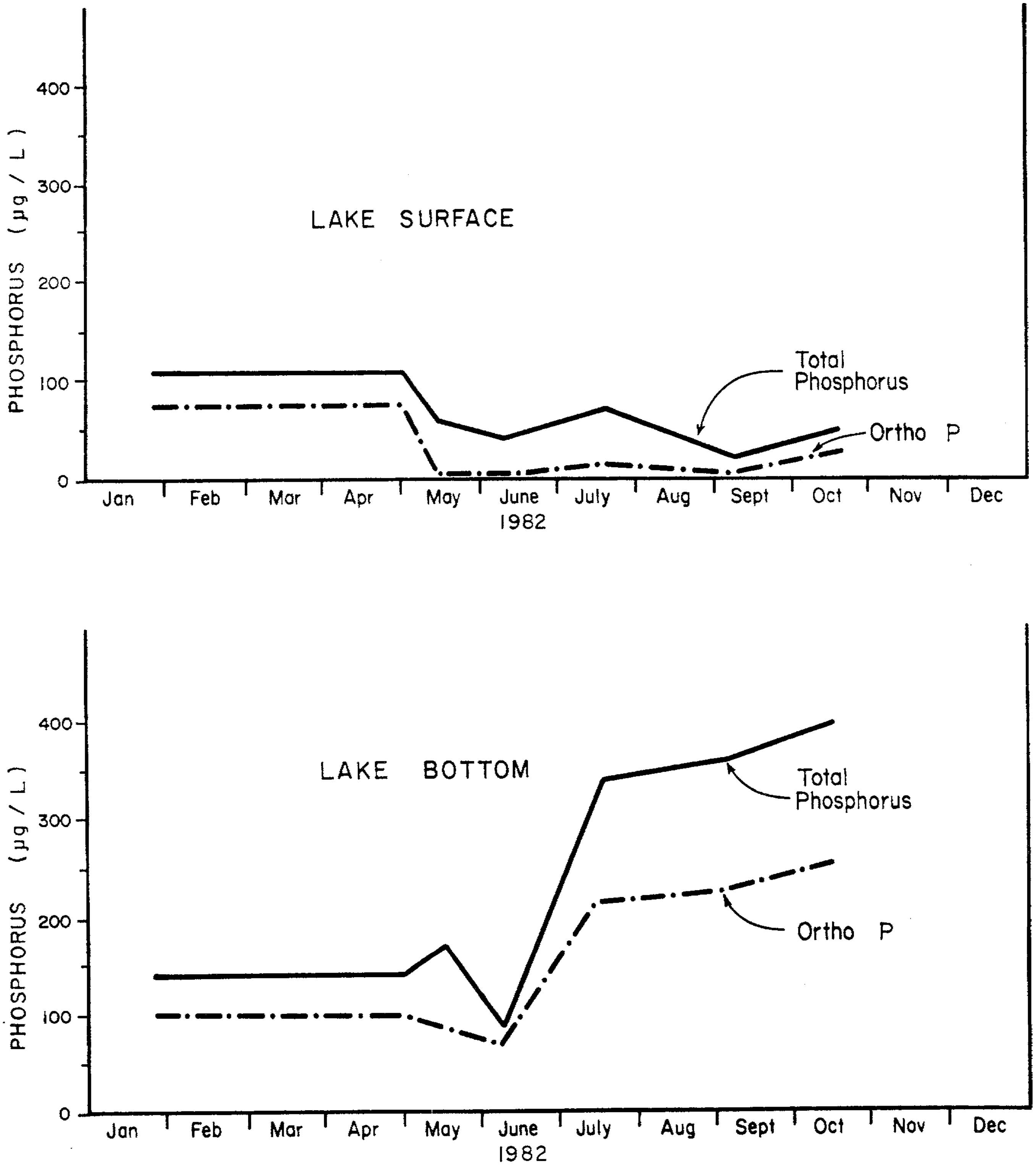


FIGURE 21: PHOSPHORUS CONCENTRATIONS IN THE SURFACE AND BOTTOM WATERS OF ROUND LAKE

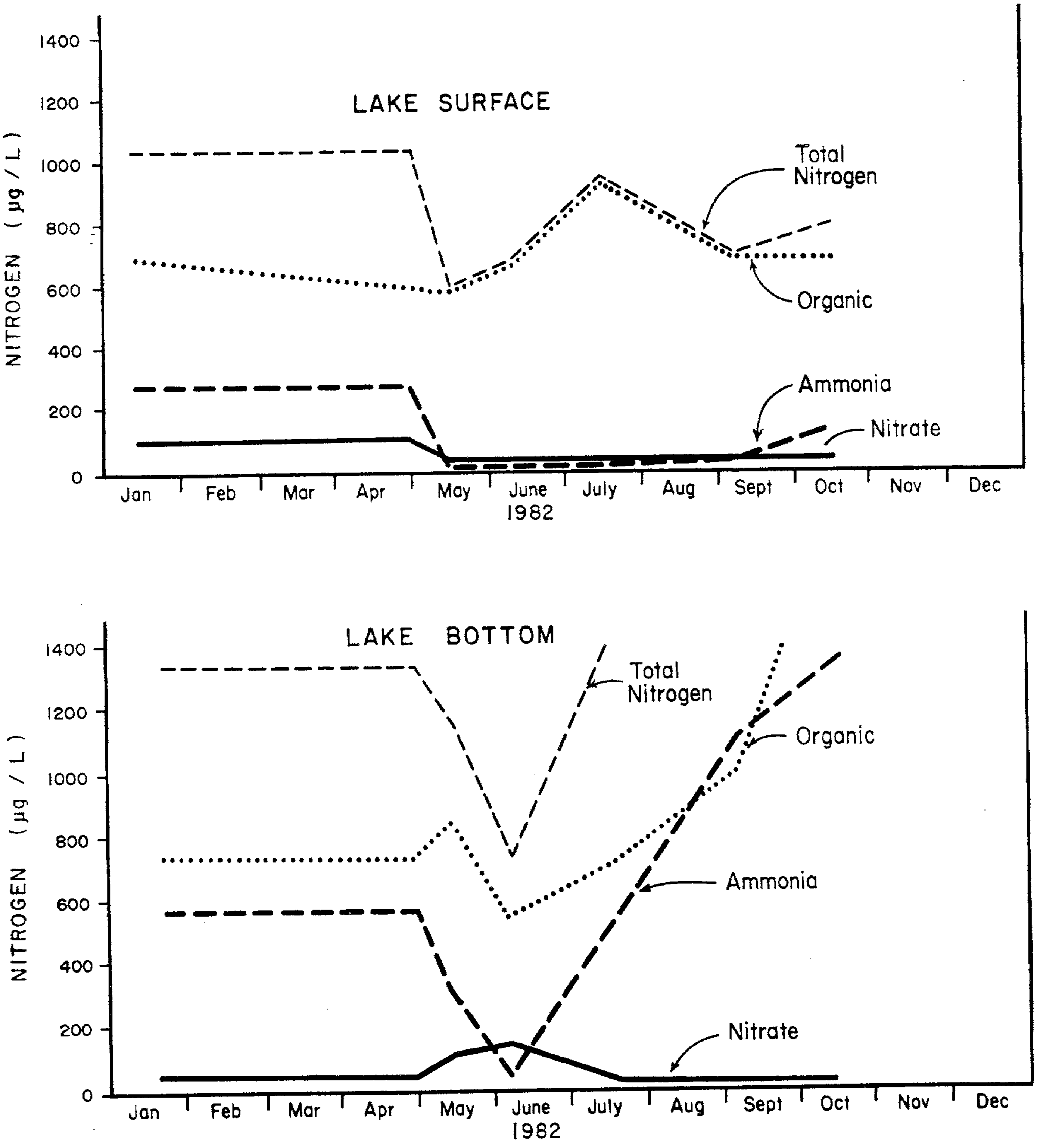


FIGURE 22: NITROGEN CONCENTRATIONS IN THE SURFACE AND BOTTOM WATERS OF ROUND LAKE

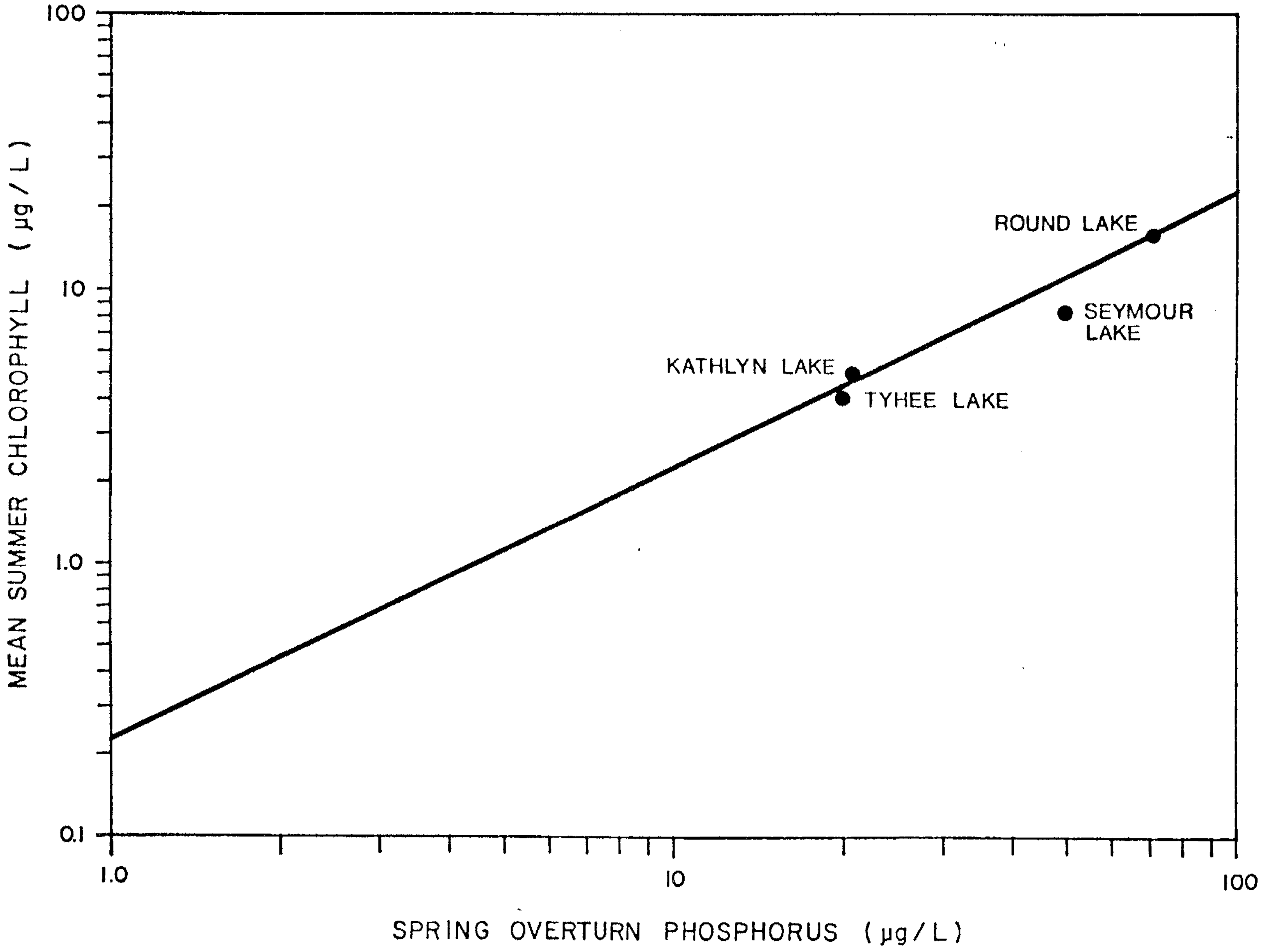


FIGURE 23: PHOSPHORUS-CHLOROPHYLL a RELATIONSHIP FOR BRITISH COLUMBIA LAKES, IN RELATION TO THE STUDY LAKES

TABLE 1
SUMMARY OF MORPHOMETRIC DATA*

Attribute	KATHLYN	SEYMOUR	ROUND	TYHEE
Elevation (m)	472	496	579	549
Surface Area (ha)	170	89.5	182	318
Volume (dam^3)**	7780	5120	17 516	35 278
Mean Depth (m)	4.6	5.7	9.6	11.1
Maximum Depth (m)	9.5	9.2	20.4	22.2
Perimeter (m)	6130	4115	5 334	9 754

* from Resource Quality Section, Water Management Branch
** dam^3 = cubic decametre (1000 m^3)

TABLE 2
HYDROMETRIC DATA USED*

STATION NUMBER	STATION NAME	PERIOD OF RECORD	DRAINAGE AREA (km^2)	Median Basin Elevation (m)
08EE014	Canyon Cr. nr. Smithers	73-81	252 (256)**	1006
08EE008	Goathorn Cr. nr. Telkwa	60-81	149 (132)	1104
08EE018	Maxum Cr. ab. Bulkey Lk.	74-79&	323 (368)	1030
08EE012	Simpson Cr. at the Mouth	69-71 74-81	12.2 (13.2)	1540
08EE009	Richfield Cr. nr. Topley	64-74	120 (173)	1174
08EE010	Kathlyn Cr. ab. Simpson Cr.	67-79	20.0 (24.6)	1112
08EE011	Kathlyn Lk. nr. Smithers	68-80		

* Source: Water Survey of Canada (1977)
** Drainage Areas in brackets are Water Survey of Canada figures.

TABLE 3
AVERAGE RUNOFF, WATER RETENTION TIME AND FLUSHING RATES OF THE FOUR STUDY LAKES

LAKE	ESTIMATED AVERAGE RUNOFF (dam^3)*			LAKE VOLUME (dam^3)	WATER RETENTION TIME (yr.)			FLUSHING RATE (yr^{-1})		
	Max.	Min.	Mean		Max.	Min.	Mean	Max.	Min.	Mean
Kathlyn			6700	7 780			1.15			0.9
Seymour	6000	3020	4510	4 150	1.33	0.73	0.92	0.75	1.4	1.1
Tyhee	12 000	2130	7065	35 275	16.6	2.94	5.0	0.3	0.06	0.2
Round	9000	2000	5500	17 260	1.9	8.6	3.1	0.52	0.12	0.3

* Estimates from Weiss (1982)

TABLE 4
WATER LICENCES ON KATHLYN LAKE*

PRIORITY DATE	LICENCE NUMBER	POINT OF WITHDRAWAL (FIGURE 2)	VOLUME	USE	LOCATION	LICENCEE
1941-12-10	C 35769	Q	455 m^3/d	IND*	Lease #70463 situated in E 1/2 of NES 1/4 of Sec 11 TP 1A R 5 Coast Dist	Engineering Branch Forests, Ministry of
1958-12-09	F 20844	B	9 m^3/d	DOM	L 10-13 Incl of Frac Sec 11 TP 1A R 5 Coast Dist Plan 1243	Roda Holdings Ltd.
1958-12-09	F 21526	C	2.3 m^3/d	DOM	L 8 of Frac Sec 11 TP 1A R 5 Coast Dist Plan 3958	Gelley, Louis J.
1963-01-28	F 19245	DD	2.3 m^3/d	DOM	L 67 of Sec 11 TP 1A R 5 Coast Dist Plan 1243	Kent, Ralph E. and Wendy N.
1965-06-15	F 38109	U	2.3 m^3/d	DOM	Blk 4 of Sec 14 TP 1A R 5 Coast Dist Plan 1225	Miller, Ronald J. Dr. and E.
1965-06-21	F 57178	NN	2.3 m^3/d 1.2 dam^3	DOM IRR	L 4 of Sec 11 TP 14 R 5 Coast Dist Plan 1243	Deguchi, Harry/ Chiyo
1965-07-30	F 20861	PP	2.3 m^3/d	DOM	L 10 of Sec 14 TP 1A R 5 Coast Dist Plan 1225	Graham, Dorothy I.
1965-11-15	F 21527	RR	2.3 m^3/d	DOM	PCL A (81862I) of Blk B Ref Plan 1589 Sec 14 TP 1A R 5 Coast Dist Plan 1463	Graydon, Edmund T.
1966-02-03	F 38713	XX	2.3 m^3/d	DOM	L 17-19 Incl of Frac Sec 11 TP 1A R 5 Coast Dist Plan 1243	Harvey, Ruth M.
1966-04-28	F 42177	YY	2.3 m^3/d	DOM	L B of Frac Sec 14 TP 1A R 5 Coast Dist Plan 1622	Balz, Herbert
1966-04-28	F 21126	ZZ	2.3 m^3/d	DOM	L 3 of Sec 14 TP 1A R 5 Coast Dist Plan 1225	Lundy, Bernard B. and Cecile C.M.

* From Water Management Files, Ministry of Environment

TABLE 4 (Continued)

PRIORITY DATE	LICENCE NUMBER	POINT OF WITHDRAWAL (FIGURE 2)	VOLUME	USE	LOCATION	LICENCEE
1970-07-27	F 51340	N3	4.5 m^3/d	DOM	L 3 of Sec 14 TP 1A R 5 Coast Dist Plan 6025 Exc Plan 8579	Nelson, Roy E. and Ivadell L.
1972-06-14	C 48043	X4	23 m^3/d	IND	Blk 1 and Blk B C/T 9034 of Frac SW 1/4 of TP 1A R 5 Coast Dist Plan 1225	Olson, Esther M.
1975-06-20	C 46911	M4	2.3 m^3/d	DOM	L 3 of Sec 14 TP 1A R 5 Coast Dist Plan 1463	Forward, Beatrice E.
1975-06-24	C 46251	N4	2.3 m^3/d	DOM	Blk 13 of Sec 14 TP 1A R 5 Coast Dist Plan 1225	Raymond, William G. and Sandra L.
1975-06-27	C 46464	R4	2.3 m^3/d	DOM	L A of Sec 14 TP 1A R 5 Coast Dist Plan 1475	Jackson, Geoffrey G. and Trotter, Thomasine G.
1975-06-30	C 46465	Q4	2.3 m^3/d	DOM	L 17 of Sec 14 TP 1A R 5 Coast Dist Plan 1225	Greene, A. Grace
1975-07-15	C 46690	S4	2.3 m^3/d	DOM	L 7 of Sec 11 TP 1A R 5 Coast Dist Plan 1243	Watson, James C.
1975-09-25	C 45914	V4	0.5 dam^3	IRR	0.25 AC of L 9 of Frac Sec 14 TP 1A R 5 Coast Dist Plan 1225	Pflugbeil, Diethart O. and Joan M.
1976-07-09	C 47860	C5	23 m^3/d	DOM	L 5 of Frac Sec 14 TP 1A R 5 Coast Dist Plan 1463 Exc Plan 1475	Clean, Thelma
1976-07-29	C 47683	D5	2.3 m^3/d	DOM	L 7 of Sec 14 TP 1A R 5 Coast Dist Plan 1225	Candela, Paul and Alison

TABLE 5
WATER LICENCES ON SEYMOUR LAKE*

PRIORITY DATE	LICENCE NUMBER	POINT OF DIVERSION (FIGURE 3)	VOLUME	USE	LOCATION	LICENCEE
1964-08-21	C 44688	AA	2.3 m³/d	DOM	L 18 of L 4266 R 5 Coast Dist Plan 1329	Hawley, Edwin J. Seymour Lake W U C
1964-08-21	F 20865	AA	2.3 m³/d	DOM	L 12 of L 4266 R 5 Coast Dist Plan 1329	Doornbos, Hendrik/T. Seymour Lake W U C
1964-08-21	F 20866	AA	2.3 m³/d	DOM	L 13 of L 4265 R 5 Coast Dist Plan 6913	Krausnig, Waltraud Seymour Lake W U C
1964-08-21	F 20867	AA	2.3 m³/d	DOM	Blk 4 of L 4266 R 5 Coast Dist Plan 2094	Kawerninski, Dr. Michael Seymour Lake W U C
1964-08-21	F 20869	AA	2.3 m³/d	DOM	L 1 of L 4266 R 5 Coast Dist Plan 1329 Exc Plan 4907	Moore, Kenneth Seymour Lake W U C
1964-08-21	F 20870	AA	2.3 m³/d	DOM	L B of L 4266 R 5 Coast Dist Plan 6701	Rietmann, Harry & Sandra Seymour Lake W U C
1964-08-21	C 29855	AA	2.3 m³/d	DOM	L 3 of L 4266 R 5 Coast Dist Plan 2094	Boonstra, Jerry Seymour Lake W U C
1964-08-21	C 44687	AA	2.3 m³/d	DOM	L 17 of L 4266 R 5 Coast Dist Plan 1329	DeJong, Age Seymour Lake W U C
1964-08-21	F 21528	AA	2.3 m³/d	DOM	L 10 & 11 of L 4266 R 5 Coast Dist Plan 1329	Van Veldhuizen, Marinus A. Seymour Lake W U C

* From Water Management Files, Ministry of Environment

TABLE 5 (Continued)

PRIORITY DATE	LICENCE NUMBER	POINT OF DIVERSION (FIGURE 3)	VOLUME	USE	LOCATION	LICENCEE
1964-08-21	F 21531	AA	2.3 m³/d	DOM	L 13 od L 4266 R 5 Coast Dist Plan 1329	Stewart, Kenneth Seymour Lake W U C
1967-06-23	F 20872	AA	2.3 m³/d	DOM	L 10 of L 4265 R 5 Coast Dist Plan 1057	Miller, Allen Wayne Seymour Lake W U C
1967-07-04	F 42181	AA	2.3 m³/d	DOM	L 13 of L 4266 R 5 Coast Dist Plan 4907	Drummond, Mrs. Dorothy A. Seymour Lake W U C
1967-08-03	F 20871	AA	2.3 m³/d	DOM	L A of L 4265 R 5 Coast Dist Ex Plan 6913	Mosley, Wilfred B.& Doreen H. Seymour Lake W U C
1968-01-15	F 21612	AA	2.3 m³/d	DOM	L of 7 L 4266 R 5 Coast Dist Plan 1329 Exc Plan 5897	Oud, Peter Seymour Lake WUC
1968-01-15	F 21612	AA	2.3 m³/d	DOM	L A of L 4266 R 5 Coast Dist Plan 5897	Souter, Donald S.
1969-11-12	C 37769	AA	2.3 m³/d	DOM	L 1 of Frac Sec 18 TP 4 R 5 Coast Dist Plan 5917	Phillips, Rosalind
1970-06-24	F 42180	AA	2.3 m³/d	DOM	L 12 od L 4265 R 5 Coast Dist Plan 1057	Pederson, Craig & Myrna Seymour Lake W U C
1970-10-02	C 37739	NN	2.3 m³/d	DOM	L 45 of L 4264 R 5 Coast Dist Plan 1057	Veenman Gary & Alice

TABLE 5 (Continued)

PRIORITY DATE	LICENCE NUMBER	POINT OF DIVERSION (FIGURE 3)	VOLUME	USE	LOCATION	LICENCEE
1970-12-21	F 38577	AA	2.3 m^3/d	DOM	L 2 of L 4266 R 5 Coast Dist Plan 1329	Kilback, Lloyd Seymour Lake W U C
1970-12-30	F 40386	AA	2.3 m^3/d	DOM	L A of L 4266 R 5 Coast Dist Plan 6701	Bennett, Albert E. Seymour Lake W U C
1972-06-07	C 40455	AA	2.3 m^3/d	DOM	L 1 of Blk 2 of L 4266 R 5 Coast Dist Plan 6555	Hearnden, Shirley, Terrance G. Seymour Lake W U C
1975-08-25	C 48680	S3	2.3 m^3/d	DOM	L 3 of Sec 18 TP 4 R 5 Coast Dist Plan 5917	Madsen, Orla
1975-08-25	C 48822	R3	2.3 m^3/d	DOM	L 6 of Sec 18 TP 4 R 5 Coast Dist Plan 5917	Hunt, E.
1976-05-20	C 47686	AA	2.3 m^3/d	DOM	L 14 of L 4266 R 5 Coast Dist Plan 1329	Stewart, John C.. Seymour Lake W U C
1979-09-05	C 55152	G4	2.3 m^3/d	DOM	L 42 of L 4264 R 5 Coast Coast Dist Plan 1057	Dejong, Folkertjed
1981-09-02		A3	2.3 m^3/d	DOM	Frac NW 1/4 Sec 7 TP 4 R 5 Coast Dist	Manton, J.N.

TABLE 6
WATER LICENCES ON TYHEE LAKE*

PRIORITY DATE	LICENCE NUMBER	POINT OF DIVERSION (FIGURE 3)	VOLUME	USE	LOCATION	LICENCEE
1972-03-25	C 9855	K	23 m³/d	WWK**	L 2 of L 252 R 5 Coast Dist Plan 5949	Lowe, Ronald, & Elaine
1972-04-13	C407588	N	2.3 m³/d	DOM	L 3 of L 252 R 5 Coast Dist Plan 5949	Murdoch, Gary & Elizabeth C.
1972-05-03	C 51653	BB	27 m³/d	WWK	L 1-12 Incl of L 794 R 5 Coast Dist Plan 6345	Hidber, J. A. & Louise E.
1972-07-11	C 44560	V	27 m³/d	IND	Blk 2 of Frac Sec 2 TP 4 R 5 Coast Dist Plan 3190	Kilpatraick, Bernard W. & Frances R.
1973-11-05	C 43095	R	2.3 m³/d	DOM	L 1 of L252 R 5 Coast Dist Plan 5949	Haye, Jens & Joan
1974-06-28	C 45178	W	2.3 m³/d	DOM	L 3 of L 794 R 5 Coast Dist Plan 7352	Van Tine, G. & Margaret M.
1979-07-31	C 53281	GG	2.3 m³/d	DOM	L 5 of Sec 36 TP 5 R 5 Coast Dist Plan 8647	Burger, R. & Carol J.
1981-09-28	C 54595	K	2.3 m³/d	DOM	L 7 of Sec 36 TP 5 R 5 Coast Dist Plan 5233	Sandberg, Sally A.
1981-04-30		JJ	2.3 m³/d	DOM	L 5 of L 794 R 5 Coast Dist Plan 7352	Campbell, Joan J.

* From Water Management Files, Ministry of Environment

** WWK = Waterworks

TABLE 7
WATER LICENCES ON ROUND LAKE*

PRIORITY DATE	LICENCE NUMBER	POINT OF DIVERSION (FIGURE 4)	VOLUME	USE	LOCATION	LICENCEE
1966-06-24	C 31778	H	36m³/d	WWK	L 1 of L 755 R 5 Coast Dist Plan 4188	Karelis, Nikolaj C/ Lise
1974-11-19	C 436918	K	2.3m³/d	DOM	L A of L 766A R 5 Coast Dist Plan 6632	Mortensen, Eilf H. & Yolana
1978-08-18	C 52599	W	4.5m³/d	DOM	L 782 R 5 Coast Dist Exc Plan 6878	Van Der Meulen,

* From Water Management Files, Ministry of Environment

TABLE 8
PHOSPHORUS LOADING FROM SEPTIC TANKS AROUND KATHLYN LAKE

SOIL TYPE (from Runka, 1972)	0-50 m ZONE			50-100 m ZONE			>100m ZONE		
	# of Houses	Phosphorus Transmission Coefficient (%)*	Phosphorus Loading From Zone (kg/yr)	# of Houses	Phosphorus Transmission Coefficient (%)*	Phosphorus Loading From Zone (kg/yr)	# of Houses	Phosphorus Transmission Coefficient (%)*	Phosphorus Loading from zone (kg/yr)
BA_2 Th:cd	13**	5	3.5	6	2	0.6	11	1	0.6
BA_2-M_1 Th-Gm:cd	17	7	6.4	5	3	0.8	9	1.5	0.7
M_2-SG_2 Gm-FF:c	16	15	12.9	3	7	1.1	6	4	1.3
TOTALS			22.8 kg/yr			2.5 kg/yr			2.6 kg/yr

Total = 27.9 kg/yr

* From Wiens (1983b).

** Each house will discharge an average of 5.5 kg of phosphorus/year in septic effluent.

BA = Barrett soil
M_1 = Mapes soil
M_2 = Morice soil
SG_2= Slug soil

TABLE 9

SUMMARY OF THE 1982 WATER QUALITY DATA FOR KATHLYN AND SEYMOUR LAKES

PARAMETER	KATHLYN LAKE		SEYMOUR LAKE	
	EPILIMNION (0-2 m)	HYPOLIMNION (4-10 m)	EPILIMNION (0-2 m)	HYPOLIMNION (4-7 m)
Physical Parameters				
1) Temperature (°C)	18.0 (Max)	17.7 (Max)	18.4 (Max)	16.5 (Max)
2) Oxygen-Dissolved (mg/L)	4.0 (Min)	0.0 (Min)	3.5 (Min)	0.0 (Min)
General Ions				
1) Specific Conductivity (µs/cm)	58 ±2.2 (n=4)	59 ±2.7 (n=5)	81 ±5.3 (n=4)	82 ±4.8 (n=5)
2) Total Dissolved Solids (mg/L)	47 ±4.1 (n=4)	47 ±4.3 (n=5)	74 ±2.4 (n=4)	74 ±0.9 (n=5)
3) Hardness (mg/L)	23.7 (n=1)	23.0 (n=1)	44.4 (n=1)	42.5 ±0.78 (n=2)
4) Calcium - Total (mg/L)	7.2 (n=1)	6.9 (n=1)	10.2 (n=1)	10.0 ±0.4 (n=2)
5) Magnesium - Dissolved (mg/L)	1.4 (n=1)	1.4 (n=1)	4.6 (n=1)	4.25 ±0.07 (n=2)
6) Inorganic Carbon (mg/L)	5.0 (n=1)	6.0 ±1.4 (n=2)	8.0 (n=1)	10 ±1.4 (n=2)
7) Alkalinity (mg/L)	20 ±0.09 (n=2)	21 ±0.71 (n=2)	37 (n=1)	--
8) pH (relative units)	7.0 (n=1)	7.2 ±0.35 (n=2)	7.5 (n=1)	7.3 ±0.14 (n=2)
Water Clarity and Colour				
1) True Colour (T.C.U.)	13.3 ±7.6 (n=3)	16.7 ±5.8 (n=3)	50.0 ±10.0 (n=3)	45.0 ±5.8 (n=4)
2) Secchi Disc Depth (m)	2.7 ±0.8 (n=5)		1.8 ±0.7 (n=6)	--
3) Total Suspended Solids (mg/L)	3.8 ±1.9 (n=4)	3.8 ±2.6 (n=5)	3.0 ±0.8 (n=4)	3.2 ±1.6 (n=5)
4) Turbidity (N.T.U.)	3.1 (n=1)	3.9 ±0.7 (n=2)	1.6 (n=1)	2.8 ±0.35 (n=2)
Nutrients				
1) Nitrogen-Ammonia (mg/L)	0.012 ±0.009 (n=4)	0.218 ±0.32 (n=6)	0.012 ±0.01 (n=4)	0.186 ±0.34 (n=6)
2) Nitrogen-Nitrate (mg/L)	<0.02 ±0.0 (n=4)	0.023 ±0.008(n=6)	0.02 ±0.0 (n=4)	<0.02 ±0.0 (n=6)
3) Nitrogen-Total (mg/L)	0.327 ±0.06 (n=4)	0.643 ±0.47 (n=6)	0.555 ±0.017 (n=4)	0.705 ±0.40 (n=6)
4) Phosphorus-Total (mg/L)	0.022 ±0.011(n=7)	0.0304 ±0.018(n=8)	0.0319 ±0.012(n=7)	0.0401 ±0.012 (n=7)
5) Phosphorus-Ortho (mg/L)	0.0035 ±0.0006(n=4)	0.0038 ±0.001(n=6)	0.0055 ±0.003(n=4)	0.0063 ±0.002 (n=6)
6) Carbon-Organic (mg/L)	6.0 (n=1)	6.0 ±0.0 (n=2)	14.0 (n=1)	--

58.0 ±2.2 (n=4): mean ± standard deviation (n=sample size).

TABLE 10
SUMMARY OF THE 1982 WATER QUALITY DATA FOR ROUND AND TYHEE LAKES

PARAMETER	ROUND LAKE		TYHEE LAKE	
	EPILIMNION (0-5 m)	HYPOLIMNION (8-20)m	EPILIMNION (0-5 m)	HYPOLIMNION (10-22)
Physical Parameters				
1) Temperature (°C)	17.2 (Max)	5.8 (Max)	17.0 (Max)	8.5 (Max)
2) Oxygen-Dissolved (mg/L)	2.9 (Min)	0.0 (Min)	4.0 (Min)	0.0 (Min)
General Ions				
1) Specific Conductivity (µs/cm)	232 ±8.3 (n=3)	244 ±5.5 (n=3+	226 ±71.5 (n=4)	280 ±9.3 (n=3)
2) Total Dissolved Solids (mg/L)	163 ±13.6 (n=3)	164 ±7.6 (n=3)	176 ±14.2 (n=3)	173 ±7.0 (n=3)
3) Hardness (mg/L)	118 (n=1)	116 (n=1)	81 ±83 (n=2)	140 (n=1)
4) Calcium-Total (mg/L)	31.1 (n=1)	30.9 (n=1)	36.4 ±4.6 (n=2)	39.4 (n=1)
5) Magnesium-Dissolved(mg/L)	9.9 (n=1)	9.5 (n=1)	6.0 ±5.5 (n=2)	10.0 (n=1)
6) Inorganic Carbon (mg/L)	31 ±5.6 (n=2)	34 ±2.8 (n=2)	35 ±4.9 (n=2)	38 ±1.4 (n=2)
7) Alkalinity (mg/L)	118 ±8.1 (n=2)	123 ±.7.0 (n=2)	131 ±6.9 (n=3)	138 ±4.04 (n=3)
8) pH (Relative Units)	8.0 ±0.99 (n=2)	7.5 ±0.4 (n=2)	7.6 ±1.0 (n=3)	7.6 ±0.3 (n=2)
Water Clarity and Colour				
1) True Colour (T.C.U.)	20.0 ±10.0 (n=3)	15.0 ±5.0 (n=3)	8.3 ±2.9 (n=3)	13.3 ±7.6 (n=3)
2) Secchi Disc Depth (m)	2.7 ±1.4 (n=5)	--	4.2 ±2.1 (n=5)	--
3) Total Suspended Solids (mg/L)	2.6 ±1.1 (n=3)	3.3 ±1.5 (n=3)	1.6 ±0.6 (n=3)	2.3 ±1.5 (n=2)
4) Turbidity (N.T.U.)	1.1 ±0.1 (n=2)	1.2 ±0.1 (n=2)	0.8 ±0.4 (n=3)	1.0 ±0.6 (n=2)
Nutrients				
1) Nitrogen-Ammonia (mg/L)	0.084 ±0.113(n=5)	0.580 ±0.418 (n=4)	0.008 ±0.007 (n=5)	0.208 ±0.191 (n=5)
2) Nitrogen-Nitrate (mg/L)	0.034 ±0.031(n=5)	0.05 ±0.047 (n=4)	0.038 ±0.033 (n=6)	0.062 ±0.08 (n=5)
3) Nitrogen-Total (mg/L)	0.816 ±0.164(n=5)	1.335 ±0.520 (n=4)	0.542 ±0.057 (n=5)	0.862 ±0.418 (n=5)
4) Phosphorus-Total (mg/L)	0.0533 ±0.028(n=6)	0.247 ±0.128 (n=6)	0.018 ±0.006 (n=6)	0.0908 ±0.045(n=6)
5) Phosphorus-Ortho (mg/L)	0.022 ±0.029(n=5)	0.153 ±0.079 (n=4)	0.006 ±0.004 (n=5)	0.047 ±0.033 (n=5)
6) Carbon-Organic (mg/L)	10.67 ±0.6 (n=3)	11.5 ±0.7 (n=3)	8.3 ±0.6 (n=3)	7.3 ±1.5 (n=3)

Data from EQUIS

TABLE 11
SUMMARY OF METALS DATA IN THE STUDY LAKES

METALS (TOTAL)	KATHLYN LAKE	SEYMOUR LAKE	TYHEE* LAKE	ROUND LAKE
Cadmium (µg/L)	<0.5	<0.5	<0.5*	<0.5
Copper (µg/L)	<1	<1	<1 *	<1
Lead (µg/L)	3	5	2.5	4
Nickel (µg/L)	<10	<10	<10 *	<10
Zinc (µg/L)	<5	<5	<5 *	<5

*two samples taken
Data from EQUIS

TABLE 12
SUMMARY OF NITROGEN : PHOSPHORUS WEIGHT RATIOS FOR LAKE WATER IN 1982

DATE	KATHLYN LAKE	SEYMOUR LAKE	ROUND LAKE	TYHEE LAKE
January 25	*	*	10:1	23:1
May 14	16:1	19:1	11:1	29:1
June 9	21:1	23:1	16:1	21:1
July 21	6:1	26:1	15:1	33:1
September 8	23:1	29:1	39:1	52:1
October 20	22:1	13:1	18:1	35:1

* insufficient data

TABLE 13
SUMMARY OF STREAM NUTRIENT DATA TO KATHLYN LAKE

KATHLYN LAKE	SAMPLE SIZE	AMMONIA NITROGEN (µg/L)	NITRATE-NITROGEN (µg/L)	TOTAL NITROGEN (µg/L)	ORTHO PHOS-PHORUS (µg/L)	TOTAL PHOSPHORUS (µg/L)
N.W. Inflow 1131035	1	8	L20	670	12	42
S.E. Inflow 1131037	2	975±304	1600±1300	3550±2050	1560±200	1980±525
W. Inflow 1131038	1	23	60	480	L3	26
E. Inflow 1131039	1	42	30	1220	37	58
N.E. Inflow 1131040	1	21	30	1160	10	89

Data from EQUIS

TABLE 14
SUMMARY OF STREAM NUTRIENT DATA TO SEYMOUR LAKE

SITE	DATE (1982)	AMMONIA (µg/L)	NITRATE (µg/L)	TOTAL NITROGEN (µg/L)	ORTHO-PHOSPHORUS (µg/L)	TOTAL PHOSPHORUS (µg/L)
N. Inflow 1131041	May 14	L5	L20	330	L3	14
N.W. Inflow 1131042	May 14	L5	L20	360	L3	12
N.W. Inflow 1131042	July 21	2200	130	15000	3220	5100

Data from EQUIS

TABLE 15
A SUMMARY OF INFLOW STREAM NUTRIENT DATA FOR TYHEE LAKE

A. SAMPLING DATES: May 15/82 and June 7/82.

	SAMPLE SIZE	AMMONIA NITROGEN (μg/L)	NITRATE NITROGEN (μg/L)	TOTAL NITROGEN (μg/L)	ORTHO PHOSPHORUS (μg/L)	TOTAL PHOSPHORUS (μg/L)
Inflow Streams 1131048 → 1131064	28	5 ±0.5	21 ± 4	535 ± 116	5 ± 5	18 ± 8
West Inflow #1 1131065	1	8	<20	740	15	89
West Inflow #2 1131066	1	6	<20	540	72	107

x=23

B. SAMPLING DATES: JULY 21, 1982

	SAMPLE SIZE	AMMONIA NITROGEN (μg/L)	NITRATE NITROGEN (μg/L)	TOTAL NITROGEN (μg/L)	ORTHO PHOSPHORUS (μg/L)	TOTAL PHOSPHORUS (μg/L)
Inflow #2 1131049	1	17	1 670	2 660	11	98
West Inflow #1 1131065	1	49	1 350	3 000	15	840
West Inflow #2 1131066	1	15	30	1 050	14	660

Data from EQUIS

TABLE 16
SUMMARY OF STREAM NUTRIENT DATA TO ROUND LAKE

ROUND LAKE	SAMPLE SIZE	AMMONIA NITROGEN (µg/L)	NITRATE NITROGEN (µg/L)	TOTAL NITROGEN (µg/L)	ORTHO PHOSPHORUS (µg/L)	TOTAL PHOSPHORUS (µg/L)
N.E. Inflow 1131044	2	9±7	30±14	810±311	51.5±45	80±64
N. Inflow 1131045	2	8.5±5	25±7	575±176	6.5±2.1	38.5±12.0

Data from EQUIS

TABLE 17
TYPICAL RANGES OF PHYTOPLANKTON AND NUTRIENT PARAMETERS FOR DIFFERENT TROPHIC LEVELS AND THE STUDY LAKES

	Phytoplankton: Growing Season mean (cells/mL)	Chlorophyll a: Growing Season mean (µg/L)	Total P at Spring Overturn (µg/L)	Total N at Spring Overturn (µg/L)	Mean Summer Secchi Disc Depth (m)*
Oligotrophic	<1000	0-2	1-10	<100	>5.4
Mesotrophic	1 000-5 000	2-5	10-20	100-500	3.3-5.4
Eutrophic	>5 000	>5	>20	500-1 000	<3.3
Kathlyn	2300±3040 (n=4)	5	20	420	3.2±0.3 (n=3)
Seymour	7950±6570 (n=4)	8.4	52	630	2.1±0.7 (n=4)
Tyhee	610±530 (n=3)	4	20	570	4.2±2.4 (n=4)
Round	19 370±29 700 (n=4)	15.5	70	570	2.4±1.5 (n=4)

*Predicted from Nordin and McKean (1984)

TABLE 18

NUISANCE ALGAE IN THE STUDY LAKES

ROUND LAKE	
Aphanizomenon flos-aquae	Taste and odours, and filter clogging.
Microcystis aeruginosa	Toxic, taste and odours, aesthetic nuisance.
SEYMOUR LAKE	
Anabaena planktonica	Taste and odours, aesthetic nuisance
Aphanizomenon flos-aquae	Taste and odours, toxic, aesthetic nuisance
KATHLYN LAKE	
Aphanizomenon flos-aquae	Taste and odours, toxic, aesthetic nuisance.
TYHEE LAKE	
No nuisance algae found in 1982.	

From Palmer, 1962

TABLE 19

SUMMARY OF RECOMMENDED WATER QUALITY STANDARDS AND OBJECTIVES FOR DOMESTIC DRINKING WATER

PARAMETER	RECOMMENDED WATER QUALITY STANDARDS	RECOMMENDED WATER QUALITY OBJECTIVES	AGENCY THAT SET THE STANDARDS AND OBJECTIVES
Physical Parameters			
1) Temperature (°C)	15	≤15*	B.C. Health (82)
2) Oxygen-Dissolved (mg/L)	3	-	SSPA, WQMO
General Ions			
1) Specific Conductivity (μs/cm)	-	-	-
2) Total Dissolved Solids (mg/L)	500	-	B.C. Health (82)
3) Hardness (mg/L)	**		
4) Carbon-Inorganic (mg/L)	-	-	-
5) Alkalinity (mg/L)	-	-	-
6) pH (Relative Units)	6.5-8.5	-	B.C. Health (82)
Water Clarity and Colour			
1) True Colour (T.C.U.)	15	≤15	B.C. Health (82)
2) Secchi Disc Depth (metres)	-	-	-
3) Total Suspended Solids (mg/L)	-	-	-
4) Turbidity (N.T.U.)	5	≤1	B.C. Health (82)
Nutrients			
1) Ortho-Phosphorus (mg/L)	-	0.065	B.C. Health (69)
2) Ammonia-Nitrogen (mg/L)	-	0.500	B.C. Health (69)
3) Nitrogen-Nitrate (mg/L)	10	≤0.001	B.C. Health (82)

* ≤ denotes less than or equal to

** 80-100 good; > 200 poor; >500 unacceptable (B.C. Health)

NOTES:

SSPA: Scientific Stream Pollution Analysis, Nemerow, 1974.

WQMO: Guidelines and Criteria for Water Quality Management in Ontario, 1979

B.C. Health: Ministry of Health, British Columbia Drinking Water Quality Standard 1969 and 1982.

TABLE 20

NUMBER OF NEW HOMES PERMITTED IN KATHLYN, ROUND AND TYHEE LAKE WATERSHEDS

LAKE	SEPTIC TANK	SEWER
Kathlyn	30 - 55	200 - 350
Round	30 - 55	200 - 350
Tyhee	25 - 45	150 - 300

APPENDIX 1:

TYHEE LAKE INFLOWS AND OUTFLOW WATER QUALITY SITES

(brackets indicate diameter of culverts)

1131047 Outflow - at Highway 16 and Tyhee Lk. Rd. (24").

1131048 East Inflow #1 - Section 25, NE quadrant at Tyhee Lk. Rd. (18").

1131049 East Inflow #2 - Section 36, SE quadrant at Tyhee Lk. Rd. between Lockwood Rd. and Hislop Rd. (18").

1131050 East Inflow #3 - Section 36, NE quadrant. Tyhee Lk. Rd. at Lot 1. (24").

1131051 East Inflow #4 - Section 36, NE quadrant. Tyhee Lk. Rd. at Lot 2. (18").

1131052 East Inflow #5 - Section 36, NE quadrant. Tyhee Lk. Rd. at boundary of Lot 3. (18").

1131053 East Inflow #6 - Section 36, NE quadrant. Tyhee Lk. Rd. at boundary of Lots 3 and 4. (18").

1131054 East Inflow #7 - Section 36, NE quadrant. Tyhee Lk. Rd. at Lot 4. (18").

1131055 East Inflow #8 - Section 36, NE quadrant. Tyhee Lk. Rd. at Lot 6. (18").

1131056 East Inflow #9 - Section 1, southern-most culvert. (15").

1131057 East Inflow #10 - Section 1, Victor Ck. south of green house on east side of Tyhee Lk. Rd. (30").

1131058 East Inflow #11 - L. 252 at Tyhee Lk. Rd. N. of Penner Rd. (15").

1131059 East Inflow #12 - L. 794. Tyhee Lk. Rd. at Hidber Rd. (30").

1131060 East Inflow #13 - L. 794, Plan 1543 (yellow and red house) on Tyhee Lk. Rd. (30").

1131061 East Inflow #14 - L. 794, Plan 1543. Next culvert north of 1131060 on Fisher Rd.

1131062 NE Inflow. L. 794A at Fisher Rd.

1131063 North Inflow. L. 794A at Fisher Rd.

1131064 NW Inflow. L. 794A at Fisher Rd.

1131065 West Inflow #1 - First culvert south of intersection of Fisher Rd. and Telkwa High Rd. on Telkwa High Rd.

1131066 West Inflow #2 - Section 2. Culvert immediately north of seaplane base Rd. on Telkwa High Rd.