MINISTRY OF ENVIRONMENT
PROVINCE OF BRITISH COLUMBIA

SKEENA-NASS AREA

LAKELSE LAKE
WATER QUALITY ASSESSMENT AND OBJECTIVES

TECHNICAL APPENDIX

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1. INTRODUCTION

1.1 STUDY AREA

Lakelse Lake is located south of Terrace and drains via the Lakelse River into the Skeena River (Figure 1). A detailed map of the basin is shown in Figure 2. The Lakelse River from the outlet of the lake to the Skeena River is not included in this review.

1.2 PREVIOUS STUDIES AND REPORT OBJECTIVES

The morphology, hydrology, water quality and aquatic biota of Lakelse Lake have been studied by Brett (1950), Ableson (1976), Cleugh *et al.* (1978), Imbleau (1978), Hatlevik *et al.* (1981) and McMahon (1954). Sinclair (1974) considered the recreational importance of the Lakelse watershed. Two reports by Harrison (1959) and Odynsky (1950) consider the water input from the hotsprings located on the east side of the lake.

This report summarizes the pertinent data, proposes provisional water quality objectives, and develops several watershed management strategies designed to minimize the impact of foreshore development on the water quality of Lakelse Lake.

1.3 MORPHOLOGY

The general morphometric parameters for Lakelse Lake were obtained from Cleugh *et al.*, (1978) and are summarized in Table 1. The bathymetry of Lakelse Lake (Figure 3) was completed by Fisheries and Marine Service, Department of Fisheries and Oceans, in 1976 (in Cleugh *et al.*, 1978). The lake has a maximum depth of 32 m, but a large portion of the lake (42 percent) is considered littoral. This extensive littoral zone affects temperature, dissolved oxygen, aquatic plants, and the overall productivity of the lake. These aspects will be discussed in Section 5.

2. HYDROLOGY

The average lake flushing rate was estimated by Ableson (1976) to be 6 times per year, and by Cleugh et al., (1978) to be 5 times per year. The high flushing rates are caused by both a large watershed size and high annual precipitation (1131 mm average at Terrace Airport).

A large percentage of the precipitation occurs during the winter as snow. The resulting hydrograph (Figure 4) indicates maximum water input during the spring and summer months. This input influences the summer water clarity, temperature, dissolved oxygen and overall lake productivity, which are discussed further in Section 5.

3. WATER USE

3.1 WATER LICENCES

There are 30 water licences within the Lakelse Lake watershed, of which only one (waterworks) is located within the lake. The waterworks licence is used for drinking water supply for the provincial campground at the north end of the lake. The remaining water licences are almost exclusively for domestic use, withdrawing water from the inflow creeks (Table 2; Figure 5). There are 8 nondomestic water licences on the inflow creeks, which include one irrigation licence on Cole Creek and one industrial licence (not used) for a fish hatchery on Schulbuckhand Creek. Two conservation licences allow fish counting fences on Williams and Schulbuckhand Creeks. Finally, there are four mineral trading licences associated with the Lakelse Lake hot-springs.

3.2 RECREATION

Sinclair (1974) reviewed the recreational importance of Lakelse Lake in great detail. His analysis showed that the residents of the Terrace-Kitimat-Prince Rupert area were the greatest users of the lake. The most popular use was swimming, then picnicking, sunbathing, camping and fishing in decreasing order of importance. Other activities included photography, sailing, etc., but these were of minor importance. In total, 800 000 activity-days were spent at the lake. The majority occurred in June, July, August and September. At the time of Sinclair's study, there were 250 property owners around the lakeshore. Most property owners do not live on the lake on a year-round basis, but rather they visit the lake during the summer months.

Nonresident visitors use the lake for rest, camping, hiking and walking. Swimming, which is the major reason that Terrace residents visit the lake, is not as important for nonresident visitors. In 1973 an estimated 31 000 activity-days, mostly during the summer months, were attributed to nonresident visitors.

The value of the recreation from Lakelse Lake was estimated by Sinclair (1974). Residents of the Terrace-Kitimat-Prince Rupert area are estimated to have spent $6 000 000 (1973). The nonresidents travelling to the lake were estimated to have spent $657 000. The annual value of Lakelse Lake can therefore be estimated at $6 700 000 (measured in 1973 dollars). Assuming a similar volume of use, the recreational value was estimated at $17 041 000 in 1984 (Reid, pers. comm.).

3.3 FISHERIES

The importance of the recreational fishery was addressed by Sinclair (1974) and is included in the recreation value estimated in Section 3.2. The cutthroat and steelhead fisheries are very important in the Lakelse Lake system (Imbleau, 1978). Winter and summer-run steelhead trout are angled in the Lakelse River downstream from the lake by fly fishermen. Approximately 3 000 steelhead angler-days were expended in 1984-1985 for a catch of almost 1 500 fish (Steelhead Harvest Analysis, 1985). These runs are considered "world class". Other species caught in the Lakelse River are cutthroat trout, Dolly Varden char, and coho and chinook salmon. Many summer-run steelhead overwinter in the lake prior to spawning in Lakelse River or upstream from the lake in Williams Creek, a tributary at the north end of the lake (Chudyk, pers. comm.).

Cutthroat trout are the main sports catch in Lakelse Lake, while rainbow trout and Dolly Varden char are minor. A total of 1 400 angler-hours in 1979 were reported by Hatlevik _et al_., (1981). The resident cutthroat spawn in the upper reaches of the Lakelse River as well as in a series of springs on the east side of the lake, between Hatchery and Schulbuckhand Creek (Figure 2). The springs are also ideal cutthroat rearing habitat because of relatively constant water flow and temperature. Spawning and rearing habitat improvement on these creeks was planned in 1985 (Chudyk, pers. comm.).

The recent anadromous fisheries statistics in Lakelse Lake were obtained from the Department of Fisheries and Oceans regional office in Terrace (Hipp, pers. comm.) The pink salmon returns in 1984 and 1985 were 600 000 and 1 600 000 respectively, and represent the alternating nature of the pink runs in the Lakelse River.. Sockeye returns averaged 14 000 over the past few years. The sockeye run is unusual in that it enters the Skeena River very early and is not subject to commercial fishing pressure. The population has been stable over the years, and is thought to have fully utilized the spawning and rearing habitat within the Lakelse watershed. At present there are no plans to enhance the Lakelse sockeye runs. In 1985, there were 25 000 adult coho spawners observed in the majority of the inflow streams and the Lakelse River below the lake. Chinook returns have increased from 50 in 1984 to 300 in 1985. Decreased sport and commercial fishing pressure have increased the chinook returns.

There are two changes in the Lakelse Lake salmon statistics since the Sinclair (1974) report. First, there has been a dramatic drop in chinook salmon returns (2 000 to 300), and secondly, the sockeye are early-run fish and are not available to the commercial fishery. The commercial and sports catches of pink, coho, and chinook are reported by Hipp (pers. comm.) to approximate the number of returning adults.

The value of the Lakelse Lake anadromous fish resource was estimated using the average of the 1984 and 1985 pink salmon returns and the 1985 coho and chinook returns. The weight and price per unit weight of the fish were based on the 1984 fishery results (Nielson, pers. comm.) listed below.

	Average Weight (kg)	Price Per Kilogram	Number Caught	Estimated Value
Pink	1.6	0.89	1 100 000	$1 566 000
Coho	2.8	3.52	25 000	246 000
Chinook	6.2	5.97	300	11 000
				$1 800 000

A large percentage of the returning pink, chinook and coho adults spawn below Lakelse Lake and their hatching fry do not use the lake for rearing. The sockeye exclusively use the tributaries of the lake for spawning, and the fry utilize the lake for one year (Cleugh et al., 1978). The sockeye underyearlings are typically pelagic utilizing the hypolimnetic waters in the day and migrating to the surface to feed on zooplankton during dusk and dawn. Maintaining suitable dissolved oxygen conditions in the hypolimnion is essential for the sockeye salmon of Lakelse Lake.

In contrast, the coho fry may spend up to two years in the inflow creeks or in the lake. Within the lake, the underyearlings are reported to utilize the aquatic macrophyte beds within the littoral zone as rearing habitat. Warrington (pers. comm.) noted an abundance of small fish in and around the aquatic plants. The importance of the aquatic plant beds for coho rearing was not investigated at that time.

The preservation of the water quality and the biological integrity of Lakelse Lake is essential for maintaining the salmonid spawning and rearing habitat in the Lakelse River downstream from the lake. Increased eutrophication in the lake could lead to increased periphyton growth within the gravel beds in the outflow river, which may interfere with spawning success and swim-up fry survival. The water quality objectives outlined in Section 6 are designed to maintain suitable water quality in Lakelse Lake and Lakelse River for fisheries spawning and habitat.

3.4 WATER USE SUMMARY

The largest water uses of Lakelse Lake are recreation and rearing habitat for cold water fisheries. The tributaries are important for domestic water supply and spawning habitat for salmonids. Other uses of the tributaries include an irrigation supply and the potential commercial use of natural hotsprings.

The most sensitive water use is the cold water fishery and water quality objectives are proposed in Section 6.2 that are designed to protect that use. Attainment of the objectives for the most sensitive use will ensure suitable water quality for the other water uses.

4. WASTE DISCHARGES

4.1 DIRECT DISCHARGES

Parker Investments Ltd. Vancouver, B.C. operated the Skoglund Hotspring Resort during the late 1960's to 1978. Untreated sewage was discharged directly to the lake prior to 1973 via a drainage ditch. Health Branch bacteriological surveys identified Skoglund Hotsprings Resort as the principle source of contamination in the lake. In 1969 chlorination was added to the sewage treatment plant. Files located at the Waste Management office in Victoria indicate the chlorination system was frequently inoperative or ineffective. In 1970 the effluent discharge from the Skoglund Hotsprings Resort was registered with the Pollution Control Branch. Through 1971 and 1972 several complaints regarding inadequate operation of the sewage treatment plant and the discharge of raw sewage to Lakelse Lake were received by the Pollution Control Branch. In June 1972, Skoglund Hotsprings Resort was ordered to make an application for a permit to cover the discharge of domestic effluent. By November 1972, an application was received for the discharge of effluent from the existing treatment system to a 670 m canal leading to Lakelse Lake. Objections to the application were received from Water Rights Branch, Health Branch, Department of Recreation and Conservation and Environment Canada. The objections were withdrawn when the applicant agreed to install an outfall line and diffuser in the lake. In July 1973, the Pollution Control Branch initiated a two-year water quality study (Ableson, 1976). A Pollution Control Permit (PE-1900) was issued on July 31, 1973 in the name of Parker Investments Ltd. The hotel operated until 1978 when it was closed permanently and the hotel was dismantled. A proposal to build a new hotel at the Skoglund Hotsprings was received in January 1986 at the Waste Management Branch's Smithers regional office. The specific details of the waste discharge system were not available when this report was published.

4.2 NONPOINT DISCHARGES

4.2.1 SEPTIC TANK DISCHARGES

The suitability of the soils around Lakelse Lake to renovate septic effluent was determined by Dr. N. Nagpal, the Water Management Branch Soils Specialist. The soil characteristics were evaluated using a 1:50 000 land-form map. The maps only allow a preliminary assessment of the area's suitability to renovate septic tank discharges. A detailed soils map is required to estimate the phosphorus contribution from nonpoint sources. The criteria used to classify the landforms were the physical characteristics: permeability, depth, texture; and the chemical characteristic: phosphorus adsorption ability.*

Figure 6 and Table 3 outline the landforms immediately around the lake and their septic suitabilities. Landform groups 1 through 4 have good physical and chemical characteristics. Groups 5, 6, and 7 have good physical characteristics but poor phosphorus adsorption capacity. The largest proportion of present and probably future development (because of its proximity to the lake shore) is located here. Group 8 to 10 also have moderate rating because their silty clay texture will not provide a good percolation rate. The poor landforms (11 to 17) are restricted to organic deposits, as well as the morainal and colluvium veneers, overlying bedrock.

The residential developments are concentrated around the lake's shore line. Figure 6 outlines the areas of foreshore development (based on 1983 air photos) and Table 4 summarizes the watershed development to 1983. There are 10 different landforms within the watershed with residential development (Table 4). Only one of these landforms has a good rating for renovating septic effluent. It accounts for 12 percent of the houses within the watershed. Approximately 56 percent of the watershed development lies within the

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*This is a judgement based on observations made by Dr. Nagpal.

landforms considered moderately suitable for septic tank tile fields. About 30 percent of the development or seventy-two houses, of which 60 houses are adjacent to the lake shore, are located on poor landforms.

4.2.2 FORESTRY

The impact of forestry on water quality is a concern in the Lakelse Lake watershed. Logging activities that impact water quality include road building, active logging, slash burning, and post-logging land disturbances. The impacts are difficult to predict because of site-specific differences in rainfall, terrain, soil type, and the methods of logging used.

The main concern of logging within the Lakelse Lake watershed is the siltation of spawning and rearing streams. There have not been any data collected within the Lakelse Lake watershed to quantify the degree of siltation attributable to logging. This section will summarize the historical and future logging activities within the Lakelse watershed.

The locations of the logging activities over the past 20 years, and the proposed logging for the next 20 years, are outlined in Figure 7 (Perras, pers. comm.). A total of 4 700 ha of timber has been cut, while an additional 2 900 ha is proposed principally within the Williams and Hatchery Creek watersheds (Table 5). Turbidity objectives for the affected creeks are outlined in Section 6.4. Monitoring for the objectives is outlined in Section 7.3.

5. WATER QUALITY

Two water quality reports have been completed on Lakelse Lake (Abelson, 1976 and Cleugh et al., 1978). Figure 8 distinguishes the sites of the two previous studies. The following sections compare the historical data collected from 1972 by provincial and federal agencies.

5.1 TEMPERATURE

The data analyzed by Ableson (1976) and Cleugh et al., (1978) were for 1974 and 1975, respectively. In both years, maximum surface temperatures did not exceed 17°C. A weak thermocline developed between 7 and 10 metres during July and August. These conditions were the result of limited hours of sunshine in the summer (typical for the Prince Rupert-Terrace area), and the rapid flushing rate in the summer caused by snow melt within the Williams Creek watershed.

It is believed the moderate temperature regime (15-17°C max.) is an important reason for the high juvenile salmonid production of the lake and the Lakelse River. The near optimal growing temperatures combined with the extensive littoral zone (the most productive area of a lake) are two physical reasons for the high fisheries production in the lake.

5.2 DISSOLVED OXYGEN

There are very few dissolved oxygen measurements taken in Lakelse Lake. Surface concentrations, measured by Ableson (1976) and Cleugh et al., (1978), approached 100 percent saturation (between 8-12 mg/L depending on water temperature). Cleugh et al., (1978) took three hypolimnetic oxygen concentrations on March 3, June 29 and October 13, 1975. The dissolved oxygen results were 6.5, 9.8 and 9.6 mg/L respectively. The Ministry of Environment (Wilkes, pers. comm.) took a single profile on July 26, 1984. The minimum hypolimnetic oxygen concentration was 8.0 mg/L at 28 m.

During periods of thermal stratification, hypolimnetic oxygen concentrations are critical for adult and juvenile salmonids. Davis (1975) reviewed the oxygen requirements of aquatic organisms, and provided three dissolved oxygen threshhold levels (A to C). Anadromous salmon (juvenile and adult) are considered by Davis (1975) to be the fresh water species most sensitive to low oxygen levels. Ideal oxygen conditions (level A) provide a high degree of safety for anadromous salmon (>7.75 mg/L). Level B (6.0 mg/L) represents the point where oxygen stress will affect the average member of a species. Level C (4.0 mg/L) represents the point where a large portion of a given species may be affected by low oxygen.

With the exception of one measurement in March, 1975, the hypolimnetic oxygen concentrations were above level A (7.75 mg/L) indicating no oxygen stress will occur to fish within the hypolimnion.

5.3 WATER CLARITY

Water clarity is important aesthetically for recreation, drinking water suitability, and light penetration for primary productivity. Well flushed lakes have a tendency to be turbid during freshet (May and June). The data indicate limited turbidity (approximately 1 to 2 N.T.U.) during freshet. These conditions will not restrict light penetration into the water column, photosynthetic productivity, or the use of the water for drinking.

Nonfreshet turbidity data were collected in November and December of 1974. High turbidities (12.2 and 7.4 N.T.U.) were recorded. High suspended sediment associated with watershed runoff is a possible explanation for the lake's high turbidity values during this period. It should be noted that precipitation and stream flows prior to the sampling dates were not abnormally high. Conseqently, the high turbidities were possibly the result of activities within the watershed, and not due to flood conditions.

Secchi disc records are sparse, with four recorded values. The average Secchi disc depth was 3.7 m (n=4) with a maximum of 4.8 m on July 21, 1974 and a minimum of 2 m on May 8, 1974. The trophic state of a lake can be predicted using Secchi disc values when turbidity is caused by algal biomass. Oligotrophic lakes typically have Secchi readings greater than 6 m; mesotrophic lakes 3 to 6 m; and eutrophic lakes less than 3 m (Nordin, 1985). Based on the Secchi measurements, Lakelse Lake is mesotrophic. However, some turbidity was caused by suspended inorganic solids associated with watershed runoff. Consequently, the Secchi measurement is not a good estimate of trophic state in Lakelse Lake.

The turbidity and Secchi values indicate the water of Lakelse Lake is relatively clear throughout the summer months, but winter turbidity values may exceed the maximum acceptable limit for drinking water (5 NTU) thus reducing its aesthetic appeal.

5.4 GENERAL WATER CHEMISTRY

The general water chemistry has been summarized by Ableson (1976), and Cleugh *et al.*, (1978). Table 6 summarizes their information and additional Ministry of Environment data collected since 1974.

The low levels of dissolved inorganic residues in Lakelse Lake were typical of a lowland lake in a high precipitation area where the main geologic type is volcanic noncalcareous rock. Station IV (from Cleugh *et al.*, 1976; Figure 8) clearly shows the influence from the hotsprings located on the west side of the lake near the lakeshore. The higher ionic content was localized to that area because of the size of the lake and the high flushing rate.

The general water quality of the lake was excellent for drinking water supplies and contact recreation. Disinfection of drinking water is recommended because the lake is heavily used for recreation and septic tank/tile fields are the form of sewage disposal around the lake.

Water samples have been collected to assess the sensitivity of Lakelse Lake to acid rain. Based on the calcium concentrations and alkalinity values the lake is at the upper limit of the moderate-sensitivity range used by Swain (1985). An alkalinity titration curve from a water sample collected in June, 1982, was completed (Swain, unpubl.).

The Terrace area receives small amounts of acid precipitation generated from industrial sources. The Ministry of Environment (Kotturi, 1982) completed a thorough assessment of the rates of acid rain deposition in the Terrace area. The following is a summary of Kotturi's report.

The aluminum smelter, and to a lesser degree the pulp mills at Kitimat and Prince Rupert, are the major sources of acid generating air pollutants in the area. The pH of rain at the Terrace Airport ranged between 4.58 and 5.97. The majority of the samples were mildly acidic with pH greater than 5.00. A few highly acidified results <5.00 were measured during the summer months.

The mean monthly fluoride wet deposition rate at the Terrace Airport in 1981 was 0.055 kg F/ha. The loadings are thought to have decreased over the past 10 years because of improved pollution control and reduced emissions from the aluminum smelter at Kitimat.

Storm movements in the fall, winter, and spring in the Kitimat Valley are predominantly from the north; i.e., from Terrace towards Kitimat. In the summer, the storm movements are reversed, causing more acidic rain in the Terrace area. Despite the lower pH values of rain at Terrace in the summer, the lower precipitation rates resulted in lower monthly fluoride loading rates (0.026 kg F/ha).

There have been 8 fluoride measurements taken in 1983 and 1984 from the Lakelse River downstream from the lake. All results were below the detectable limit of 0.1 mg/L. Detectable fluoride concentrations do not pose a hazard to fisheries or drinking water supplies, and fluoride emissions should not pose an acidification problem to the lake or streams.

5.5 NUTRIENTS

In any eutrophication study, nutrients (nitrogen and phosphorus) are the key elements. Of particular interest will be their temporal variation, an estimation of the nutrients limiting algal growth, the relationship between spring overturn phosphorus concentration and summer mean chlorophyll a concentration, the annual phosphorus input, the major sources of phosphorus, the present trophic status, and the sensitivity of the lake to future development within the watershed.

5.5.1 TEMPORAL VARIATION OF NITROGEN AND PHOSPHORUS

Nutrient concentrations will vary during the year, and between years. The nutrient data for nitrogen and phosphorus from all sources are summarized in Table 7.

Total phosphorus (TP) values were consistently below 10 µg/L except from November 1974 through May 1975. Both Ableson (1976) and Cleugh et al. (1978) noted increased nutrient concentrations in this period. Maximum concentrations reached 66 µg/L. This increase was possibly due to the phosphorus leaching from fire retardant dropped on the 'Lakeside Fire' on August 19, 1974. The fire reached 1 ha in size, and 2.4 metric tonnes of "Firetrol" fire retardant were dropped (Fire Protection Branch, Ministry of Forests). Although "Firetrol" fire retardant does not contain large amounts of phosphorus, leaching from the retardant and the burnt area appeared to cause the elevated spring overturn phosphorus concentrations observed by Cleugh et al., (1978) on May 28, 1975. Subsequent flushing reduced the lake concentrations to below 10 µg/L, a level typical for the lake.

Following the 1974-1975 phosphorus peaks, the 1983 and 1984 spring overturn concentrations were 8 and 10 µg/L respectively. Consistent monitoring of Lakelse Lake (see Section 7.2) is needed to evaluate future trends in phosphorus loading.

Nitrogen concentrations have remained relatively constant since 1974

(Table 7). Ammonia-nitrogen concentrations remained near the detection limits and are considered inconsequential. For a brief period concentrations were observed above 20 µg/L, but this is again thought to be the consequence of dropping "Firetrol" on the 'Lakeside Fire'. Concentrations were quickly diluted during the 1975 freshet and have remained low.

In most years, nitrate-nitrogen was near 50 µg/L following spring overturn (Table 7). Concentrations decreased and became undetectable by late July or August. Nitrate input during freshet runoff would be the largest source during the summer months, and may account for the detectable concentrations extending from May through July.

Total nitrogen concentrations were affected by the rapid flushing during freshet (Table 7). Concentrations decreased in June or July during maximum watershed runoff. Maximum nitrogen concentrations of 200 µg/L were observed following freshet in late July, August or September.

5.5.2 NUTRIENTS LIMITING GROWTH

In most aquatic systems, nitrogen, phosphorus or light are usually the factors limiting the growth of microscopic algae. During the summer, algae in lakes fed by turbid glacial meltwater may be limited by light. Algae in the remainder of lakes are limited by either nitrogen or phosphorus.

Nitrogen or phosphorus limitation is usually based on the total nitrogen to total phosphorus weight ratios of the lake surface water. If the weight ratio in the water is greater than 15:1 then phosphorus is assumed to be limiting, and if the ratio is 5:1 or less, nitrogen is assumed to be limiting (Nordin, 1985).

Cleugh et al., (1978) reported that Lakelse Lake was nitrogen limited in 1975. The conclusion is not fully supported as the ratio was calculated using nitrate, rather than total nitrogen results. Also, the lake had experienced abnormally high inorganic phosphorus input following the 'Lakeside Fire' in 1974. The total nitrogen to total phosphorus weight ratio averaged 14:1 in 1974 (Ableson, 1976). Excluding the results during freshet in June 1974, the N:P ratio in Lakelse Lake averaged that year 20:1, clearly a phosphorus-limited condition. The period of freshet produced an N:P weight ratio of 6:1, a condition approaching nitrogen limitation. The 1983 and 1984 nitrogen to phosphorus ratios at spring overturn were 21:1 and 19:1. These results suggest the algal growth in Lakelse Lake will be phosphorus limited, except possibly during freshet when nitrogen limiting conditions are approached.

5.5.3 PHOSPHORUS-CHLOROPHYLL RELATIONSHIP

The direct relationship between spring overturn phosphorus and mean summer chlorophyll a concentration in phosphorus-limited lakes was first observed by Sakamoto (1966). Several authors (Dillon and Rigler, 1975; Hern et al., 1981; Forsberg and Ryding, 1981) have observed similar relationships in north-temperate lakes. Nordin and McKean (1984) described a relationship using data collected from British Columbia lakes (Figure 9). To measure the trophic state of the lake, Nordin (1985) recommends that the mean summer phosphorus concentration be compared to the mean summer chlorophyll a concentration for lakes with epilimnetic flushing rates greater than twice per year (The spring overturn phosphorus concentration is used in lakes with lower flushing rates).

The summer phosphorus data for Lakelse Lake are limited. The mean summer phosphorus concentration at the surface in 1974, based on four samples, was 5 μg/L (Abelson, 1976). The corresponding chlorophyll a concentration was 2.5 μg/L. The 1975 phosphorus and nitrogen data collected by Cleugh et al., (1978) were not used because of artificially high values (Section 5.5.4). The only other summer phosphorus data are single samples collected in 1982 and 1984 (14 and 10 μg/L respectively, Table 7).

The chlorophyll a data collected by Abelson (1976) are graphed in Figure 8. The mean summer chlorophyll was above the predictive line using the mean summer phosphorus concentration of 5 μg/L. In other words the lake was more productive than predicted according to the phosphorus concentration. Additional phosphorus and chlorophyll a data are required before any firm conclusions about the productivity of Lakelse Lake can be made. This is important because future watershed development and the concomitant increase in phosphorus loading could have a dramatic effect on the lake's productivity and trophic status.

5.5.4 ANNUAL PHOSPHORUS INPUT

Two methods are commonly used to estimate the annual phosphorus input to north-temperate lakes. The first method involves the collection of samples and the calculation of loading rates from all possible sources such as atmospheric deposition, streams, septic tanks, agriculture, direct discharges, and internal loading. This method is very time consuming and costly as it requires large numbers of laboratory analyses. The advantage of this method is it identifies and quantifies the sources of phosphorus so lake restoration techniques can be designed to reduce the annual phosphorus input.

The second method involves the use of lake models. Models are much simpler as they require fewer data. Lakelse Lake is typical of the lakes used to develop the Dillon and Rigler (1975) and Reckhow and Simpson (1980) models, therefore it is assumed the models will provide a good estimate of the annual phosphorus loading.

Some nutrient data have been collected from streams during freshet and direct discharges from around the lake. The phosphorus input from septic tanks to the Lakelse Lake watershed was estimated to be 1 150 kg/year. The proportion of phosphorus discharged from the septic tanks which reaches the lake can not be estimated because of insufficient soils data.

The water quality of the effluent discharged by the Skoglund Hotsprings Hotel is summarized in Table 8. The effluent phosphorus concentrations were 100 to 500 times greater than the lake values causing some localized impact on the water quality within the drainage ditch and point of entry into the lake. The contribution of the discharge from the hotel to the annual phosphorus loading of Lakelse Lake can not be estimated as the effluent discharge volumes were not measured.

During the 1982 freshet, stream nutrient data were collected from the majority of the inflow streams around the lake (Table 9). Stream orthophosphorus concentrations were usually below the detection level of 3 μg/L. Total dissolved phosphorus concentrations averaged 4.9±0.9[1] μg/L (n=12), while total phosphorus concentrations were much higher averaging 12.8±4.0[1] μg/L (n=12). Phosphorus in suspended organic and inorganic particles associated with the freshet may not be biologically available. Consequently, the loading of biologically available phosphorus to the lake will be less.

Finally, a single sample was collected from the main pool of the Skoglund Hotsprings (Table 10) which showed phosphorus and nitrogen concentrations were very low.

There have been many models developed to estimate the annual phosphorus input to lakes. Two commonly used lake models are Dillon and Rigler (1975) and Reckhow and Simpson (1979). The equations of these models are summarized below:

Dillon and Rigler (1975)	$L = (Pxqs) \div (1-R_{LM})$
Reckhow and Simpson (1979)	$L = P \times (1.2\ qs + 11.6)$

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[1]Standard deviation

Table 11 gives an explanation of the equations and a summary of results of applying the models to Lakelse Lake. The models in Table 11 used the average water retention time (0.19 years) as calculated by Cleugh et al., (1978). Calculations of phosphorus loading in specific years require accurate mean summer phosphorus concentrations and water retention estimates for the previous 12 months.

Table 11 gives loading values for a range of mean summer phosphorus values and the concomitant loading values. The annual phosphorus input in kilograms was calculated by multiplying L(g/m^2/year) by the surface area of the lake (m^2), and dividing by 1000 (to convert g to kg).

The two models produced similar results ranging from an annual phosphorus input of 4 610 kg (at 5 μg P/L) to 18 250 kg (at 20 μg P/L). Four mean summer total phosphorus data points have been collected to date:

7 μg/L in 1974
66 μg/L in 1975
8 μg/L in 1983
10 μg/L in 1984

As the 1975 concentration was influenced by the "Lakeside Fire", it is not considered typical. Recent data indicate that the mean summer concentrations have increased only slightly from 1974 to 1984. Future summer samples will determine short or long term changes in phosphorus concentrations. The estimated phosphorus input was 6 500 kg in 1974, 7 300 kg in 1983 and 9 100 kg in 1984.

The phosphorus loading to the Lakelse Lake watershed by septic tanks was estimated at 1 150 kg/year in 1983. This estimate assumed the 257 houses (Table 4) around the lake had an average of 3 people occupying each dwelling on a year-round basis. Using a phosphorus loading rate of 1.5 kg P/year/person (Nordin et al., 1981), the annual watershed phosphorus loading is 1 150 kg (this represents 15% of the 1983 total phosphorus loading to Lakelse Lake).

Not all phosphorus discharged from a septic tank will reach a lake or stream because of the ability of the soils to adsorb phosphorus. The efficiency of phosphorus adsorption by soils varies depending on the distance between the septic tank tile field and the water course and the physical and chemical characteristics of the soil. Consequently, only a portion of the phosphorus discharged to the watershed will reach Lakelse Lake. Because of incomplete soils data around Lakelse Lake, phosphorus loading from septic tanks to the lake can not be estimated; however, it will be significantly less than the loading to the watershed.

5.5.5 CHLOROPHYLL a

Chlorophyll a is used to estimate algal biomass. Ableson (1976) estimated the mean summer chlorophyll a in 1974 at 2.5 µg/L. Dillon and Rigler (1976) considered 2 µg/L chlorophyll a to be the optimal concentration for lakes with important cold water fisheries resources. Because of annual variations in phosphorus and chlorophyll a, a range of 1.75 to 3.0 µg/L of chlorophyll a is recommended for lakes like Lakelse Lake containing important cold water fisheries resources. This range provides a level of productivity that is beneficial to fish production while avoiding an anoxic hypolimnion.

Lakelse Lake in 1974 was near the upper limit of the recommended chlorophyll a concentration for cold water fisheries (Figure 9). However, the summer oxygen depletion rates (which are strongly influenced by the chlorophyll a concentration in the surface waters) are minimal because of the high flushing during the summer months. Consequently, Lakelse Lake would tolerate a mean summer chlorophyll a concentration of 3.0 µg/L.

Excluding the 1975 mean summer total phosphorus values, there appears to be an increasing trend from 1974 to 1984. This apparent trend is weak because only three data points are available, and the samples were not collected in the same month. Spring overturn samples should be taken in the last week of April prior to thermal stratification. Improved monitoring in the future will test the observed trend.

5.5.6 TROPHIC STATUS

The trophic status of Lakelse Lake can be estimated using a Secchi disc and mean summer nutrient or chlorophyll a concentrations (Table 12). A graphical method was developed by Vollenweider (1976; Figure 10) positioning the lakes in the oligotrophic or eutrophic zone. Mesotrophy was defined as the area between the permissible and excessive phosphorus loading rates. Based on the hypolimnetic oxygen concentrations and the phosphorus loading rates (calculated from mean summer concentrations), Lakelse Lake was oligotrophic. Based on the chlorophyll a and total nitrogen values in Table 12, Lakelse Lake would be classified as mesotrophic.

It is not unusual for a lake to be classified in two categories when different criteria are used. The observation that the lake is mesotrophic based on the chlorophyll a criterion is an important consideration in determining sensitivity of the lake to watershed development (Section 5.5.8), and in setting water quality objectives (Section 6.3).

5.5.7 WATERSHED DEVELOPMENT

The sensitivity of a lake to watershed development can be assessed by calculating the additional phosphorus input that will not significantly change the lake's trophic status. The number of new houses permitted within the watershed can then be estimated based on the allowable increase in phosphorus loading.

At present the phosphorus data are so sparse that only general conclusions regarding allowable watershed loading are possible. The present phosphorus concentrations are near the permissible levels (10 µg/L) outlined by Vollenweider (1976, Figure 10). Consequently, large scale watershed development should be discouraged. Small scale watershed development on landforms determined to be good for the renovation of septic tank effluents (Section 4) should not be detrimental to the lake's long-term water quality.

All watershed development should be discouraged if the mean summer phosphorus concentration were to exceed 12 µg/L.

At least three years of additional hydrologic, phosphorus and chlorophyll a data in conjunction with a detailed soils survey around the lake are required to properly assess the sensitivity of the lake to large scale development.

The Sewage Disposal Regulations (Regulation 7:16/e; Ministry of Health, 1975), require a 30 m set-back to prevent a bacterial health hazard to adjacent ground and surface waters. One important aspect of septic tank tile fields not covered by the regulations is phosphorus adsorption by the soil. The physical characteristics and chemical composition of the soil determine the rate and amount of phosphorus adsorbed. Consequently, a 30 m set-back will not be adequate for soils with poor phosphorus adsorption qualities. The phosphorus adsorption capability of the Lakelse Lake watershed was based on landform data. A more detailed soils survey, either of the entire watershed or on a site specific basis, would provide more information regarding phosphorus adsorption and better estimates of adequate septic tank set-back distances.

In addition to the enhanced set-back distances for septic tank tile fields, regular maintenance and inspection of existing tile fields will ensure proper operation of a septic tank and maximize phosphorus adsorption. To accomplish the regular inspection and maintenance, the residents within the Lakelse Lake watershed may apply to the Ministry of Municipal Affairs and form a Lake Improvement District. By including water quality and septic tank inspection in the "Letters Patent", the Improvement District can raise money through taxation or other methods, and fund projects designed to improve and maintain existing septic tanks to prevent degradation in the water quality of the lake and inflow streams.

The set-back distance on landforms with a good phosphorus adsorption rating corresponds to the present Sewage Disposal Regulations. The set-backs distance on landforms rated moderate and poor are judged on the relativive efficiency of phosphorus adsorption.

Good: 30 m
Moderate: 90 m
Poor: 175 m

Note: set-backs should apply also to development around inflow creeks.

In the meantime, the above minimum set-back distances are suggested as a guide for septic tank tile fields based on the septic suitablity of the landforms (Table 3).

5.6 LAKE SEDIMENTS

The chemical composition of lake sediments is a useful indicator of the influences of the watershed on the lake. The sediment results, fo sediment collected on July 26 1984 with an Eckman grab, are listed in Table 13 together with the mean concentrations of sediments from other B.C. lakes.

The sediments are described as moderately consolidated, brownish grey clay with some organics. There were some small sand particles throughout the sample, indicating periods of high turbidity from flood events.

The results listed in Table 13 are typical for lakes with a high flushing rate (McKean in press). Parameters such as % volatile, organic carbon, and Kjeldahl nitrogen relate to the lake's productivity and are typical for a well flushed oligotrophic lake.

Metal concentrations in lakes are strongly influenced by mineral deposits, basin geology, and flushing rates. Most metals were near the average for B.C. lakes. Mercury was well below the provincial average indicating mercury loading was low. Calcium was also low because of the non-calcareous bedrock geology.

5.7 BIOLOGY

5.7.1 COLIFORM BACTERIA

The Ministry of Environment collected fecal and total coliform samples from eight stations throughout the lake (Figure 8) on six occasions in 1973 and 1974 (Table 14). The results for July 9, 1973 indicate substantial coliform contamination at station 6 which was located at the mouth of the drainage ditch that contained sewage effluent from the Skoglund Hotsprings Resort. Total coliform results on the same day at stations 5, 7, and 8 also appeared to be influenced by the discharge. Additional sampling in 1974 did not detect any bacterial contamination from the effluent contained within the drainage ditch. The discharge of effluent was terminated in 1978 when the hotel was permanently closed.

The Ministry of Health collected in 1984 and 1985 coliform samples from two water sources within the provincial park located on the east side of the lake, and five public beaches located around the lake (Figure 8). Drinking water total coliform analyses showed two detectable results (less than 5 cells/100 mL) from 14 samples (Table 15). All beach sample coliform results were below 50 cells/100 mL (n=15) with only two samples exceeding 10 cells/100 mL.

Ministry of Health guidelines for coliform contamination and Ministry of Environment provisional water quality objectives for coliform bacteria in drinking water supplies and beaches are outlined in Section 6.2.

5.7.2 ZOOPLANKTON

A thorough survey of the zooplankton community of Lakelse Lake was completed between 1949-1952 (McMahon, 1954 a and b). The raw data are contained in McMahon (1954 a). McMahon (1954 b) reported that the diet of underyearling sockeye salmon in Lakelse Lake was zooplankton, and the fish appeared to select different species (not identified) in different seasons.

Two copepods (Cyclops and Epischura) and two cladocerans (Bosmina and Diaphanosoma) dominated the zooplankton community during McMahon's study. The zooplankton population peaked in July, 1949 with 6 000 orgs./m^3. The genera Epischura and Cyclops dominated from July through October. The Bosmina and Diaphanosoma populations peaked in mid-September with 1 000 and 300 orgs./m^3 respectively. The majority of the zooplankton community was found near the surface of the lake during the day. Mid-lake samples had consistently higher zooplankton samples than near-shore samples.

Other data collected by Abelson (1976) and Cleugh et al., (1978) are not comparable to McMahon (1954) because of different sampling methods. However, the zooplankton community reported by Abelson and Cleugh, was dominated by Cyclops bicuspidata. Data collected in 1984 by the Regional Waste Management office were comparable to McMahon's (1954 b), although not as complete (Table 16). The March and July samples in 1984 were dominated by the copepod C. bicuspidata. The zooplankton numbers in July 1984 were approximately 50% of the numbers collected by McMahon in 1949. This probably does not reflect a decrease in zooplankton numbers, rather differences in zooplankton growth patterns between the two years. Water quality objectives for the zooplankton community are not proposed in Section 6. By maintaining water quality (i.e., hypolimnetic oxygen concentrations and the trophic status at the oligotrophic-mesotrophic interface) the zooplankton community should remain unaffected. Because of the importance of the zooplankton community as a food source to the sockeye underyearlings, and presumably the trout and coho fry in the lake and Lakelse River, monitoring of the zooplankton community is recommended and outlined in Section 7.

5.7.3 AQUATIC MACROPHYTES

Aquatic macrophytes have been studied by Ableson (1976), Cleugh et al., (1978), and Warrington (in prep.). The most complete species list has been prepared by Warrington (in prep.), and the identifications are summarized in Table 18. The general distribution of macrophytes was plotted by Cleugh et al., (1978). Scirpus lacustris surrounds most of the lake shore, while

Potamogeton is the dominant genus in the lake. Cleugh et al., (1978) note that macrophyte density is sparse below 4.6 m, and absent below 6 m.

Because of the recreational and fisheries value of Lakelse Lake, a detailed survey of the aquatic macrophytes by Dr. P. Warrington was completed in 1984. The survey was designed to assess the conflicts between aquatic macrophytes and recreation use and the utilization of aquatic macrophytes by juvenile sockeye salmon (Warrington, in prep.).

Rooted aquatic plants obtain the majority of their nitrogen and phosphorus via roots from the sediments. McKean and Nordin (in prep.) collected emergent Nuphar polysepalum shoots from Brannen Lake (Vancouver Island) from areas with undeveloped and developed shoreline containing septic tank tile fields. The content and ratio of nitrogen and phosphorus of the plants from both locations were similar, and the results did not indicate that nutrients were limiting the growth of N. polysepalum. In addition, visual inspection of the plant beds did not indicate any differences in plant biomass. The conclusion of the study was that the septic tank discharges did not appear to influence the growth of rooted aquatic plants (particularly N. polysepalum). Freeman and Canale (1977) reported similar findings from a eutrophic lake in Michigan. Their conclusion was that the macrophytes were restricted by space and light.

Increased lake nutrients in two lake studies either resulted in few changes in submerged macrophytes (Solander, 1978) or a reduction in species diversity (Dale and Miller, 1978). Sustained lake nutrient concentrations may cause an increase in nonrooted macrophytes that take nutrients from the water column, not the sediments. In eutrophic conditions plants like Ceratophyllum, and to a lesser extent Elodea, can reach nuisance proportions. Warrington and McKean (in Nordin and McKean, 1984) observed that spring overturn phosphorus concentrations must exceed 15 µg/L before Ceratophyllum spp. will form nuisance populations. This result is unlikely in Lakelse Lake considering the flushing rate and the present phosphorus loading rates.

6. PROVISIONAL WATER QUALITY OBJECTIVES

6.1 DESIGNATED WATER USES

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

- aquatic life (anadromous fish rearing habitat, recreational freshwater fishery)
- primary contact recreation
- drinking water supply

The tributaries of Lakelse Lake are important for:

- aquatic life (spawning and rearing of anadromous and nonanadromous salmonid species)
- drinking and irrigation water supplies
- primary contact recreation in the Lakelse Hotsprings

It is proposed that these be adopted as the designated water uses to be protected in the lake and inflow streams.

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.

6.2 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 as follows: the fecal coliform density shall not exceed 10 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 as follows: the fecal coliform density shall not exceed a running log mean of 200/100 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 400/100 mL.

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

The objective for drinking water supply should apply to grab samples taken near or in drinking water intakes in either the lake or its tributaries. The objective for recreation applies to bathing beaches.

6.3 ALGAL GROWTH, NUTRIENTS, AND HYPOLIMNETIC OXYGEN CONCENTRATION

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

As mentioned earlier, the biomass of algae is controlled by the availability of phosphorus. To achieve a mean summer chlorophyll a concentration of 3 µg/L or less, the average total phosphorus concentration should not exceed 10 µg/L (Figure 8). Consequently, the provisional water quality objective for the lake is an average total phosphorus concentration of

10 µg/L or less over the spring and summer periods. The objective applies to the average of at least four monthly samples taken from May to August, at 0.5, 6, and 30 m depths, at a site over the deepest part of the lake.

A water quality objective for the average chlorophyll a, of 3 µg/L, is also proposed for the May to August period. It applies to the average of at least four monthly composites, each taken at depths of 0, 2, 4 and 6 m.

An objective is also set for the dissolved oxygen content of the hypolimnion to maximize the fisheries and zooplankton habitat. The dissolved oxygen should not drop below 6.0 mg/L (level B) at any point >5 m above the sediment-water interface. This objective takes into account that the D.O. content of oligotrophic lakes at the sediment-water interface may drop below 6 mg/L because of the BOD of the sediments. An objective which applies 5 m above the sediment-water interface will ensure that over 90% of the hypolimnetic volume of Lakelse Lake will be suitable for fisheries production.

6.4 TURBIDITY

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

The proposed provisional water quality objective is a maximum level of 5 NTU and an average level of ≤1 NTU. These objectives are based on B.C. Ministry of Health, (1982), Drinking Water Quality Standards. The maximum level shall supply to any grab sample taken near or in a domestic intake, and the average level shall apply to at least 5 weekly samples taken in a period of 30 days at any point in the lake, during the nonfreshet period.

Turbidity can be induced by algal growth or soil erosion within the watershed. The present freshet turbidity levels (1 to 2 NTU) were below the maximum level of 5 NTU, but slightly above the average level of 1 NTU. Nonfreshet levels were below 1 NTU, except following flooding events.

To protect fish spawning habitat in lake inlet streams from the effects of logging, or other disturbances, the following objectives are proposed: the induced turbidity shall not exceed 5 NTU when background turbidity is ≤50 NTU, nor shall the induced turbidity be more than 10% of background when background is >50 NTU.

7. MONITORING

The purpose of the monitoring program outlined below is to check compliance of the water quality objectives outlined in Section 6, as well as provide a complete biological and water quality data base so that future lake management programs can be formulated. Long-term continuous monitoring of key limnological characteristics is essential to maintain the high value of the fisheries and recreational aspects of the lake and associated streams.

7.1 FECAL COLIFORM BACTERIA

The fecal coliform monitoring related to drinking water supplies should be five weekly samples per month. The number of sites and their location are left to the discretion of the sampler, but should be associated with a domestic licence. The samples can be collected near the intake, at a tap, or at an outside location that comes directly from the lake or stream (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 carried out during the summer months (July or August). The beach at the north end of Lakelse Lake should be sampled for five consecutive weeks. Samples should be taken 1 m from shore at the surface. The presence of swimmers must be noted at the time of sampling.

7.2 PHOSPHORUS, CHLOROPHYLL a, AND HYPOLIMNETIC OXYGEN

The interdependence of these three parameters necessitates a similar monitoring program. The objective of the monitoring is to calculate the mean summer phosphorus and chlorophyll a concentrations, and record the minimum hypolimnetic oxygen concentrations.

Samples must be collected monthly from May to August, at a station over the deepest point of the lake. Sample depths for nutrients should be surface (0 m), 6 and 30 m. Chlorophyll a samples should be a composite of 100 mL aliquots collected from 0, 2, 4, and 6 m, or a continuous sample from 0 to 6 m, using a tygon tube.

The analyses to be completed on the nutrient samples are: ammonia-nitrogen, nitrate-nitrogen, organic nitrogen, total nitrogen, orthophosphorus, total dissolved phosphorus and total phosphorus. Temperature and dissolved oxygen profiles should also be taken at the same time.

7.3 TURBIDITY

Two turbidity objectives were proposed. The first was designed to protect domestic and recreational water use of the lake, and domestic use of inflow streams. The second was to protect spawning areas possibly affected by logging.

Turbidity monitoring around domestic water intakes is very flexible. Samples can be taken at the same time as the fecal coliform samples. The number and location of the sampling points is left to the discretion of the sampling agency, but at least five samples per year must be collected per site.

Secchi disc readings are recommended when the nutrient samples are collected. Although there is no Secchi disc objective, the readings will provide a cheap but effective method of monitoring the water clarity of the lake.

Turbidity monitoring of inflow creeks subject to logging requires more intensive sampling. One year of data prior to logging, and two sites per stream are required. Samples should be collected at an upstream and downstream site monthly throughout the year prior to, during, and following a logging operation.

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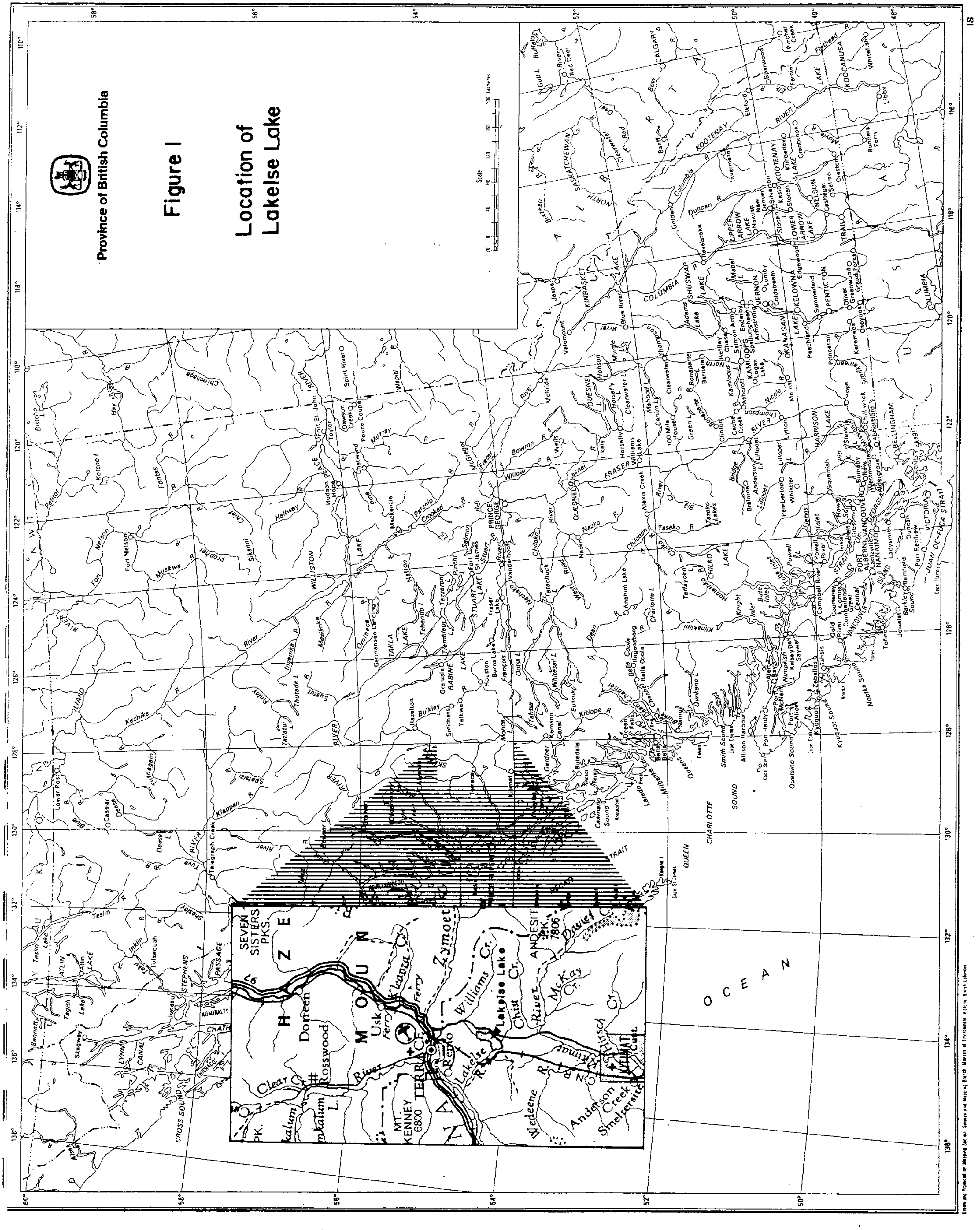


Figure I
Location of Lakelse Lake

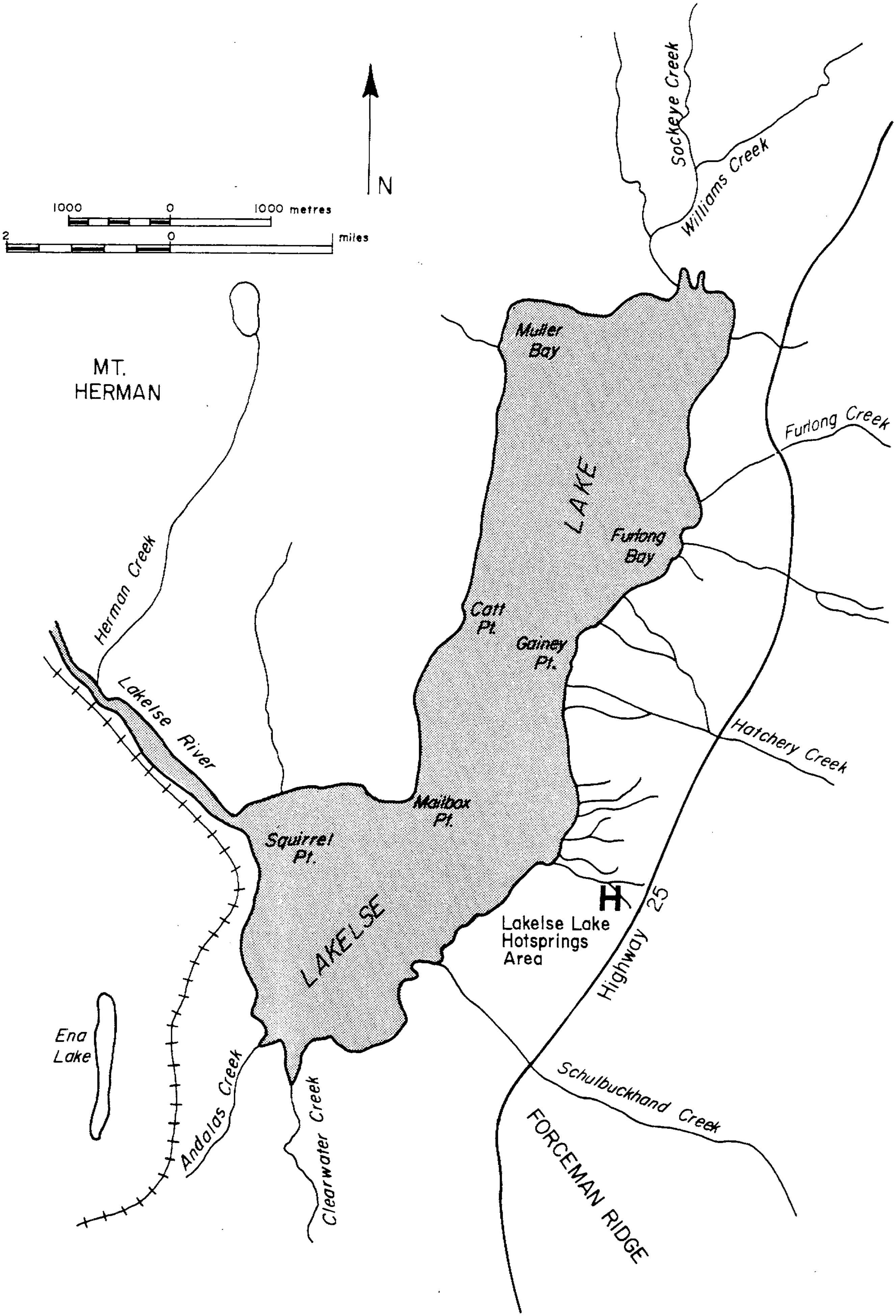


Figure 2: Map of Lakelse Lake, Major Tributaries, and Landmarks.

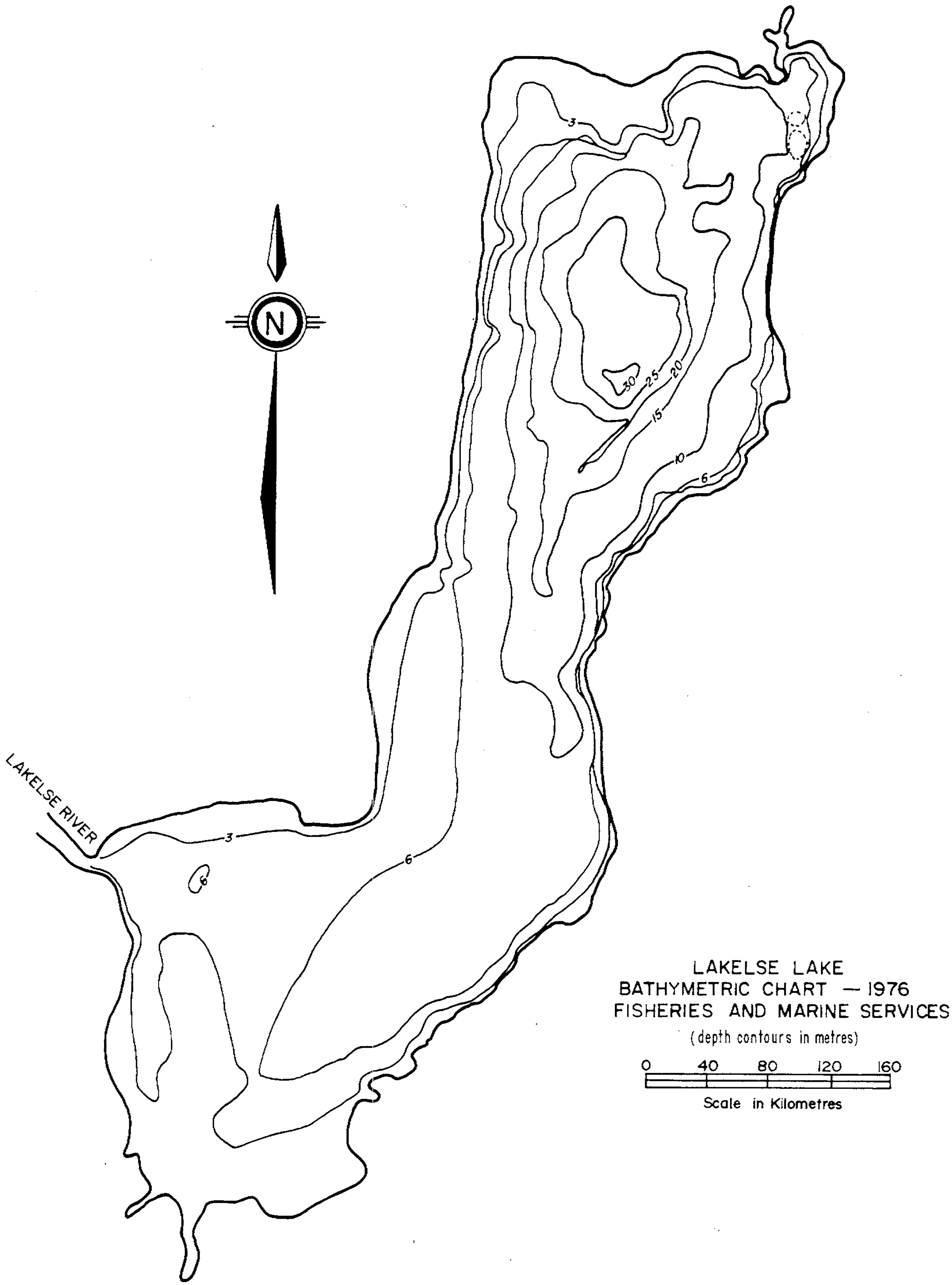


Figure 3: Bathymetry of Lakelse Lake

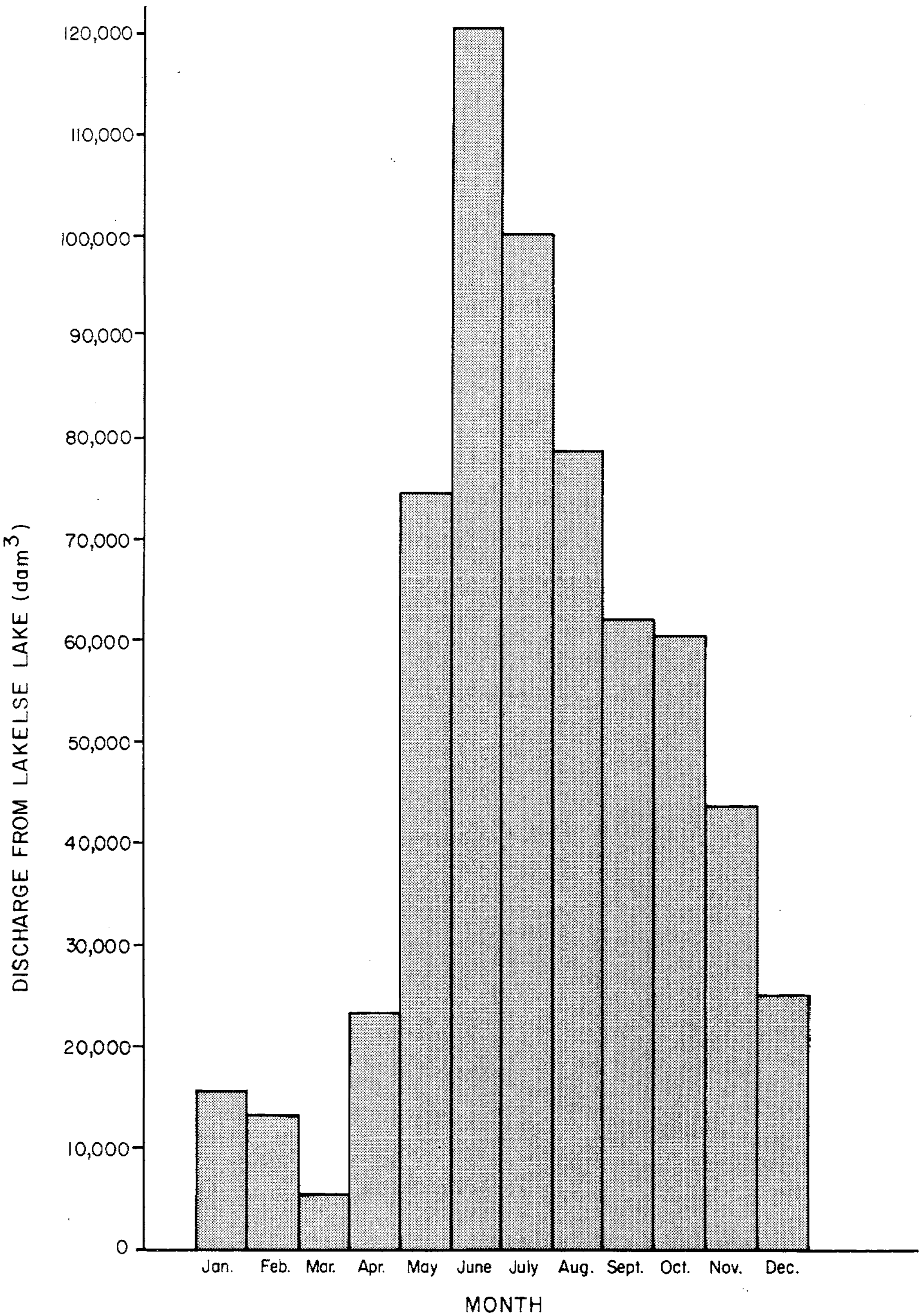


Figure 4: Mean Monthly Discharge of the Lakelse River at the Outlet of Lakelse Lake
(from Cleugh et al, 1978)

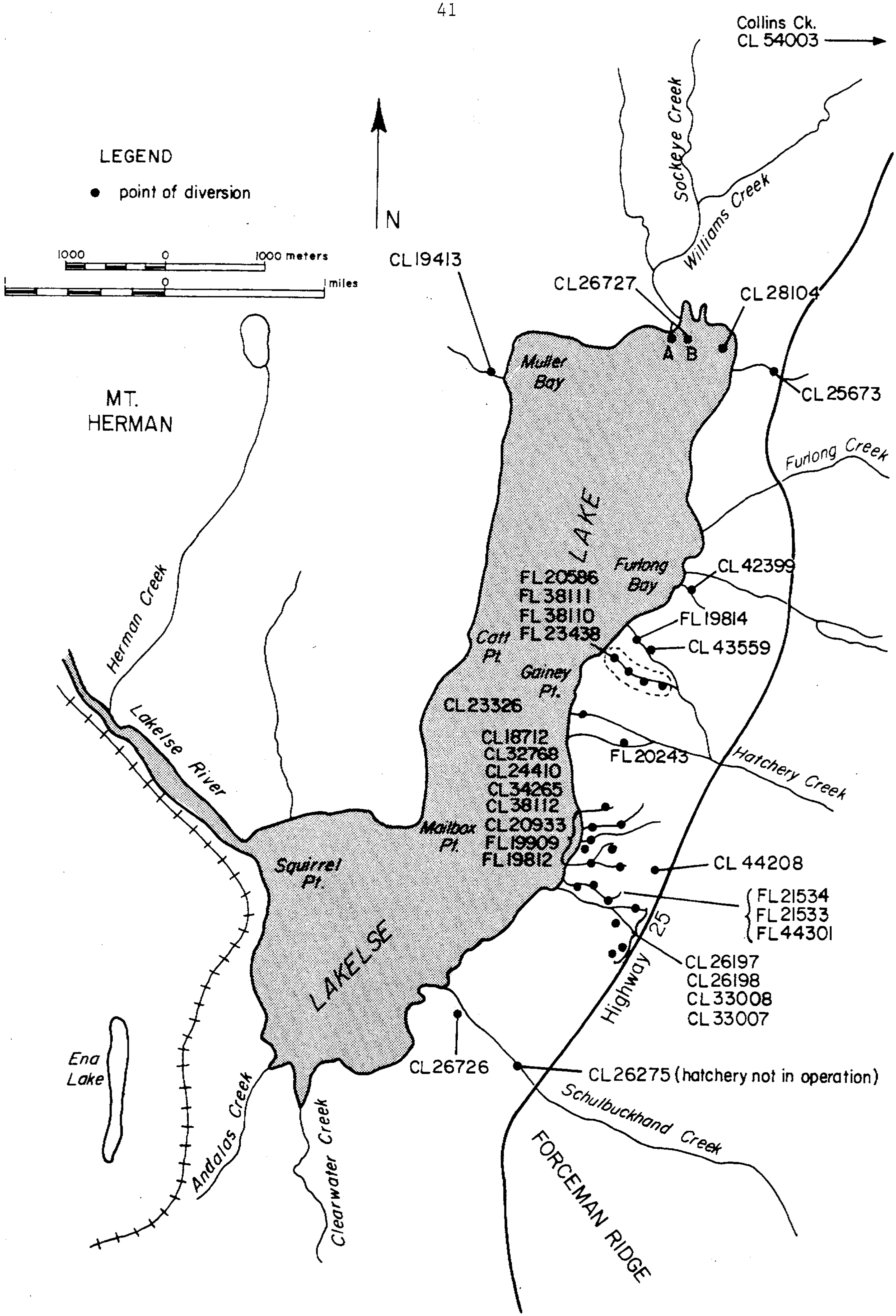


Figure 5: Water Licence Points of Withdrawal for Lakelse Lake

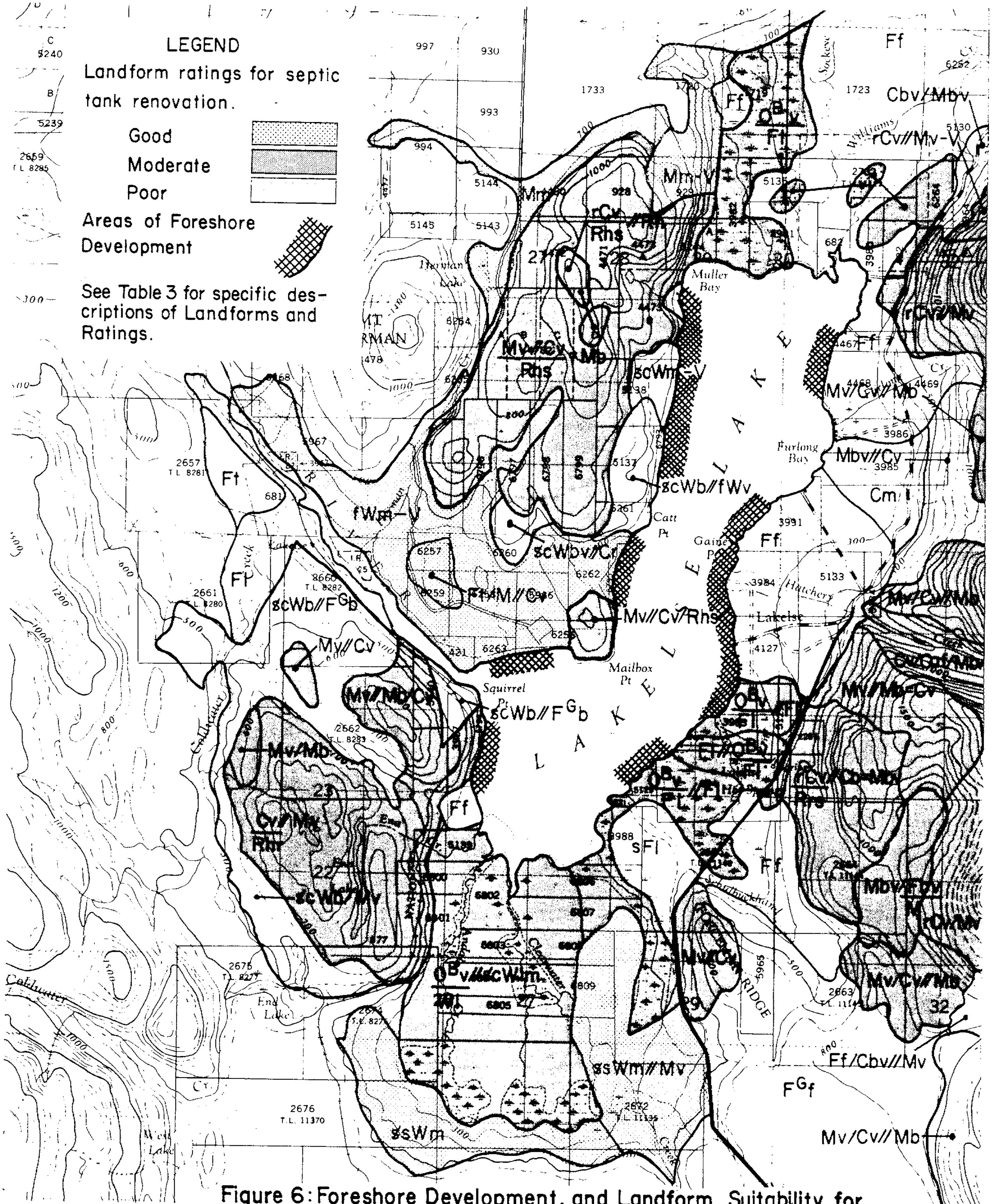
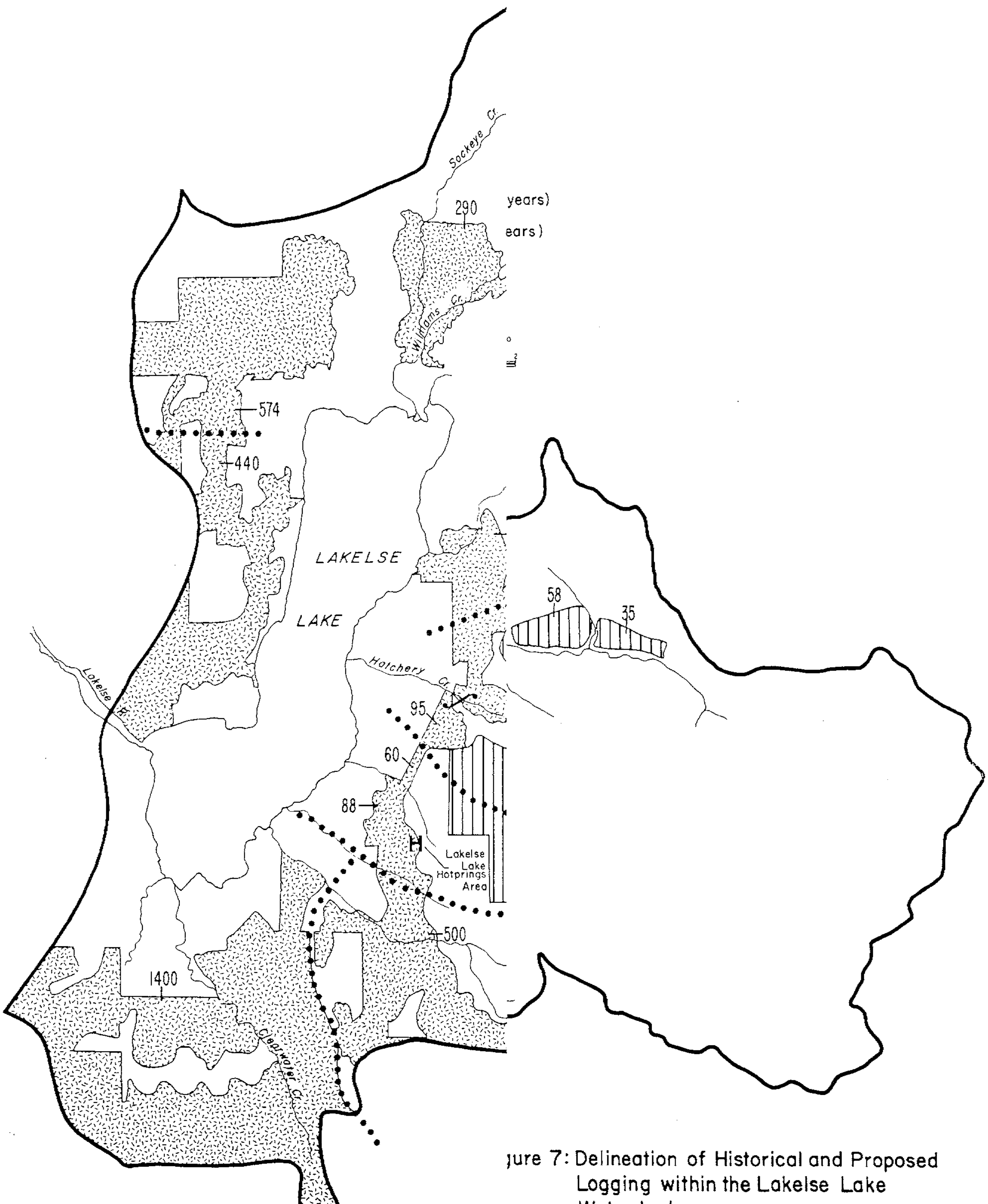


Figure 6: Foreshore Development, and Landform Suitability for Septic Tank Renovation around Lakelse Lake.



jure 7: Delineation of Historical and Proposed Logging within the Lakelse Lake Watershed.

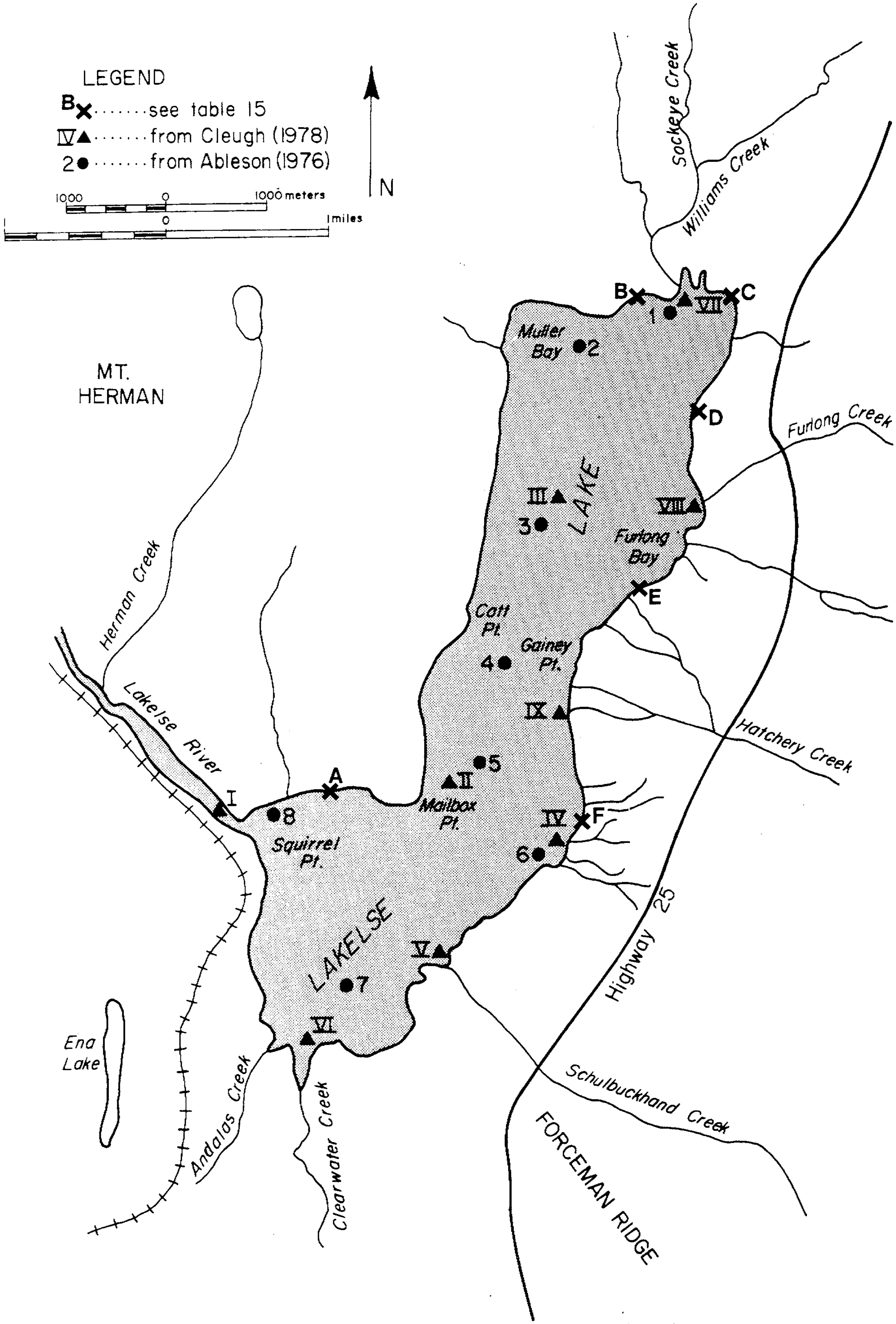


Figure 8: Water Quality and Coliform Monitoring Sites in Lakelse Lake

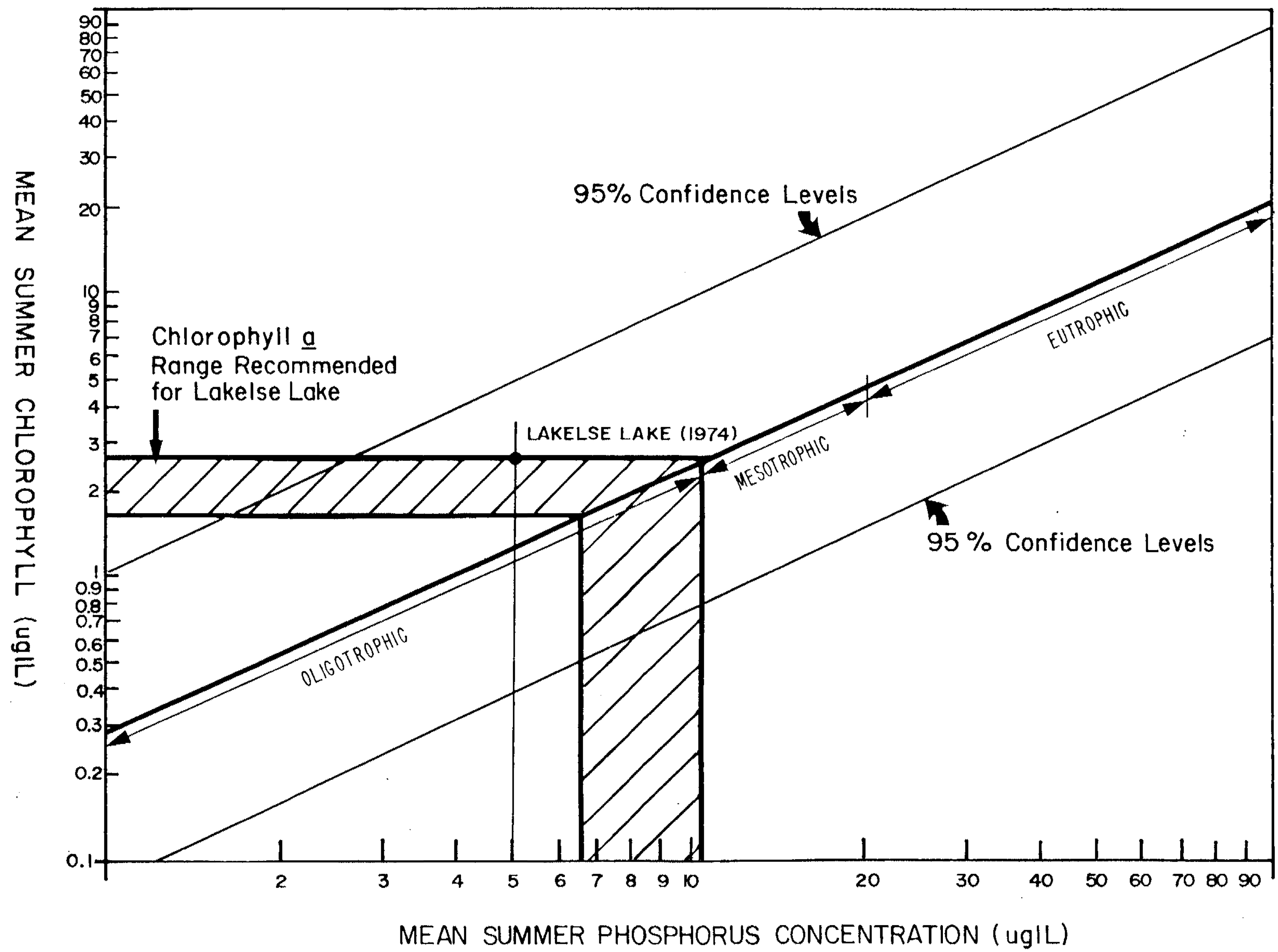


Figure 9 : Mean Summer Chlorophyll a as a Function of Spring Phosphorus Concentration.

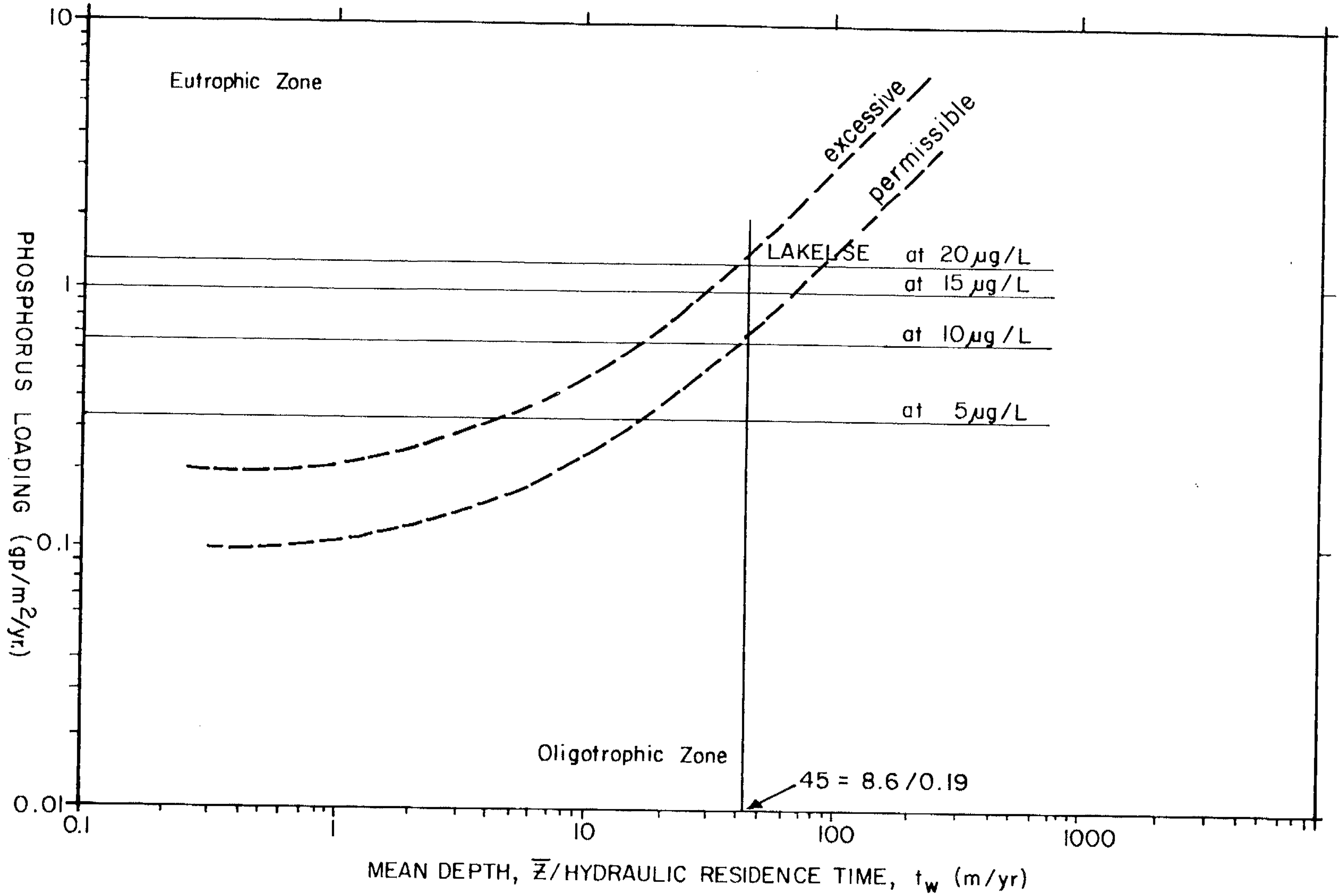


Figure 10: Excessive and Permissible Phosphorus Loading Rates as Determined by Vollenweider (1976).

TABLE 1

MORPHOMETRIC PARAMETERS OF LAKELSE LAKE

Lake area	1416 ha
Maximum depth	32 m
Mean depth	8.6 m
Volume	120 000 dam^3
Shoreline length	26.87 km
Altitude	72.2 m

TABLE 2

WATER LICENCES IN LAKELSE WATERSHED

PRIORITY DATE	LICENCE NUMBER	LOCATION	VOLUME	USE
1949.10.24	CL 19413	Cole Cr.	4.5 m^3/d	Dom
			3.7 dam^3	Irr
1955.05.02	FL 19812	Morgan Br.	2.3 m^3/d	Dom
1956.08.27	FL 19814	Hatchery Cr. Smith Outlet	2.3 m^3/d	Dom
1961.09.27	FL 19909	Edward Cr.	2.3 m^3/d	Dom
1955.09.26	FL 20243	Hatchery Cr. S. Outlet	2.3 m^3/d	Dom
1953.07.07	FL 20586	Hatchery Cr. N. Outlet	2.3 m^3/d	Dom
1948.10 06	FL 20933	Edward Cr.	4.5 m^3/d	Dom
1966.08.16	FL 21533	Crystal Cr.	2.3 m^3/d	Dom
1966.08.29	FL 21534	Crystal Cr.	2.3 m^3/d	Dom
1956.05.16	CL 23326	Hatchery Cr.	4.5 m^3/d	Dom
1956.09.06	CL 23438	Hatchery Cr. N. Outlet	4.5 m^3/d	Dom
1958.07.11	CL 24410	Martinson Cr.	2.3 m^3/d	Dom
1959.08.24	CL 25673	Sparkes Cr.	2.3 m^3/d	Dom
1958.10.21	CL 26197	Lakelse Hot Sprs.	454 m^3/d	Mtr
1960.01.25	CL 26198	Lakelse Hot Sprs.	65 m^3/d	Mtr
1960.10.26	CL 26725	Schulbuckhand Cr.	4.5 m^3/d	Ind
1960.10.26	CL 26726	Schulbuckhand Cr.	0	Con
1960.10.26	CL 26727	Williams Cr.	0	Con
1962.04.26	CL 28104	Lakelse Lk.	182 m^3/d	Wwk
1967.05.23	CL 32768	Creech Cr.	6.8 m^3/d	Dom
1967.02.13	CL 33007	Lakelse Hot Sprs.	227 m^3/d	Mtr
1967.02.13	CL 33008	Lakelse Hot Sprs.	182 m^3/d	Mtr
1968.07.25	FL 38110	Hatchery Cr. N. Outlet	2.3 m^3/d	Dom
1968.10.16	FL 38111	Hatchery Cr. N. Outlet	2.3 m^3/d	Dom
1965.04.15	FL 38112	Edward Cr.	2.3 m^3/d	Dom
1973.05.09	CL 42399	Wylie Cr.	2.3 m^3/d	Dom
1973.11.01	CL 43559	Hatchery Cr. Smith Outlet	2.3 m^3/d	Dom
1957.09.05	FL 44301	Crystal Cr.	2.3 m^3/d	Dom
	CL 54003	Collins Cr.	2.3 m^3/d	Dom

TABLE 3

DESCRIPTION OF LANDFORMS AND PRELIMINARY SOIL RATINGS

Soil Areas	Landforms*	Preliminary Soil Rating	Description
1	Mm	Good[1]	- morainal with 1) irregular and linear features with slopes ranging up to 10° and local relief greater than 1 m or 2) modified with surface crossed by deep, steep sided, parallel or sub parallel ravines.
2	Mm-V	Good[1]	
3	fWm-V	Good[1]	- marine deposits may be fine textured or silt sands. May be associated with a morainal veneer.
4	Ft/M//Cv	Good[1]	- mixture of terraced fluvial, morainal and some colluvial materials.
5	Ff	Moderate[2]	- fluvial materials, may be sandy, level, fan or terraced.
6	F^Gt	Moderate[2]	- fluvial glacial, usually terraced.
7	Cm	Moderate[2]	- morainal blanket or veneer. Usually overlying fluvial or colluvial materials.
8	scWm-V	Moderate[3]	- silt clay marine sediments. Usually gullied.
9	scWb//fWv	Moderate[3]	- silt clay marine sediments. Usually gullied.
10	scWb//FG_b	Moderate[3]	- silt clay marine sediments. Usually gullied.
11	Ov//Fl	Poor[4]	- organic materials. Usually from bogs overlying marine or fluvial deposits
12	Ov//scWlm Wl	Poor[4]	
13	O^Bv//Fl Fl	Poor[4]	-same as 11
14	Fl//O^Bv Fl	Poor[4]	-same as 11
15	Mv//Cb=Mb Rhs	Poor[4]	-same as 11
16	Mv//Cv/Rhs	Poor[4]	-same as 11
17	Cbv//Mv Rhr	Poor[4]	-same as 11

*See Figure 6 for location of landforms
[1]good permeability and phosphorus adsorption
[2]good percolation rates but poor phosphorus adsorption
[3]poor percolation rates but good phosphorus adsorption
[4]poor permeability and poor phosphorus adsorption

TABLE 4

NUMBER OF HOUSES AS A FUNCTION OF LANDFORMS AND DISTANCE FROM SHORE

SOIL AREA	LANDFORM	PRELIMINARY SOIL RATING	0-60 (m)	60-120	>120
3	fWm-v	Good	26	4	0
9	scWb//F^{G}b	Moderate	3	0	0
9	scWb//fWv	Moderate	13	4	0
8	scW -V	Moderate	18	0	0
5	Ff	Moderate	74	13*	20
14	Fl//$\frac{\overset{B}{0\ v}}{Fl}$	Poor	1	0	0
15	Mv//$\frac{Cb}{Rhs}$=Mb	Poor	3	0	0
16	Mv//Cv/Rhs	Poor	7	0	0
17	$\frac{Cv}{Rhr}$ //Mv	Poor	16	0	0
13	$\frac{\overset{B}{0\ v}}{Fl}$//Fl	Poor	43	10	2
			Σ 204	31	22

257 houses within watershed

* A marina within this zone was not included as a permanent residence.

TABLE 5

APPROXIMATE SIZE OF PAST AND FUTURE LOGGING ACTIVITIES WITHIN INDIVIDUAL WATERSHEDS AROUND LAKELSE LAKE

	Logged	Proposed
Williams Creek	1200	1020
Hatchery Creek	95	455
Furlong Creek	200	67
Hotsprings Creek area	145	120
Schulbuckhand Creek area	500	0
Clearwater Creek area	1400	0
West Side of Lake	1140	0
	4680	1662

Perras (pers. comm.) noted an additional 1 200 ha will be cut in the watershed; however, the locations were not included on Figure 7.

TABLE 6

SUMMARY OF WATER QUALITY DATA FOR LAKELSE LAKE

Residue	From Cleugh *et al.*, (1976)		From Abelson (1976)	Unpublished Data Collected in 1974 from EQUIS File
	Lakelse Lake Station III Mar. 13/75 Surface and Bottom Samples	Lakelse Lake Station IV Mar. 3/75 Surface Samples	Average of all samples taken in 1973-1974 Surface and Bottom Samples	South end (1100304) and North end (1100395) Surface and Bottom Samples
Hardness (mg/L $CaCO_3$)	18.8±6.7 n=5	32.5±2.5 n=4	19.7	-
Potassium (mg/L)	1.6±1.8 n=7	1.6±0.5 n=3	-	-
Magnesium (mg/L)	0.7±0.2 n=3	1.4±0.2 n=3	-	0.8 ± 0.3 (n=9)
Calcium (mg/L)	7.3±2.2 n=6	12.3±0.5 n=4	-	7.6 ± 1.6 (n=9)
Chloride (mg/L)	4.4±1.9 n=5	16.4±0.5 n=4	-	-
Sulphate (mg/L)	7.1±2.7 n=7	57.0±5.4 n=5	-	-
Silicate (mg/L)	2.2±0.4 n=7	6.5±0.7 n=5	-	-
Sodium (mg/L)	3.5±1.3 n=5	51.0±13.1 n=4	-	-
Specific Conductivity (µS/cm)	42.5±19.8 n=4	243±15.7 n=3		5.8 ± 13.8 (n=9)
pH	7.3±0.3 n=3	6.4± 0.1 n=3	-	7.4 ± 0.01 (n=9)
Total alkalinity (mg/L)	-	-	20.5	21.9 ± 4.1 (n-9)
Total Dissolved Solids (mg/L)	-	-	38	-

results= average±standard deviation (sample size)

TABLE 7

SUMMARY OF NITROGEN AND PHOSPHORUS DATA FOR LAKELSE LAKE.
Results are single samples taken from the centre of the lake.

Location and Date	Depth (m)	OP	TP	NH_3	NO_3	ON	TN
STATION III	Cleugh *et al*., 1978						
Dec. 11, 1974	Surface	<5	26	20	10		
Feb. 3, 1975	Surface	<5	20	20	50		
Mar. 3, 1975	Surface	<5	20	10	20		
May 28, 1975	Surface	<5	66	10	20		
June 29, 1975	Surface	<5	10	<5	20		
Aug. 14, 1975	Surface	17	10	18	20		
	10 m	5	10	10	10		
Oct. 13, 1975	Surface	<5	10	10	<10		
0400310	Ableson, 1976						
June 9, 1973	0	-	6	-	20	-	70
	5	-	5	-	30	-	70
	16	-	5	-	20	-	60
May 8, 1974	0	-	8	-	50	70	120
	5	-	7	<5	50	110	160
	16	-	22	-	40	70	110
June 19, 1974	0	-	3	<5	20	<10	20
	5	-	5	<5	20	<10	20
	16	-	5	<5	30	<10	30
July 16, 1974	0	<3	3	<5	20	90	110
	5	<3	4	<5	20	70	90
	16	<3	5	<5	30	50	80
August 20, 1974	0	<3	5	<5	<20	40	40
	5	<3	4	-	<20	50	50
	16	<3	5	<5	<20	<10	<10
Nov. 20, 1974	0	-	23	-	-	-	-
	5	-	22	-	-	-	-
	16	-	22	-	-	-	-
Dec. 10, 1974	0	<3	18	12	30	11	160
	5	<3	18	21	30	20	70
	16	<3	69	24	30	100	150

TABLE 7 (Continued)

OTHER MINISTRY OF ENVIRONMENT DATA

0400310 or 1131082							
May 12, 1974	0	<3	7	-	40	30	70
	16	<3	7	-	40	50	90
July 21, 1974	0	<3	4	-	<20	210	210
	16	<3	4	-	<20	200	200
July 7, 1976	0	<3	4	6	<20	10	20
	5	-	-	-	-	-	-
	16	<3	9	11	20	190	20
June 9, 1982	0	<3	14	5	30	60	90
April 7, 1983	0	<3	8	<5	70	140	210
March 1, 1984	2	<3	10	6	70	110	190

OP = orthophosphorus
TP = total phosphorus
NH_3-N = ammonia-nitrogen
All results in μg/L

NO_3-N = nitrate-nitrogen
ON = organic nitrogen
TN = total nitrogen

TABLE 8

WATER QUALITY SUMMARY FOR SKOGLUND HOTSPRINGS DISCHARGE PE 01900 (1972-1978)

	Mean	N	Min.	Max.	Standard Deviation
Turbidity (N.T.U.)	10	2	8	12	2.8
Chloride Res. (mg/L)	1	4	0	2.5	1.2
Hardness (mg/L)	37.1	1			
Ammonia-N (mg/L)	0.096	1			
NO_2+NO_3^-N (mg/L)	0.647	6	<0.02	1.9	0.76
NO_2-N (mg/L)	0.077	4	<0.005	0.219	0.098
NO_3-N (mg/L)	0.55	3	0.18	1.00	0.41
Kjeldahl Nitrogen (mg/L)	9.67	6	2	20	8.69
BOD (mg/L)	16.6	30	40	63	11.2
Orthophosphorus (mg/L)	1.48	5	0.759	2.48	0.80
Total Phosphorus (mg/L)	1.96	6	0.318	3.76	1.44
Calcium, dissolved (mg/L)	13.5	1			
Magnesium, dissolved (mg/L)	0.82	1			
Potassium, dissolved (mg/L)	4.1	1			
Fecal Coliform	3222	9	2	<20000	6392
(cell/100 mL)	10149	5	<2	25700	11874
Fecal Total (cells/100mL)	103870	8	33	790000	277290

TABLE 9

STREAM NUTRIENT CONCENTRATIONS COLLECTED MAY 19, 1982

	Lakelse River near Lake 0400210	Andalus Cr 0700104	Clearwater Cr 0700105
Nitrogen: Ammonia (mg/L)	<0.005	<0.005	<0.005
: $NO_2 + NO_3$ (mg/L)	0.03	0.08	0.02
: Kjeldahl (mg/L)	0.14	0.06	0.04
Phosphorus: Ortho (mg/L)	<0.003	0.004	<0.003
: Total dissolved (mg/L)	0.005	0.005	0.004
: Total (mg/L)	0.009	0.015	0.010

	Furlong Creek 0700099	Hatchery Creek 0700094	Unnamed Cr 0700095
Nitrogen: Ammonia (mg/L)	<0.005	<0.005	0.008
: $NO_2 + NO_3$ (mg/L)	<0.02	0.05	0.10
: Kjeldahl (mg/L)	0.11	0.04	0.08
Phosphorus: Ortho (mg/L)	<0.003	<0.003	<0.003
: Total dissolved (mg/L)	0.004	0.005	0.004
: Total (mg/L)	0.014	0.006	0.016

TABLE 9 (Continued)

	Unnamed Cr #2: 0700096	Unnamed Cr #3: 0700104	Unnamed Cr #4: 0700105	Unnamed Cr #5: 0700099
Nitrogen: Ammonia (mg/L)	0.008	<0.005	<0.005	<0.005
: NO_2 + NO_3 (mg/L)	0.05	0.07	<0.02	<0.02
: Kjeldahl (mg/L)	0.14	0.07	0.07	0.21
Phosphorus: Ortho (mg/L)	<0.003	<0.003	<0.003	<0.003
: Total dissolved (mg/L)	0.006	0.005	0.005	0.007
: Total (mg/L)	0.013	0.009	0.018	0.012

	Unnamed Cr #6: 0700094	Unnamed Cr #7: 0700095	Williams Cr. 0700098
Nitrogen: Ammonia (mg/L)	<0.005	<0.005	0.007
: NO_2 + NO_3 (mg/L)	<0.02	<0.02	0.07
: Kjeldahl (mg/L)	0.05	0.11	0.09
Phosphorus: Ortho (mg/L)	<0.003	<0.003	<0.003
: Total dissolved (mg/L)	0.005	0.005	0.004
: Total (mg/L)	0.008	0.019	0.014

#5 West of Williams Lake
#6 Creek flows into Muller Bay

TABLE 10

NUTRIENT ANALYSIS FROM THE SKOGLUND HOTSPRINGS MAIN POOL
(March 23, 1983)

Ammonia-nitrogen (mg/L)	0.006
NO_2 + NO_3-N (mg/L)	<0.02
Kjeldahl nitrogen (mg/L)	0.06
Total nitrogen (mg/L)	0.06
Orthophosphorus (mg/L)	0.003
Total phosphorus (mg/L)	0.003

TABLE 11

SUMMARY OF RESULTS FROM PHOSPHORUS MODELS USED ON LAKELSE LAKE

MODEL	SPRING OVERTURN PHOSPHORUS CONCENTRATION							
	0.005 mg/L		0.010 mg/L		0.015 mg/L		0.020 mg/L	
	L ($g/m^2/yr$)	Annual Input (kg)	L ($g/m^2/yr$)	Annual Input (kg)	L ($g/m^2/yr$)	Annual Input (kg)	L ($g/m^2/yr$)	Annual Input (kg)
Dillon and Rigler	0.33	4610	0.65	9130	0.98	13 750	1.30	18 250
Rickhow and Simpson	0.31	4330	0.62	8160	0.93	12 900	1.24	17 320

<u>Values used in Model Calculations</u>

qs = areal water loading rate (Z/tw) = 8.6/0.19 = 45 m^2/yr.

tw = water retention time = 0.19 years.

Z = mean depth = 8.6 m.

P = spring overturn phosphorus (mg/L).

L = phosphorus loading rate ($g/m^2/yr$).

R_{LM} = phosphorus sedimentation coefficient as measured by Larsen and Mercier (1975).

$R_{LM} = 0.854 - 0.142 \ln qs$

R_{LM} = 0.31 in an average hydraulic year.

TABLE 12

TYPICAL RANGES OF PHYTOPLANKTON AND NUTRIENTS FOR DIFFERENT TROPHIC LEVELS

Trophic Status	Chlorophyll a Growing Season Mean µg/L	Total P at Spring Overturn µg/L	Total N at Spring Overturn µg/L
Oligotrophic	0-2	1-10	<100
Mesotrophic	2-5	10-20	100-500
Eutrophic	>5	>20	500-1000

From Wetzel (1975), Rast and Lee (1978), and Carlson (1977).

TABLE 13

ANALYSIS OF LAKELSE LAKE SEDIMENTS

	DATA FROM LAKELSE LAKE, JULY 26, 1984*		DATA FROM OTHER B.C. LAKES	
	SOUTH BASIN STATION 7	DEEPEST POINT STATION 3	MEAN AND STANDARD DEVIATION	n
Sample, depth (m)	6	22	16.9 ± 17.6	197
Volatile (%)	12.6	16.7	28.7 ± 19.8	100
Carbon, total (mg/g)	39	63	118 ± 90.8	201
, organic (mg/g)	24	63	112 ± 89	198
, inorganic (mg/g)	15	<0.5	13.9 ± 25.8	198
Nitrogen, Kjeldahl (mg/g)	1.64	2.68	10.1 ± 8.2	201
Phosphorus, total (µg/g)	1310	1100	1134 ± 758	202
Mercury, total (µg/g)	0.06	0.06	0.17 ± 0.13	191
Aluminum, total (µg/g)	20.6	20.9	19.8 ± 70.8	202
Arsenic, total (µg/g)	37	<25	40.4 ± 121	202
Cadmium, total (µg/g)	<1	<1	1.3 ± 1.35	202
Calcium, total (mg/g)	7.49	7.80	34.8 ± 64.4	202
Chromium, total (µg/g)	47	44	36.3 ± 33.3	202
Cobalt, total (µg/g)	<10	10	15.3 ± 9.8	202
Copper, total (µg/g)	46	63	42.4 ± 46.5	202
Iron, total (mg/g)	47.3	42.1	28.2 ± 36.6	202
Lead, total (µg/g)	36	22	42.2 ± 63.7	202
Magnesium, total (mg/g)	13.1	14.5	9.3 ± 21.0	202
Manganese, total (µg/g)	2400	1900	866 ± 1468	202
Molybdenum, total (µg/g)	18	16	14.2 ± 17.9	202
Nickel, total (µg/g)	25	26	29.9 ± 37.3	202
Zinc, total (µg/g)	93	93	90.8 ± 80.3	202

*See Figure 8 for location of sites

TABLE 14

FECAL AND TOTAL COLIFORM RESULTS COLLECTED BY THE MINISTRY OF ENVIRONMENT IN 1973 and 1974

Date	1 0400305		2 0400307		3 0400310		4 0400313		5 0400316		6 0400318		7 0400319		8 0400321	
73 07 09	<2	11	<2	11	<2	4	2	8	2	17	1600	G 2400	<2	110	<2	9
	<2	4	<2	2	<2	8	<2	8	<2	17	1600	G 2400	2	13	<2	13
	<2	23	<2	<2	<2	8	<2	5	2	23	540	G 2400	<2	140	2	14
74 05 08	2	2	<2	2	<2	<2	<2	<2	2	5	2	8	2	8	2	5
	2	2	<2	2	<2	2	<2	<2	<2	<2	<2	4	<2	<2	2	8
	<2	5	<2	<3	<2	<2	<2	<2	2	8	2	5	<2	5	2	7
74 06 19	<20	-	<20	-	<20	-	<20	-	<20	-	20	-	<20	-	<20	-
	<20	-	<20	-	-	-	<20	-	<20	-	<20	-	<20	-	<20	-
74 07 16	<2	<2	<2	2	<2	2	<2	2	<2	2	<2	2	<2	2	<2	<2
	<2	<5	<2	2	<2	<2	<2	2	<2	<2	<2	11	<2	5	<2	2
74 08 06	2	2	<2	2	2	2	<2	2	<2	<2	5	17	<2	7	<2	2
74 11 20	<2	2	2	8	2	2	2	5	2	5	<2	5	2	13	-	-
	<2	5	5	13	2	5	-	-	-	-	2	8	-	-	-	-

See Figure 8 for site locations
Coliform results in MPN/100mL

TABLE 15

TOTAL COLIFORM RESULTS COLLECTED BY THE MINISTRY OF HEALTH IN 1984 AND 1985 (LEE, PERS. COMM.)

Coliform Results from Drinking Water Supplies (Cells/100 mL)

Site Code for Figure 8		Date	Result
		1984	
C	Provincial Park Picnic Site	July 4	<2.2
		August 7	5.1
		Sept. 5	2.2
		1985	
		June 18	<2
		July 9	<2
		July 22	<2
		July 30	<2
		August 6	<2
		August 12	<2
		August 26	<2
E	Provincial Park Furlong Bay	1984	
		July 4	<3
		August 12	<2
		August 19	<2
		August 26	<2

Coliform results from beach samples (cells/100 mL)

C	Picnic Site Beach	May 16	<3, <2.2
		June 25	9
		July 23	<3
A	Beam Street Beach	June 5	<3 (fecal)
		August 7	43
F	Olies Beach	June 6	3 (fecal)
		June 25	4
		July 25	15
		August 1	3
E	Furlong Bay Beach	May 30	4
		July 4	3
		July 23	<3
B	Grouchies Beach	July 16	9
		August 15	<3

TABLE 16

1984 ZOOPLANKTON CONCENTRATIONS (#/m³) FROM LAKELSE LAKE AT THE DEEPEST POINT

	March 1, 1984	July 26, 1984
Nauphlia	677	637
Copepodites	124	148
Cyclops bicuspidata	96	602
Bosmina	41	-
Eubosmina longirostris	-	645
Diaphanosoma	-	30
Kellicottia	-	16126
Polyarthra	69	133
TOTAL	1007	18321
Total Copepods	897	1387
Total Cladocerans	41	675

Samples represent 30 m vertical tows

TABLE 17

LAKELSE LAKE MACROPHYTES COLLECTED IN JULY 1984
(FROM WARRINGTON, IN PREP.)

Sparganium emersum	*Potamogeton richardsonii*
Isoetes sp.	*Potamogeton gramineus*
Chara sp.	*Potamogeton zosteriformis*
Nuphar polysepalum	*Potamogeton robbinsii*
Carex sp.	*Potamogeton berchtoldii/freisii*
Equisetum fluviatile	*Potamogeton epihydrus*
Ranunculus aquatilis	*Potamogeton natans*
Ranunculus flabellaris	*Potamogeton praelongus*
Typha latifolia	*Potamogeton pectinatus*
Scirpus lacustris	*Myriophyllum exalbescens*
Scirpus subterminalis	*Myriophyllum verticillatum*
Glyceria sp.	*Utricularis vulgaris*
Nitella sp.	*Utricularis intermedia*
Menyanthes trifoliata	*Najas flexilis*
Hippuris vulgaris	*Callitriche heterophylla*
Alisma plantago-aquatica	

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