The Physical Limnology of Lakelse Lake, British Columbia

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ABSTRACT

Lakelse lake is a temperate, eutrophic lake situated on the eastern margin of the Coast Range mountains. For five years physical and chemical studies of this lake have been conducted as part of the Skeena River Salmon Investigation. Its area of 5.2 square miles (14.2 sq. km.) and mean depth of 24 feet (7.9 m.) provide a relatively small volume of water which is subject to considerable circulation from heavy winds sweeping in from the Pacific coast. Summer thermal stratification is varied and irregular, resulting in a proportionately large and unstable epilimnion. Except for a single bottom depression, oxygen concentrations remain at a high level throughout the year.

During four months of the year the lake is ice covered. Large snow and ice fields provide an excellent reservoir for stream flow.

Among the Skeena river lakes Lakelse is one of the most productive of sockeye salmon. Their survival does not appear to be limited directly by physical or chemical factors.

INTRODUCTION

During the five years, 1944 to 1948, physical and chemical studies were conducted on Lakelse lake, B.C., as part of the programme of salmon research on the Skeena river (Pritchard 1947). It was the express purpose of "The Skeena River Salmon Investigation" to examine the conditions for all species of salmon with special interest in the sockeye salmon, *Oncorhynchus nerka*. Primarily the investigation was designed to establish conservation measures.

The life cycle of the sockeye usually involves at least one year of lake residence. It is during this lacustrine stage that the greatest mortality befalls the young sockeye (Foerster 1938; Brett 1948). In recognition of the significance of lake studies in this investigation general surveys of the more important bodies of water in the Skeena river drainage were conducted. Lakelse lake was singled out for particular attention in an effort to elucidate the more limited findings in other areas by a critical study of one area.

While these data represent strictly a record and study of the physical structure of the lake, an effort has been made to demonstrate their relationship to sockeye survival, both young and old.

PHYSIOGRAPHY AND MORPHOMETRY

Location and geology

Lakelse lake, 54° 30′ N., 128° 40′ W., is situated seventy miles directly east of the coastal city of Prince Rupert and about ten miles south of the Skeena river. To the west and east of the lake, mountains rise to 5,000 feet (1,500 m.), forming a basin two to seven miles wide which crosses the Skeena valley at Terrace and extends south to the Kitimat arm of the Pacific. A low flat-topped rise of 300 feet (92 m.) in the valley basin just south of the lake forms the division of drainage between the lake and the Kitimat arm. The geological structure and fossil remains indicate that the area was once continuous with the ocean, a possibility

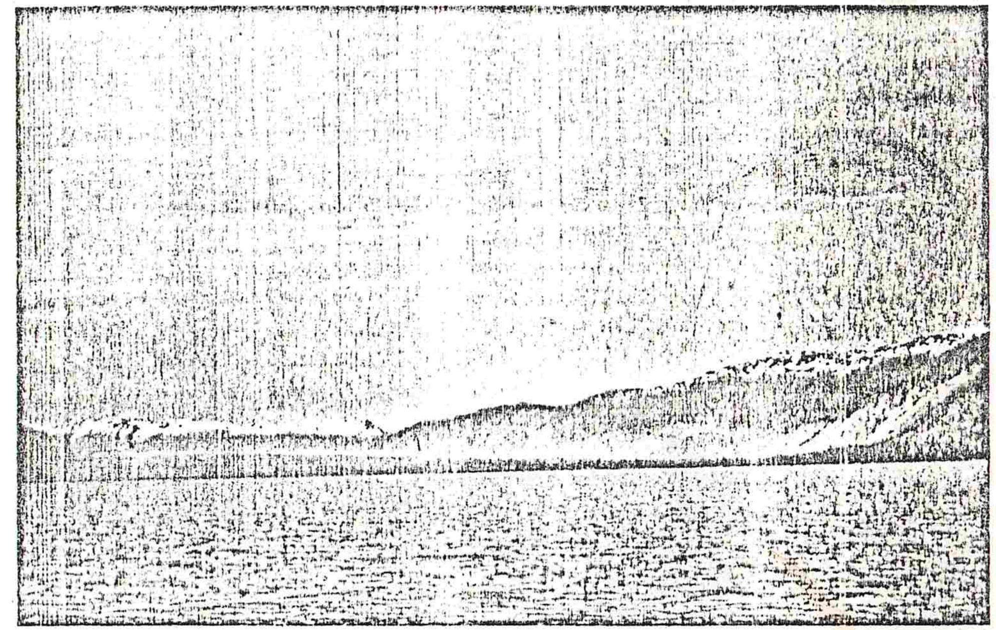

Figure 1. Looking north on Lakelse lake from a central position.

which is readily conceived by studying the land elevations. The height of the lake itself is reported as 220 feet (67 m.), about 30 feet (9.2 m.) above the level of the Skeena river at the point of confluence with the Lakelse river.

The mountains of this area constitute a portion of the eastern margin of the Coast Range which was lifted up from pre-existing rocks during the Jurassic period by enormous upwellings of igneous magmas. These rocks in the form of multiple batholiths consist mainly of granite, diorite and quartz porphyry. The exposure of the basin itself is of more recent Pleistocene time and is mainly alluvium and glacial silt (Marshall 1926).

During the evolution of the Glacial age much of this whole coastal region was depressed 500 to 600 feet by an immense thickness of ice. With its recession and the consequent uplifting of the land masses, probably some 20,000 years ago, the connection and drainage to the Kitimat arm was severed and dammed up to form the present lake (Hanson 1923).

CLIMATE

The climate of the Lakelse lake area can be judged from the records taken at the meteorological station at Terrace, ten miles north of the lake, and from later records taken during the spring and summer months at the lake itself. These latter indicate a slightly greater precipitation and a somewhat more moderate

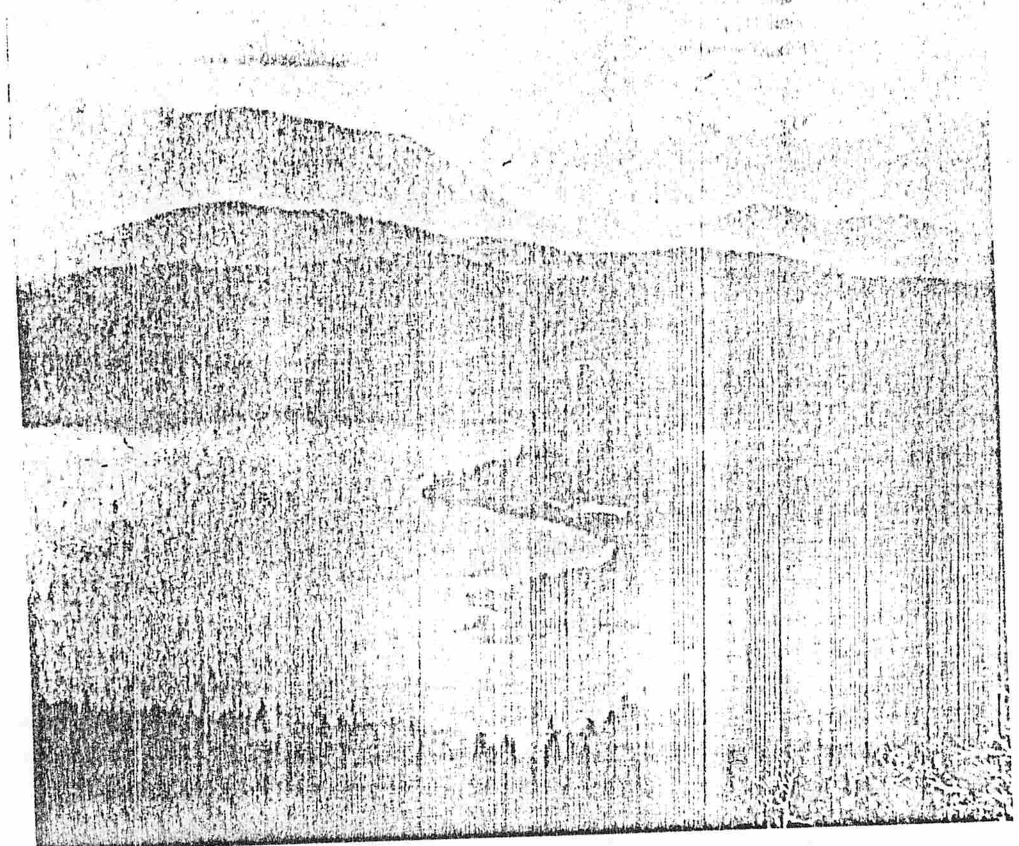

FIGURE 2. A view of the northern end of Lakelse lake from Mt. Layton, 2,000 feet.

temperature at the lake when compared with those from Terrace (May to September), although very similar weekly means exist. The body of water and the criss-crossing mountain ranges of the Lakelse and Skeena river valleys would account for such local differences.

The annual mean temperature for Terrace during the 33-year period from 1913 to 1945 (B.C. Climate 1945) was 44°F. (6.7°C.). The temperature rarely rises above 90°F. (38°C.) or falls below 0°F. (− 18°C.). Frequent heavy snowfalls and continued frost often prolong the winter well into April in the heavily

wooded country surrounding the lake. In this manner a considerable reservoir of water is retained in the form of snow and ice particularly on the mountain sides.

The spring is often a time of floods, gouging out river beds and cutting new courses, frequently leaving portions of the old waterways dry during a later period of reduced flow. This is a characteristic of a great deal of the Skeena river

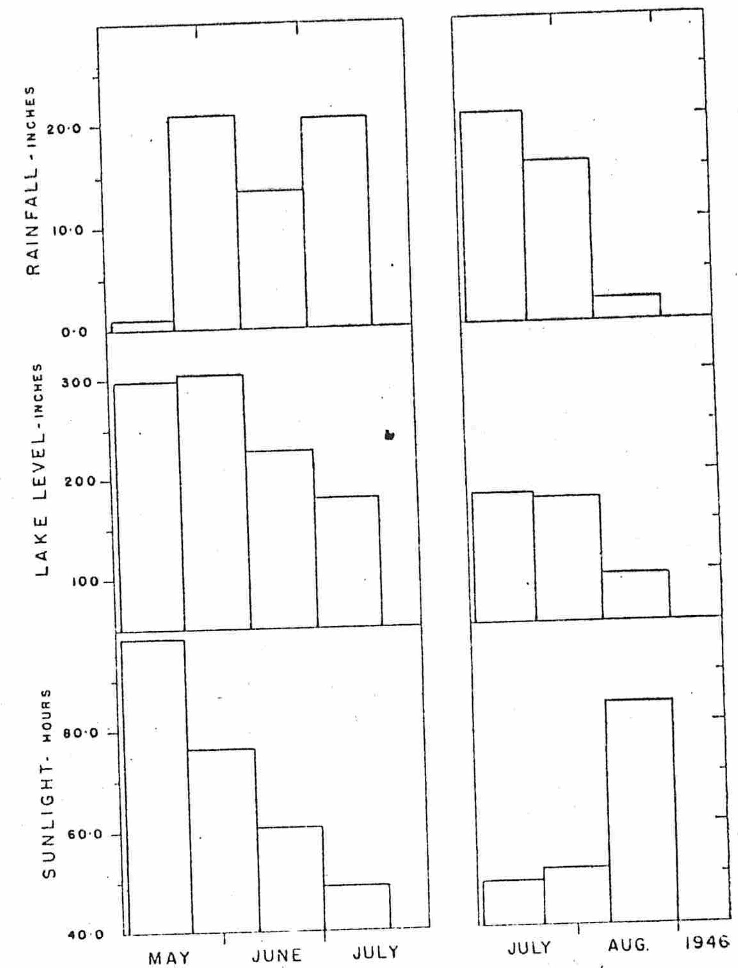

FIGURE 3. The relation between rainfall, hours of bright sunlight and lake level, plotted for 20-day intervals. The month of July has been repeated in a split graph to illustrate the difference in relation between early and late summer.

country and in both the spring and late fall constitutes a potential and unpredictable threat to the survival of salmon eggs from a given spawning.

The average precipitation for the same 33-year period is recorded (B.C. Climate 1945) as 46.85 inches (119.0 cm.). The months of May to August present the minimum period of rainfall, with an average of 2 inches (5.1 cm.) per month, following which there is a rapid increase of rain (and snow) to a peak in November of 7.48 inches (19.0 cm.). The location of the lake is such that it is on the border between coastal weather conditions and the drier inland climate. As a result, it experiences considerable variation in weather, but can be considered as characterized by a moderate climate with fairly heavy rain and snowfall.

In the spring, lake and stream levels have been found to rise more in accordance with hours of sunlight (melting snow) than with precipitation, a relation which is gradually supplanted by the effect of precipitation alone with the progress of the seasons into the late summer months (fig. 3). By August and September when the adult sockeye are entering the streams, rainfall appears to be all important in maintaining the height of the rivers and consequent covering of the spawning beds. A reduction in the precipitation during these months in the Skeena river drainage appears to result in a possible reduction in the subsequent commercial catches of adult sockeye (cf. Hagman 1938).

Size, Shoreline and Bottom Configuration

The lake is approximately 5.4 miles in length along a N.E.-S.W. axis and varies from 0.7 to 1.5 miles in width, covering an area of 5.47 square miles, or 3,500 acres (14.2 km.²). With a regular shoreline the shore development is not great, being just short of twice the minimum and equal to 1.83. It is characterized by many reed beds and very little rock. Fig. 4 illustrates the shape and the bottom configuration, the latter plotted to five metre intervals. The southern end is particularly shallow and reflects the general condition throughout, in which the mean depth is only 7.8 metres (24 feet). The areas and volumes for each 5 metre interval have been recorded in table I.

Table I. The morphometry of Lakelse lake.

Area	14.17 sq. km. (5.47 sq. mi.)
Maximum length	8.7 km. (5.4 mi.)
Maximum width	2.4 km. (1.5 mi.)
Maximum depth	32.2 m. (98 ft.)
Mean depth	7.9 m. (24 ft.)
Volume	108.0 × 10⁶ cu. m. (141.3 × 10⁶ cu. yd.)
Shore development	1.83
Elevation	72.2 m. (220 ft.)

Depth (m.)	Area (hectares)	% total surface area	Stratum (m.)	Volume (cu. m. × 10⁶)	% total volume
0	1420	100.0	0-5	55.7	51.6
5	808	77.0	5-10	30.4	28.1
10	412	29.1	10-15	15.4	14.3
15	205	14.4	15-20	4.9	4.5
20	52	3.7	20-25	1.4	1.3
25	3	0.2	25-32.2	0.2	0.2
			Total	108.0	

The particular feature of Lakelse lake which defines so much of its nature is its mean depth. Young sockeye are considered to be limnetic rather than littoral in habit during the summer months (Ricker 1937b). Since the lake is so shallow

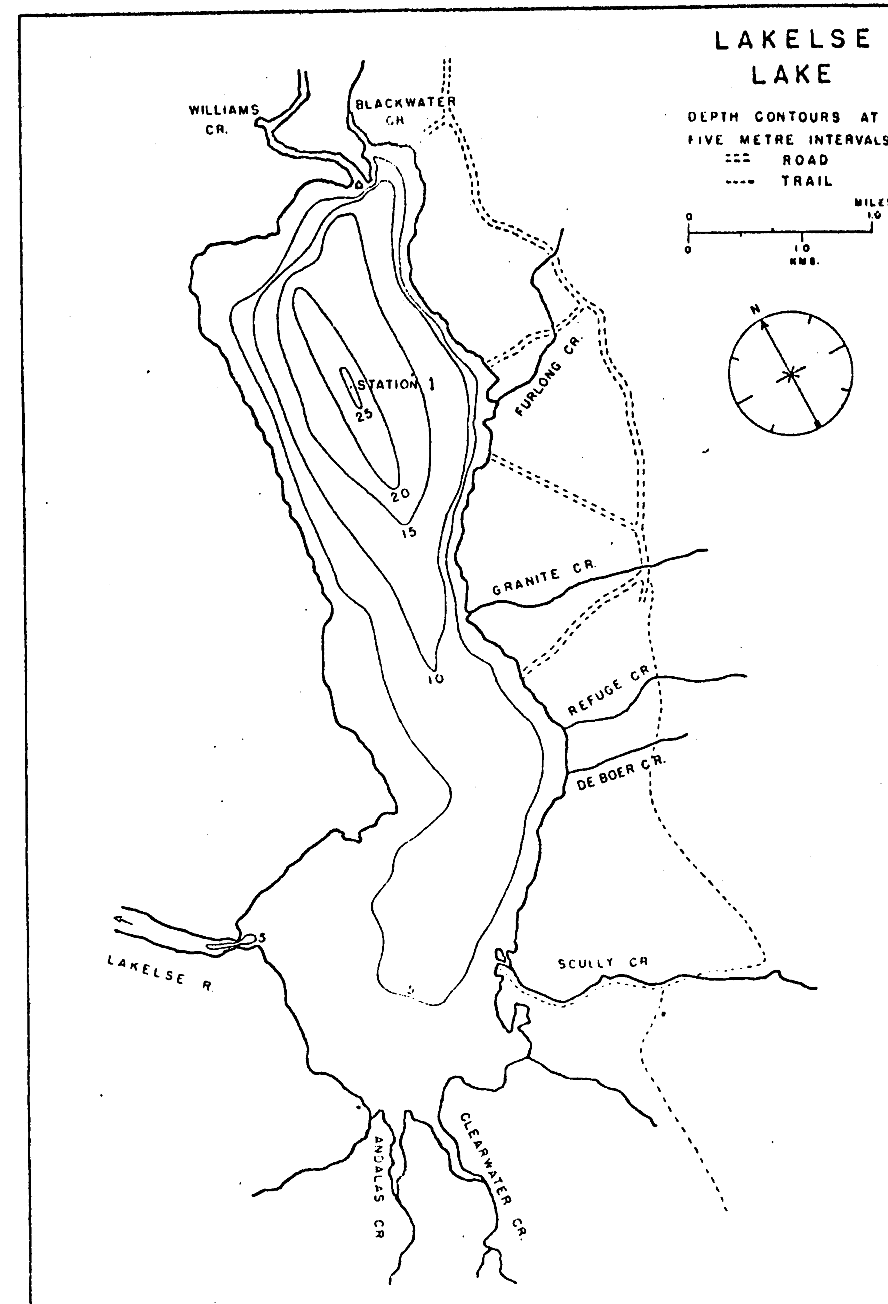

Figure 4. Map of Lakelse lake, British Columbia, showing bottom configuration.

the limnetic zone is correspondingly reduced and the average littoral temperatures rise as high as 20°C. (68°F.). This promotes growth of aquatic plants and animals resulting in a greater unit abundance of food, and a lake capable of supporting larger populations of young fish. Although restricting the inhabitable zone for young sockeye the net balance appears to be one of favourable conditions for their production. In the spring of 1948 it was estimated that between one to two million yearling sockeye migrated seaward.

Drainage and Water Level

The main stream drainage into the lake is that from Williams creek at the northern end, supplemented by the lesser streams of Granite and Scully creeks from the east, and Clearwater and Andalas creeks from the south. The outlet is via the Lakelse river in the southwest which flows almost directly northwest to the Skeena twelve miles distant. With the exception of the first mile, the Lakelse river has an even, rapid flow over coarse gravel and boulders. The mouth is narrow and deep, expanding into a wide, shallow arm with little noticeable current and preceding the more turbulent portion of the river downstream.

The general characteristics of these rivers have been outlined in table II:

Table II. Physical characteristics of the main streams entering Lakelse lake.

River	Summer temp.	pH Red	pH Blue	Clarity	At outlet Width	At outlet Depth	Bottom
Williams cr.	8-12°C.	7.3	7.1	Fairly turbid	1. 50'* 2. 80' 3. 15'	4'	Gravel and sand
Blackwater cr.	17-20°C.	—	6.5	Fairly clear	60'	5'	Mud, silt and sand
Granite cr.	8-10°C.	7.2	7.0	Clear	25'	2'	Sand and gravel
De Boer cr.	9-11°C.	7.3	6.9	Clear	25'	1'	Sand and gravel
Scully cr.	8-10°C.	7.3	7.2	Clear	25'	3'	Sand and gravel
Clearwater cr.	10-13°C.	7.9	7.7	Clear	200'	2'	Sand and silt
Andalas cr.	7-10°C.	7.9	7.6	Turbid	200'	2'	Silt

*Three separate outlets.

For the past five years approximately 80% of the total adult sockeye run has entered Williams creek. While spawning they distribute themselves over its many suitable gravel beds for a distance of four to four and one-half miles (Pritchard and Cameron 1940). The major supply of water to the lake comes from this source which is mainly glacial and run-off in origin. Williams creek, in providing the spawning beds, constitutes one of the main physical features of importance in a salmon-producing body of water.

The fluctuations in volume discharge of Williams creek are reflected by fluctuations of water level within the lake. A continuous record of the lake water level provides a picture of the variations in river height. Peaks of high water usually occur in May following melting of snow under intense sunlight and in late October or early November as a result of heavy precipitation. The low levels occur between the end of August and the beginning of September, and just prior to ice formation (fig. 5).

The late summer minimum coincides with the major spawning period. If there is a drought at this time, a reduction in the amount of spawning beds may

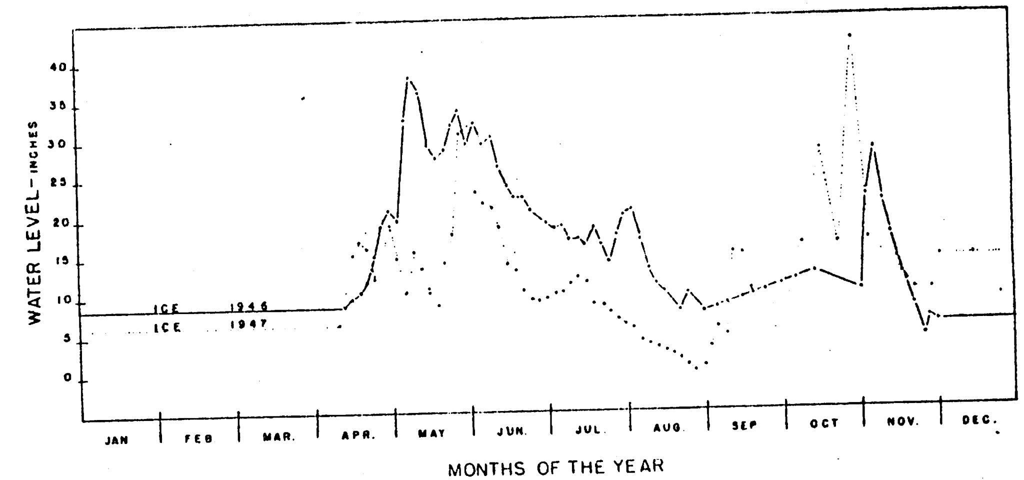

Figure 5. Annual variation in water level for 1946 and 1947 at Lakelse lake.

seriously reduce the efficiency of egg deposition. If abnormally high water exists many beds may be left exposed in a subsequent drop of level. It would appear that an average level somewhere near that of the final freeze-up level would be most suitable for successful production of young fish from a given seeding.

TEMPERATURE

Procedure

The temperature variation has been recorded for Lakelse lake at a single station in the vicinity of the greatest depth, Station 1, during the months of July to September of 1944, April to September 1945, and at two week intervals throughout all months of the year from April, 1946, to May, 1948. Throughout this study a standardized Negretti-Zambra deep-sea reversing thermometer, graduated to fifths of a degree Centigrade, has been used (Kemmerer *et al.* 1923). In addition, a bathythermograph (Spilhaus 1937) was used in 1946 and operated for more extensive recordings in the early part of each season's work. Its use was directed toward determining the thermal structure of the whole lake rather than of one column, thus testing the degree of representation afforded by the single station. Since the lake is characterized by one main depression the complications of thermal structure introduced by submerged depressions (Welch and Eggleton 1932) are not present.

SEASONAL CHANGES

1. *Spring Overturn:* With moderate climatic conditions in winter, the ice coverage is not excessive, amounting to a maximum of twenty-four inches of porous snow-ice intermingled with layers of hard ice. Toward the end of March in an average year, sunshine and warm winds constantly melt the surface and reduce the thickness. The break-up varies from abrupt upheaval to gradual displacement depending on the meteorological conditions which precede it. Once the ice has been reduced to a few inches and shows definite cracks and breaking points a heavy wind can be disruptive, the actual break-up being followed rapidly by the spring overturn and a rise in surface temperature.

For the years 1945 to 1947 the overturn has occurred within one day of April 4, while in 1948, which was an exceptional year, the overturn did not occur until April 24. The usual state is a break-up and overturn in the first week of April.

2. *Thermocline Formation and Period of Summer Stagnation:* The presence of a distinct thermocline* rarely becomes apparent in the first month of heat interchange but thermal stratification is present from the very first days and an upper circulation of water of different depths occurs to varying degrees in proportion to the intensity and duration of the wind. This is in direct contrast to the period leading up to ice formation in the fall of the year.

During the summer intense winds, sweeping up the open Kitimat Arm of the coast and through the Lakelse lake valley, often disrupt the thermal layering of the lake resulting in marked fluctuations in the presence, absence or position of one or more true thermoclines. The very deepest portion of the lake, however, remains at least partially out of circulation. Lakelse lake is consequently a poor example of the classical concept of a thermally stratified lake in midsummer. It might be described best as a lake which undergoes thermal stratification of varying degrees, sometimes exceeding 1°C. per metre, with an upper zone of water which tends to circulate as a separate body and which becomes more distinct as a maximum in water temperature is approached. This zone of water usually varies from 10 to 20 metres in depth and yet may be dispersed within a few hours by wind action.

The maximum surface and bottom temperatures for each year appear in table III. The average peak condition (1944-47) has come some time in the month of August when the whole lake became warmed to an extent which resulted in temperatures averaging 19.1 ± 0.9°C.† at the surface to 10.9 ± 1.4°C. at the bottom.

*Defined as equal to or greater than a change of 1°C. per metre (Welch 1935).

†Standard deviation used throughout.

TABLE III. Surface and bottom temperatures at the time of maximum thermal state, Station 1, Lakelse lake.

Year	Date	Surface	Bottom
1944	Aug. 8	19.4°C.	13.0°C.
1945	" 8	20.2	9.2
1946	" 29	18.8	10.3
1947	" 15	17.8	11.1
Average	Aug. 15	19.1 ± 0.9°C.	10.9 ± 1.4°C.

3. *Fall Overturn:* By September all strata of the lake with the exception of the greatest depths have commenced to cool. A month later the whole lake shows a declining temperature, the upper strata losing heat more rapidly than the lower strata, resulting in final uniformity of temperatures throughout. In 1946 this occurred by approximately October 31 with a uniform temperature of 7.0°C., while in 1947 a consistent and almost parallel decline of temperature for all strata commenced in early October and finally merged just prior to reaching 4°C. This marks the start of the overturn which continues until a new stratification in reverse occurs as cooling below 4°C. proceeds. By the end of November ice has usually sealed the lake from further wind-produced currents. Table IV contains a summary of the data for duration of overturn and commencement of surface freezing.

TABLE IV. Fall overturn and winter data, Lakelse lake.

	Fall overturn			Winter stagnation		
Year	Commenced	Temp.	Date 4°C. reached	Date of freeze-up	Min. bottom temp.	Date of break-up
1946-47	Oct. 31	7.0°C.	Nov. 8	Nov. 24	3.7°C.	April 15
1947-48	Oct. 15	11.0°C.	Dec. 8	Dec. 20	3.2°C.	April 23

4. *Winter Stagnation:* The sharp drop in temperature ceases for the lake as a whole when a temperature of 4°C. has been reached. Only the surface waters continue to cool giving rise to the usual inverse thermal stratification. The extent of the upper stratification at first exceeds 1°C. per metre of depth. As further cooling takes place and the ice surface is established this gradient is reduced. The temperatures at each depth progressively drop below 4°C. until the more stable bottom temperatures are involved. A reduction of temperature at 80 feet

has been apparent in both 1947 and 1948. A record of the temperature variation at 20 foot intervals of depth from April 1946 to April 1948 has been depicted in fig. 6.

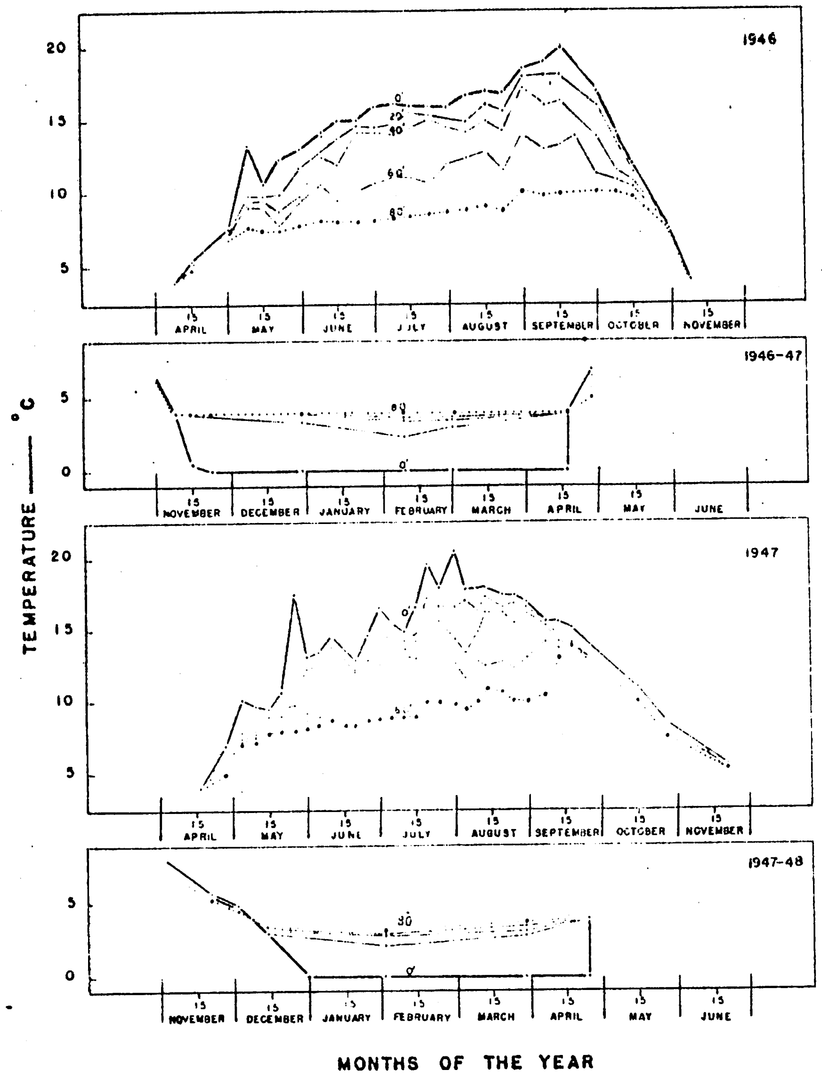

FIGURE 6. Temperature variation at depths of 20-foot intervals, Station 1, from April, 1946 to April, 1948. (The data used in plotting these graphs are available on request from the Pacific Biological Station, Nanaimo, B.C.)

With the elimination of wind effect by an ice blanket the thermal changes conform to the state described for most ice-covered lakes in a temperate climate (Welch 1935; Greenbank 1945). The term "stagnation" however is somewhat misleading here in that it would imply a marked stability for the water of greatest depth and the absence of any circulation within its bounds. That there may be some exchange as a result of river water displacement would appear possible through inference from the high oxygen content recorded throughout the winters of 1946-47 and 1947-48.

Yoshimura (1935) sub-divided the stagnation periods of fresh water lakes into eight distinguishable phases in an attempt to elucidate further the thermal evolution within a lake. Since temperature changes are dynamic in nature, division into different categories is in part arbitrary, relying on the importance attached to aspects of the study by some particular investigator. In the case of Lakelse lake, being in a north temperate zone, the two physical features which result in major differences in thermal stratification are the reduction in temperature through 4°C. and the freezing of the surface. Further subdivision of the annual temperature cycle is not particularly appropriate. The volume of water over 15 metres in depth is only 6% of the total volume. If a portion of this did become stagnant during the summer, it could hardly be considered representative of the whole lake.

HEAT BUDGETS

Attempts to set a measure of the effect of solar energy in terms of heat units and provide a means of comparing different lakes were advanced through the work of Forel (1901) and Halbfass (1905, 1913), and later developed by Birge (1915) and Birge and Juday (1914, 1921, 1929) in terms of an annual heat budget. The significance of heat budgets has been questioned by each of the above investigators and the conclusions are conflicting. In particular Birge and Juday (1914) have defended and developed its use as a comparative index. Birge (1915) states, "No doubt more complete study will show that the heat budgets of the several lakes are influenced by elevation, surroundings, size of affluents and effluents, climate, cloudiness, latitude, and other conditions as well; but at present a direct and unmistakable effect of any one of these conditions can be pointed out only in a very few cases, and it is best to consider the budgets in gross and without too much attention to particular circumstances" (p. 167). "It allows us to determine the influence of such factors as the area and depth on the amount of heat taken in by them" (p. 176). Ricker (1937a) in his study of Cultus lake, B.C., comments that "The small heat budget of Cultus lake is a direct reflection of the generally equable climate of the region" (p. 376)

Whatever the significance may be, it is interesting to compare the annual heat budgets of Lakelse lake with those from two other sockeye producing lakes on the Pacific coast, Karluk lake, Alaska (Juday *et al.* 1932) and Cultus lake, B.C. (Ricker 1937b). The immensity of the sockeye populations (Gilbert and Rich 1927) which migrate both into (adults) and out of (young migrants) Karluk lake necessitates a colossal conversion and production of food. Cultus lake, classified as oligotrophic by Ricker (1937a), is nearly one-sixth the area of Karluk lake, but only produces by comparison about one one-hundredth as many sockeye (Foerster 1938). Lakelse, in proportion to its area, has a smaller run of adult sockeye than Cultus lake (it is over twice the area of Cultus yet has just half the number of sockeye). In table V the heat budgets in gm.-calories/cm² from 1946 to 1948 are shown. The average of 13,110 for Lakelse is considerably lower than that of 24,300 for Cultus and much more so for Karluk at 33,500. Lakelse lake appears to have one of the lowest heat budgets on record.

TABLE V. Heat budgets and summer heat incomes for Lakelse lake in gm.-calories/cm².

Year	Heat budget	Summer heat income
1946	12,450	11,150
1947	13,350	12,050
1948	13,540	12,160
Average	13,110	11,190

DISCUSSION

As stated previously the fry and yearlings appear to frequent the limnetic zone, avoiding the littoral region, perhaps because of a temperature intolerance or purely from thermal preference. The latter view is supported by the work of Donaldson and Foster (1941) who state, "From the experimental evidence and field observations, it would appear that the young sockeye salmon are very selective in their choice of water of uniform temperature, choosing that water near the thermocline in preference to warmer surface water or colder waters in the depths of the lakes". They also conclude that "the temperature of the surface layer of water in the lake (Skaha lake, B.C.) was too high for optimum growth, survival, and efficient utilization of food". Ricker (1937b) has stated that "the summer feeding of fingerlings appears to be chiefly confined to the region between 5 and 15 metres depth, which includes the thermocline and adjacent narrow strips of the epilimnion and hypolimnion. Foraging is limited upward by scarcity of food, and downward by poor illumination or low temperature". The latter conclusion is one made more by inference than direct observation. The same can be said for Lakelse lake, for, with the exception of one single observation, fingerlings have not been caught or observed during the summer in the littoral zone which is the only area where suitable fishing gear has been employed.

Temperature as a direct lethal factor (cf. Fry 1947) and temperature as an indirect factor promoting death through disease have different operative levels. The effect of the myxobacterium *Chrondrococcus columnaris* as a threat to the survival of salmon under given temperatures has been demonstrated by Fish (1948) and Fish and Rucker (1943). The former states (1948) that, "Below 60°F., columnaris disease is of little consequence, but between 60° and 70°F., *C. columnaris* invades the inevitable cuts and abrasions on fish, quickly establishing a secondary infection that may prove lethal. Above 70°F., *C. columnaris* becomes a pathogen in its own right and needs no mechanical injuries to open a door through the protecting mucous coating of the skin and gills".

No significant examples of either direct or indirect effects of temperature causing high mortality in sockeye have been observed at Lakelse lake. Its fundamental effect appears to be one of promoting sockeye growth and activity while limiting the scope of foraging mainly to the limnetic and thermocline zones.

TRANSPARENCY

PROCEDURE

As a measure of transparency a standard Secchi disc was used at the time of making bi-weekly recordings in the centre of the lake at Station 1. By observing the usual methods of operating this instrument, and recording the accompanying weather conditions, a broad classification of the Skeena river lakes has been accomplished.

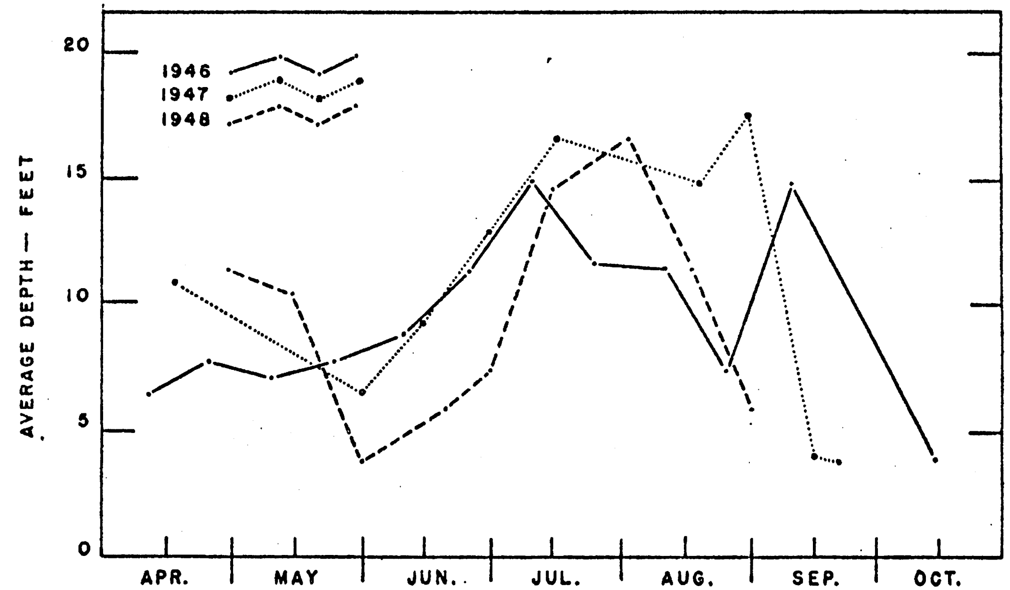

FIGURE 7. Secchi disc recordings at Station 1, Lakelse lake, 1946-1948.

VARIATION AND AVERAGE TRANSPARENCY

A peak in transparency has repeated itself in July and again in September in every summer of continuous observation on Lakelse lake, while the end of May and the middle of October have been characterized by heights of turbidity (fig. 7). These latter two coincide with periods of flood and may be compared with the graph of water level fluctuation, fig. 5. The lake cannot be considered as a heavily silted lake for its average transparency from the records of 1945-48 is 10.0 feet (approximately 3 m.) and a record of 17.5 feet (5.3 m.) exists for August 30, 1947.

Although the main stream discharge into the lake stems from mountain sides of the surrounding terrain and results in a partial silting of the waters, the obstruction to light penetration on an average day must come as much from microscopic organisms and organic matter as from inorganic suspended particles. The temperature relations are probably as responsible for this phenomenon as any other factor. In the summer season, the temperature of the epilimnion is almost invariably higher than the temperature of the river waters, thus the silt tends to be carried down to the hypolimnion zone, leaving the upper waters comparatively clear. The reverse of this has been found to be true for other colder lakes in the same drainage.

The lower limits of sight and of food abundance are very reduced in certain of the Skeena river lakes, considerably more so than in Lakelse. A preliminary survey would indicate that the suitability of a lake for sockeye production is closely linked with transparency. This may be a direct result of limitation of phyto-plankton by a reduction in light penetration. However, the presence of heavy silt in a lake reflects an even heavier suspension in the inflowing rivers, and such features reduce the area of good spawning beds. It is probable that the effects of silt in both lake and stream combine to limit the productive capacity for sockeye.

DISSOLVED OXYGEN

Procedure

With a view to recording oxygen concentrations, samples of the water at various levels, always including the surface, usually the thermocline region, and one sample within a few feet of the bottom, were taken with a Kemmerer water bottle as routine procedure while determining temperature gradients at Station 1. These samples were analysed for total oxygen by the Winkler method of determining dissolved gas (Theriault 1931).

Seasonal Changes

The variation in oxygen content of any lake is mainly a product of organic decay, animal metabolism and physical dynamics. During the spring and fall overturns no distinct deficit can occur for purely physical reasons. The periods of major concern, biologically, are during the summer and winter stagnation periods (Birge and Juday 1911; Greenbank 1945). The variation in oxygen saturation at depths of 0, 40 and 80 feet have been plotted in fig. 8 which is a typical example of the conditions at Lakelse lake for that portion of the year. No record has been taken of an oxygen saturation below 45% (5.2 p.p.m., 9.7°C., 80 ft., September 14, 1945) and since this degree of reduction is restricted to the hypolimnion very little diminution of the total oxygen content occurs. It might be expected that winter stagnation would result in a more pronounced deficit, but all attempts to measure this have indicated a consistently high level of oxygen saturation, e.g. March 1, 1947, 10.1 p.p.m. at 80 feet, 3.8°C., 76% saturation, 13 inches of ice.

It will be noted that at times the surface oxygen rises above 100% saturation, although only slightly. Each of these occasions was marked by rising surface temperatures and calm water conditions. Since the solubility of oxygen in water

decreases with rising temperature the above facts would readily explain the observed phenomena.

Undoubtedly an active wind circulation and unstable thermocline during the summer, with a submarine flow pattern during the winter, play important yet undefined roles in the oxygen saturation at all levels in the lake.

Discussion

Gardner and Leetham (1914) have shown experimentally that the amount of oxygen required by fish varies with the temperature of the water. Asphyxial points for brown trout vary from 1.13 p.p.m. at 43.5°F. (6.4°C.) to 3.4 p.p.m. at 77.0°F. (25°C.). This is also essentially true for brook trout and rainbow trout

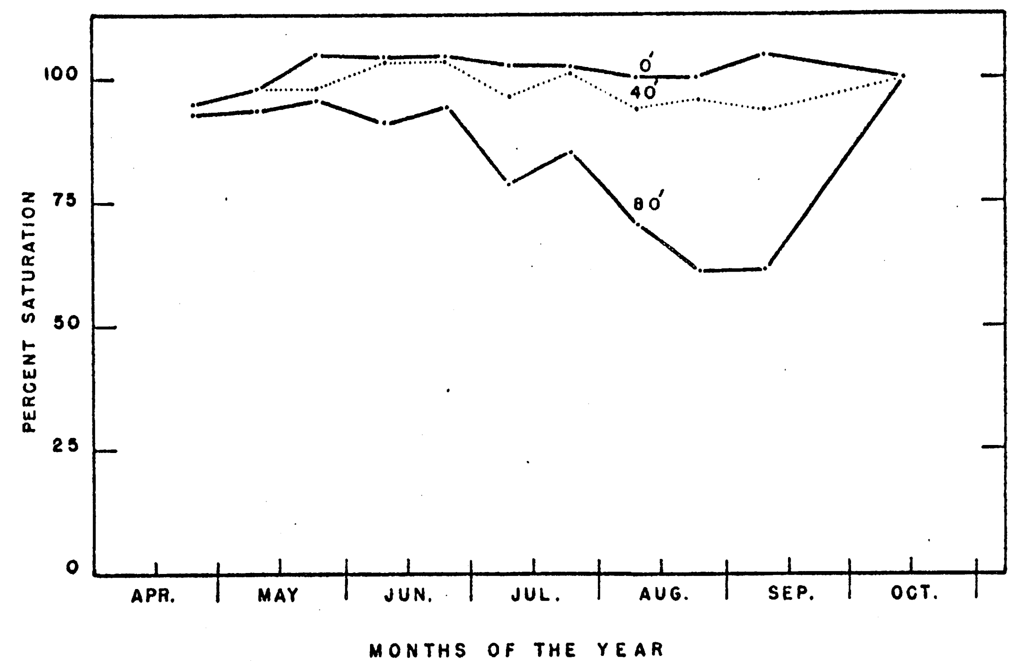

FIGURE 8. Variation in oxygen saturation at 0, 40, and 80 feet, Station 1, Lakelse lake, 1946.

(Gutsell 1929). Townsend (Townsend and Earnest 1940; Townsend and Cheyne 1944) has reviewed various minimum oxygen tolerances of salmonoid fishes and points out that these minima differ by nearly eight times the lowest value observed and that the highest is that reported by Gardner and Leetham, cited above.

With this information and taking into account that no consideration has been given to many possible complicating factors such as increased carbon dioxide (Creaser 1930; Shaw 1946), a general statement that, unless oxygen concentrations of 30% (i.e. about 3.5 p.p.m. or 2.5 cc. per liter at 10°C.), or less, are discovered in some region of the water body of a lake, then it is most likely that oxygen is not a limiting factor to either the distribution or existence of any species of fish within the water system. This has been shown to be essentially true for sockeye by Chapman (1939) who found that distress from low oxygen could be demonstrated experimentally at or below 3.5 p.p.m. with accompanying high temperatures (up to 19.2°C.) and with an above normal concentration of carbon dioxide (up to 2.3 p.p m.).

The immediate application of this conclusion for Lakelse lake would be that sockeye are in no way limited by oxygen deficits and that, in any consideration of their high lacustrine mortality the problem of oxygen deficiency, at least for the present, can be set aside.

HYDROGEN ION CONCENTRATION OR pH

Procedure

It is routine procedure in lake studies to make systematic recordings of the extent of acidity or alkalinity of the water, particularly in the deeper sections where experience has taught that the extremes are most likely to be met. The significance of the pH, especially when no determinations of carbon dioxide concentrations are made, may be useful as an index of certain environmental conditions (Rawson 1939). At Station 1, pH recordings were made at various levels including the surface and bottom (not closer than 2 feet from the actual bottom) using a Taylor pH Slide Comparator Model T-O, with a Bromthymol Blue Slide (pH 6.0-7.6) and a Cresol Red Slide (pH 7.2-8.8), manufactured by W. A. Taylor & Co., Baltimore, Md. Wherever possible, duplicate readings were made on the same samples of water with the two slides. From the discrepancies recorded and further checks on the reliability of such colorimetric field determinations, it became apparent that many inaccuracies may and do occur with this system.

Results

Using the bromthymol blue slide the average summer readings with their standard deviations were:

$$\text{Average surface pH} = 7.1 \pm 0.2$$
$$\text{Average bottom pH} = 6.6 \pm 0.2$$
$$\text{Difference} = 0.5 \pm 0.28$$

The difference is slight. Throughout the epilimnion the pH was quite constant, usually with a slight drop through the zone of thermal stratification, and a somewhat greater drop in the hypolimnion. Being close to the neutral point (pH 7.0) and exhibiting so little divergence from this state it might be inferred that water circulation and gaseous exchange are quite unimpeded, that no excess of CO_2 accumulates, and that the products of bottom decay are well dispersed. In addition the pH of the inflowing rivers is 7.0 ± 0.7 (table III) from which it can be concluded that the surrounding area of drainage is not influenced to any excess by acidic or alkaline deposits.

Discussion

Lakelse lake typifies a body of water with very little variation in pH, and which is only slightly acidic. Investigations to date indicate that even such sensitive fish as trout can withstand wide variations in pH (Needham 1940) and

that it is of little importance in affecting their distribution. Creaser (1930) states that the "range of tolerance by brook trout varies at least from 4.1 to 9.5, and furthermore the hydrogen-ion concentration throughout this range does not seem to shift the voluntary toleration limits either of temperature or of dissolved oxygen content". Even sudden changes of fair magnitude, 2.0 above and below the neutral point, can be tolerated by certain species of Centrarchidæ (Wiebe 1931). Thus, with the exception of possible microstratification of the bottom, further consideration of pH in Lakelse lake would seem unwarranted with respect to its influence on, or limitation of, animal life within the lake.

CLASSIFICATION

Lakes have been classified on various bases, mainly from separate and collective considerations of mean depth, oxygen content, temperature, bound carbon-dioxide, dissolved nutritive material, plankton communities and bottom fauna. Welch (1935, 1941) and Rawson (1939) have reviewed and criticized these classifications pointing out some of their useful aspects and short-comings. Biologically, if they constitute an index of productivity then their usefulness and application should come in large measure from this aspect.

In such a lake as Lakelse the epilimnion constitutes nearly 90% of the water volume by mid-summer and might well be expected to have an amount of oxygen far exceeding that of the hypolimnion, regardless of any discrepancy in the amount of oxygen per unit volume in the two strata. From oxygen relations alone it becomes an eutrophic lake. Its mean depth is such as to support this classification, yet its relative production of sockeye when compared with the oligotrophic Cultus lake is less and its plankton population is not particularly abundant.

Unquestionably it may be placed among the temperate lakes, order 2, (Whipple 1927), i.e., surface temperatures vary above and below 4°C.; temperature of bottom water varies only slightly from 4°C.; it has two circulation periods.

During the course of study on the Skeena river it was convenient to classify the different lakes into two distinct groups, adding a third class called "Intermediate" merely to place those which actually were intermediate in a separate group. The two major categories were: (1)deep, cold bodies of water distinctly opaque and grey from glacial silt, and (2) rather shallow bodies of water, clear, of moderate temperature, and abundant in plant life. Lakelse lake is an example of the second type and, as such, is basically eutrophic.

SUMMARY

1. Lakelse lake, in the Skeena river drainage, is a small (3500 acres), shallow (24 feet mean depth) lake, situated on the eastern margin of the Coast Range mountains. The district is of moderate climate with relatively heavy snowfall providing glacial sources for stream drainage.

2. Heavy winds tend to keep the greater part of the lake in circulation during the summer, resulting in an unstable thermal stratification and bottom

temperatures which rise to 10 and 11°C. Ice coverage usually lasts from December to early April.

3. Although the transparency varies considerably it averages 10.0 feet (Secchi's disc).

4. The dissolved oxygen remains high all year round and is only reduced in a very restricted hypolimnial zone. The minimum on record was 45% (5.2 p.p.m., 9.7°C.).

5. The pH was very stable throughout.

6. From its physical features the lake may be classified as eutrophic and temperate (second order).

7. A discussion of the application of these findings to the limitation of sockeye production has been included.

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