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**Physical and Chemical Characteristics
of Great Bear Lake, Northwest Territories**

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Physical and Chemical Characteristics of Great Bear Lake, Northwest Territories

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Great Bear Lake is geologically very young, having been derived from Glacial Lake McConnell 8,000-10,000 yr BP. The lake is made up of two basins with a total volume of 2235.7 km³. This large volume of water and the northern continental climate of the region give rise to a lake that is essentially polar (cold monomictic) although in a northern temperature setting.

Chemical composition was extremely uniform; the only observable differences were local and associated with inflowing rivers. In dissolved solids content Great Bear Lake is close to the world's average for fresh water; it is not typical of waters of the Canadian Shield. Dissolved oxygen was high at all times; it reached a maximum level under the ice in April. The deep water remained fully saturated throughout the year.

Comparisons with truly arctic lakes show that Great Bear Lake is similar in many respects but in some aspects it is even more extreme. Although similar in size to Great Slave Lake, it is much more oligotrophic.

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Le Grand lac de l'Ours est géologiquement très jeune, ayant été formé à partir du lac glaciaire McConnell 8000-10,000 A.B.P. Le lac est constitué de deux bassins d'un volume total de 2235.7 km³. Ce volume considérable et le climat continental boréal de la région en font un lac essentiellement polaire (monomictique froid) bien que situé dans un climat de température boréale.

La composition chimique est extrêmement uniforme, les seules différences discernables étant locales et associées à des tributaires. Sous le rapport du contenu en solides dissous, le Grand lac de l'Ours se rapproche de la moyenne mondiale pour les eaux douces; il n'est pas typique des eaux du Bouclier canadien. L'oxygène dissous est en tout temps élevé; il atteint un maximum sous la glace en avril; les eaux profondes demeurent entièrement saturées toute l'année.

Si on le compare avec des lacs véritablement arctiques, on constate que le Grand lac de l'Ours leur ressemble sous bien des aspects et présente même de plus grands extrêmes. Quoique de même grandeur que le Grand lac des Esclaves, il est beaucoup plus oligotrophe que ce dernier.

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ALTHOUGH Great Bear Lake is the largest lake entirely within Canada, it was almost unknown limnologically in 1962. Richardson in 1826 made some initial observations (Franklin 1828), but nothing further was done until 1928 when Porsild (1932) described the effect of seiches in Dease Arm. The first expedition whose specific objective was the examination of the lake and its biology was not until 1945 when Miller and Kennedy explored the fish populations along the southern shore from Port Radium to Fort Franklin, their work resulting in a valuable series of papers (Miller 1946, 1947; Miller and Kennedy 1948; Kennedy 1949 and Larkin 1948).^{*}

In 1958 a sportfishing industry was started

which grew rapidly over the next 4 yr. During this time there was a move to expand commercial fishing in the Northwest Territories which resulted in pressure being brought to bear on government to open Great Bear Lake. This was opposed by the sport fishing interests and the local native population.

The Fisheries Research Board decided that more extensive information on the physical and biological components of the system was required before satisfactory decisions on the utilization of the lake and its resources could be made.

With this objective, I carried out investigations on the bathymetry, limnology, and biology of the lake between 1963 and 1965. These investigations were made possible by the availability of the only vessel of adequate size on the lake, the tug

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M.V. *Radium Gilbert*. The closure of the mine at Port Radium in 1962 made it possible to charter this vessel for 6 wk in each of the following three summers. Shipborne activities were supplemented by observations made through the ice in April.

Description of the Lake

Great Bear Lake is one of the world's major freshwater bodies, ranking ninth in the extent of its surface area and 15th in order of greatest depth (Hutchinson 1957). It is situated in Canada in latitude 66°N on the edge of the boreal forest where the last remnants of woodland give way to tundra. It is within 250 km (150 miles) of the Arctic Ocean but over 1000 km from the open waters of the Pacific Ocean and more than 3 times that distance from the Atlantic. The Arctic Circle cuts across the northern arm of the lake, although, in general, the region may be classified as subarctic on the basis of either climate or vegetation.

Great Bear Lake, Great Slave Lake, and Lake Athabasca together form a series of northern great lakes which stand in similar relationship to the Mackenzie River as do the Laurentian Great Lakes to the St. Lawrence. However, in contrast to the Great Lakes which have seen immense industrial development around their periphery, the northern lakes are still virtually in their pristine condition: This is particularly true of Great Bear Lake which is the most isolated of the three, having seen little increase in the number of human inhabitants around its shores since the days before the arrival of the first Europeans at the end of the 18th century. A history of the lake has been written by L. Johnson (1975) who also provided a description of its salient geographical and biological features (Johnson 1966a).

GEOLOGY

Great Bear is the most northerly of a series of great lakes lying on the boundary separating two major physiographic regions: the Kazen portion of the Canadian Shield and the Interior Plains region (Bostock 1970). These lakes were all formed by the broadening and deepening of preglacial valleys through the erosional effects of ice during the Pleistocene (Flint 1971). Following the ice retreat, drainage developed around the periphery of the Shield northwestward to the Arctic Ocean via the Mackenzie and south and east (subsequently turning north and east) through the St. Lawrence River to the Atlantic; only one passage developed directly through the Shield, the Churchill-Nelson Trench.

The Precambrian rocks of the Shield form the eastern margin of McTavish Arm of Great Bear Lake with outliers in the Narakay Islands of Dease Arm (Douglas 1968). This Shield area of the lake provides magnificent scenery amongst the many islands and in the long fjord-like indentations of the coastline. The complex rocks of the Precambrian are made up of sedimentary and metamorphic deposits supplemented by igneous intrusions forming dykes and sills. Kidd (1932a, 1932b, 1932c, 1933) divided them into four main groups: 1) complex sedimentary and volcanic rocks of the Echo Bay group; 2) intrusions of diorite, grandiorite, and granite; 3) relatively undisturbed conglomerate, sandstone, and quartzite of the Hornby Bay group; 4) mafic dykes and sills. The Echo Bay and Cameron Bay group consists of red beds and acidic volcanic rocks occurring in northeast trending beds. These rocks consist of conglomerate arkose, red siltstone, and shale with volcanic intrusions of andesitic to trachytic compositions; they contain great thicknesses of tuffs, breccias, and ignimbrites as well as flows (Stockwell et al. 1970). Farther north in the Hornby Bay area the intrusive rocks are basaltic and less acidic. The characteristic metal of this region of the Shield is uranium; hundreds of occurrences of pitchblende, mainly in veins, are known; small deposits contain native silver, cobalt, nickel, copper, and gold (Lang et al. 1970).

Between the Shield and the Mesozoic strata which underlie most of the western portion of the shore is a narrow band of Ordovician sedimentary rock extending both north and south of the lake (Kidd 1936). The Ordovician rocks are composed of limestone and dolomite with sandstone and conglomerate inclusions (Douglas 1970).

The Great Bear Plain (Douglas et al. 1963; Douglas 1970) is largely underlain with Mesozoic strata of undivided limestone (Bostock 1970), although it is rarely exposed in this region, being overlain with a considerable thickness of glacial till. The rolling surface is in general below 300 m but occasional small semicircular hills, such as Grizzly Bear Mountain and the Scented Grass Hills, reach an elevation of 450 m.

The character and thickness of the drift in the Northern Interior Plains varies greatly. Hummocky and end moraines are widespread north of Great Bear Lake and the drift is probably very thick in this region (Prest 1970; Cook and Aitken 1973).

The events of the Pleistocene and early Holocene have contributed greatly to present land forms. At the height of the Wisconsin glaciation the majority of the land to the east of the present

Mackenzie River was covered by the Laurentide ice-sheet, but an unglaciated zone is known to have existed to the west of Great Bear Lake, where the Keewatin ice flowed northwestward along the mountain front (Prest 1970). Rutter et al. (1973) concluded that there were two glaciations from the east in this region; they also estimated from radiocarbon dates that the ice had finally withdrawn from the Mackenzie Valley by 8280 years BP.

By 10,500 BP the ice margin coincided approximately with the edge of the Shield (Bird 1967). At about this stage a large proglacial lake now known as Glacial Lake McConnell was formed, connecting the present basins of Great Bear, Great Slave, and Athabasca lakes (Craig 1965). This immense lake had an outlet to the south. There was considerable depression of the land along the eastern shore of Great Bear as evidenced by the present day existence of strandlines 145 m above the modern lake level (Craig and Fyles 1960); these show a rise of 40–80 cm/km toward the southeast, indicating a considerable crustal depression along this line due to the weight of accumulated ice.

As the ice retreated the land rebounded and the present drainage system gradually came into existence. Initially the outlet from proto-Great Bear was established at the western extremity of Smith Arm; channels can still be traced running in the direction of the present Hare Indian River which discharges into the Mackenzie well to the north of the present outlet (Craig 1965; Prest et al. 1967).

Archaeological evidence (McNeish 1955) indicates that the present outlet to Great Bear River was formed prior to 4600 BP when the lake was still 12 m above its present level. By 2600 BP another cultural group was established at a site which indicates that a lake level very close to the present one had been reached.

CLIMATE

The northerly setting of the lake in the center of a great landmass results in a northern continental climate. In summer the sun is above the horizon for 24 h a day between June 12 and 30, but in December the days are very short with the sun barely appearing. This great difference in daylength is reflected in the great differences in incident radiation varying from 556 langley (ly) (cal cm^{-2}) day^{-1} in June to 3 ly day^{-1} in December (Table 1) (Anon. 1950–74; Judge 1973). The total annual radiation is 8.7×10^5 kcal m^{-2} .

Air temperatures follow this seasonal pattern (Table 1) with about a month's delay. Maxi-

imum temperatures are recorded in July when the mean air temperature is 12 C; the highest recorded reading is 29 C (Anon 1967). The lowest temperatures are reached in January when the mean air temperature is -16 C with an extreme of -52 C. The number of frost-free days is only 60.

Precipitation (Table 1) at Port Radium is low with a yearly mean of 236 mm, over half of which falls as rain during the summer months (Anon. 1957). Close to half (47%) of the total precipitation is lost by evaporation or evapotranspiration. A detailed analysis of the climate of the Mackenzie Valley is given by Kendrew and Currie (1955) and Burns (1973).

Although freezing in the sheltered bays may start in September when air temperatures fall below 0 C, the main basin is not completely frozen until December. Ice formation continues until April when it may reach thickness of 2.6 m inshore with a mean of about 1.5 m over the offshore regions. At this time of the year the snow cover seldom exceeds a thickness of 20 cm; it is not uniform and patches of clear, bare ice alternate with areas of well-compacted snow very similar to the conditions described by Welch and Kalff (1974) for Char Lake on Cornwallis Island (75°N). Pressure ridges up to 4–5 m high provide a lee for the formation of deep drifts; the weight of snow and ice accumulating along these ridges causes depression of the surface so that water collects beneath the snow.

The ice begins to melt in May and by mid-June there is open water in the bays, but it is not until July that ice clears from the main lake. During the study period the earliest the lake was ice-free was July 11 in 1963 and the latest July 29 in 1965.

From March to December the prevailing wind is from the southeast but the strength and frequency of wind from this quarter does not greatly exceed that from other directions (Anon. 1950–74). Winds up to 64 km/h (40 mph) are liable to occur in any month but such storms are usually of short duration. During the period of open water winds produce violent seas which break with great force on the exposed shorelines. By contrast, periods of exceptional calm can be experienced during the summer when the whole lake surface is without the slightest ripple; occasionally these periods of calm coincide with the influx of warm moist air, resulting in the formation of dense fog as it comes into contact with the cold lake surface.

The short summers and severe winters, combined with the low precipitation, poor soil formation (Tarnocai 1973) and perennially frozen subsoil, result in stunted forest (Zoltai and Petta-

TABLE 1. Monthly solar radiation, precipitation, and mean daily temperature for Great Bear Lake. Solar radiation is for Normal Wells, the nearest station recording radiation; the other figures are for Port Radium. Computed from the Monthly Record Meteorological Observations, Department of the Environment. (Anon. 1950-74).

	Mean solar radiation ly day ⁻¹ (<i>cal cm⁻² day⁻¹</i>)	Precipitation (<i>mm</i>)	Mean daily temp (<i>C</i>)
Jan.	11	10.9	-27.0
Feb.	68	7.9	-27.0
Mar.	214	14.2	-19.1
Apr.	374	6.4	-10.7
May	498	13.7	1.2
June	556	14.2	9.0
July	494	35.1	12.0
Aug.	353	42.7	10.6
Sept.	202	25.2	5.3
Oct.	75	26.7	- 3.2
Nov.	17	25.2	-14.8
Dec.	3	14.0	-23.0
Total for year	87451 = 8.7×10^5 kcal m ⁻² yr ⁻¹	236.2	

piece 1973, 1974; Strang 1973; Zoltai and Tarnocai 1974) on the south side of the lake diminishing to tundra (Britton 1957) with occasional stunted trees along the northern shore. The forest (Rowe 1972; Strang 1973) on the southern shore is interspersed with extensive areas of muskeg where drainage is impeded. The best growth of timber is on Grizzly Bear Mountain where stands of black and white spruce (*Picea marina* and *P. glauca*) exist interspersed with occasional tamarack (*Larix laricina*).

The exposure of the majority of the shoreline of Great Bear Lake to severe wave and ice action precludes the establishment of emergent vegetation in all but the most secluded bays.

DRAINAGE

The drainage basin of Great Bear Lake as determined by planimetry has an area of 145,870 km² which is about 5 times the surface area of the lake itself. This relatively small basin combined with the low precipitation precludes the development of a major river system; the majority of the water enters the lakes by way of small streams, many of which have significant flow only during the period of snow-melt. The two main rivers supplying the lake are the Camsell and the Johnny Hoe; together they drain 30% of the total basin (Anon. 1970, 1972) and contribute about 20% of the total outflow.

The Camsell River, by far the larger of the two, delivers less than one-fifth (3.125 km³ yr⁻¹)

of the discharge of the Bear River, whilst the contribution of the Johnny Hoe (0.6 km³ yr⁻¹) is about one twenty-seventh.

The Camsell River, which enters Conjuror Bay in McTavish Arm, is made up of a long series of lakes which stretch to within 80 km of Great Slave Lake. These lakes, many of which are of an appreciable size (e.g. Hottah, Hardisty, Rae, and Faber) have extremely complex shorelines and very short interconnecting rivers; they lie along the junction of the Ordovician and Precambrian formations.

The Johnny Hoe, flowing parallel to the Camsell, is completely different in character. It has its origins in an extensive area of muskeg to the west of Lac la Martre; flowing north, it receives water from Keller Lake, finally discharging into Lac Ste Thérèse about 50 km south of Great Bear Lake. Keller Lake and Lac Ste Thérèse are the only two lakes of any appreciable size in the Johnny Hoe system. This watershed is confined to the Mesozoic formations of the Great Bear Plain (Douglas et al. 1963).

The only other two rivers that drain appreciable land areas are the Dease and the Whitefish. The Dease has a comparatively small basin of 3000 km² composed largely of highly insoluble Proterozoic rocks. In the summer the flow of the river is small and the character is that of a moorland stream with pools and riffles. The Whitefish River draining 4700 km² of the region between Keith and Smith arms, empties into the western end of Smith Arm. Summer flows are again low

and the river makes only a small contribution to the total input.

Along the north coast there are a large number of small streams draining the tundra, but these are essentially seasonal, having virtually no flow in either summer or winter.

The lake has a single outflow, the Great Bear River, which falls approximately 100 m (340 ft) from the lake level of 156 m (512 ft) above sea level to the Mackenzie River at Fort Norman in a distance of some 120 km (75 miles) (Rand Corporation 1963).

Methods

Before the beginning of the navigation season in June 1963, *M.V. Radium Gilbert* was fitted out with essential navigational equipment: gyrocompass, radar, and echo-sounder; a temporary laboratory was established in the hold of the vessel and a small hydrographic winch installed on the after deckhouse.

SOUNDINGS

Sounding transects were run on gyroscopic compass bearings with points of departure and arrival accurately fixed by radar and position lines; intermediate positions were determined by radar or dead-reckoning; radar positions were assisted on the run between Port Radium and Fort Franklin by a number of radar reflectors. The original chart (Canadian Hydrographic Service No. 6390) with soundings has been deposited with the Hydrography Branch, Department of the Environment, Ottawa.

TEMPERATURE

Water samples were collected using standard Nansen bottles to which were attached paired reversing thermometers of deep-sea type. These thermometers were calibrated by the National Research Council, Canada, before the start of the program and were accurate to ± 0.02 C. Complete temperature profiles in the upper 275 m were obtained with a bathythermograph.

WATER CHEMISTRY

Water analyses were carried out by Mr J. F. J. Thomas of the Industrial Waters Division of the Department of Mines and Technical Surveys (now Inland Waters Directorate, Department of the Environment). Water samples were filtered in the field through Millipore HA filters (.45 pore size) and then stored unfrozen at low temperature.

Oxygen and pH were determined immediately after collection; oxygen was measured using the modified Winkler method as described by Strickland and Parsons (1960) and converted to percentage saturation by the nomogram of Mortimer (1956). A Beckman "G" pH-meter reading to ± 0.03 pH units was used to measure pH following the procedure detailed by Strickland and Parsons (1960). Attempts

were made to measure phosphate and nitrate in the field immediately following collection using the methods of Strickland and Parsons. Concentrations appeared to be of a very low order and results were not distinguishable from the blank ratings. Values for phosphates and nitrate given in Table 3 are those obtained later in the laboratory and so probably have little significance. This is reinforced by Hobbie's (1974) observation that phosphate values determined before the mid-1960s should be viewed with caution.

Results

MORPHOMETRY

The five arms radiating from the central "body" make it difficult to describe Great Bear adequately in conventional terms of length and breadth. The length, the distance from the outlet of the Great Bear River to the south end of Hornby Bay, is 349 km and the longest line which can be drawn at right angles to this track is 173.8 km; hence it may be designated breadth (Hutchinson 1957) (Table 2). However, the accumulated distance from a point ($66^{\circ}4'N$, $120^{\circ}4'W$) in the central region to the extremity of each arm is 887 km; this gives a more realistic figure for the total length of the lake in terms of the working distances involved.

For reference purposes the lake has been divided into six areas by imaginary lines across the mouth of each arm (Fig. 1). Five of these areas are freely interconnecting whereas the sixth, McVicar Arm, is almost completely isolated. There are thus two basins which will be referred to as the Main Basin and McVicar Arm.

In a large deep lake the extent of the shoreline is of great significance as it is the area of greatest biological production. In Great Bear Lake the length of the shoreline is 2719 km with an additional 824 km contributed by the islands; this gives a development of shoreline (Hutchinson 1957) coefficient (D_L) of 4.4, a high value compared with the majority of lakes, but much of the productive potential of this shoreline is offset by its very steeply shelving nature in the region of the Shield.

DEPTH AND VOLUME

The greatest depth of 446 m is located 11 km west of Port Radium; it is situated in a small depression which has an area of 50 km² below 300 m and only 2.3 km² below 400 m. This depression is separated by a sill at 274 m from a second deep to the north, off Workman Island. This second depression is about the same size below 300 m but has an exceedingly flat bottom at a depth close to 400 m; the greatest depth is

TABLE 2. Morphometric characteristics of Great Bear Lake.

	Total	McTavish	Keith	Smith	Dease	Center	Main Basin	McVicar
Area (km^2) (A)	31,153	4533	7241	4498	3007	7107	28,387	2765
Length (km) (L)	349.7							
Breadth (km) (bx)	173.8							
Area of islands (km^2)	756.4	432.3	4.0	135.1	1144	0	682.9	73.5
Area of water (km^2)	30,397	600.7	7237	4362.9	2892.6	7107	27,704.1	2691.5
Insularity (%)	2.4	6.6	.06	3.3	3.8	0	2.4	2.66
Greatest depth (m) (z)	446.2	446.2	135	113	117	161	446.2	128
Mean depth (m) (z)	71.7	114.5	67.7	36.3	42.8	85.0	75.4	34.3
Volume (km^3) (V)	2235.7	747.8	489.6	162.9	129.3	611.1	2140.7	95.0
Development of volume (D_v)	.482	.769	1.504	1.008	1.097	1.58	.506	.803
Depth of crypto-depression (m) (z)	285	285	17.0	—	—	43	285	10
Length of shoreline (km) (L)	2719	863	521	552	329	27	2292	427
Development of shoreline (D)	4.4	—	—	—	—	—	3.84	2.29
Length of Island shoreline (km)	824.4	528.8	16.9	54.2	130.7	0	727.6	96.8

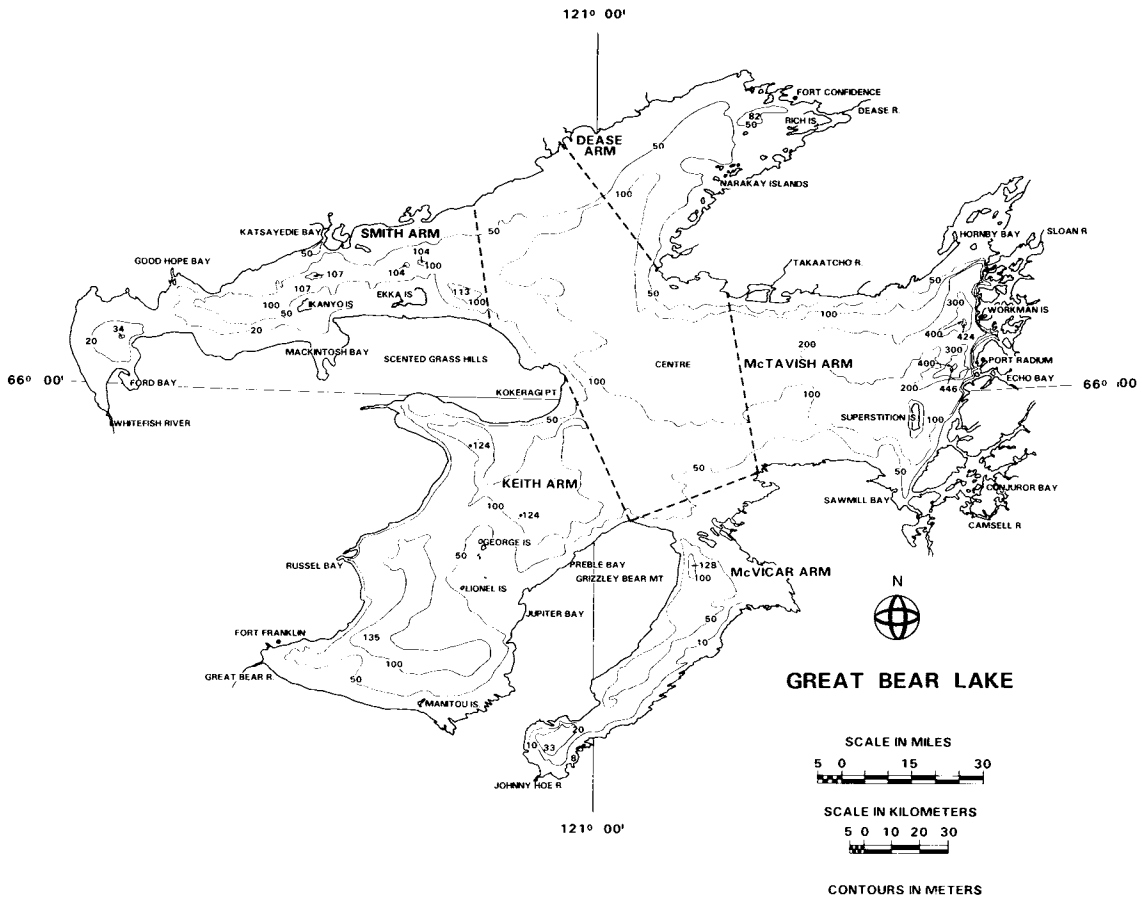


FIG. 1. Bathymetric map of Great Bear Lake.

424 m. The extreme flatness of the bottom in this deep indicates an originally deeper depression filled in by siltation after the formation of the lake, probably in the final stages of the ice retreat. From these deeps the bottom rises gradually to the west with the occasional depression below 100 m. To the east the bottom rises abruptly to the shoreline. There is nothing to impede the free circulation of water in the main basin except for islands at the extremities of Smith and Dease Arms which isolate small areas of water.

McVicar Arm forms an almost separate water body as its mouth is protected by reefs and small islands. The main connecting channel lies close to the shore of Grizzly Bear Mountain; it is less than 0.5 km wide and has a minimum depth of 28 m. Immediately beyond the bar the bottom plunges to the deepest part of the arm at 128 m.

The arm is in the form of a long narrow trench, deeper on the western side than on the east. The eastern shore is shallow with extensive marshy

bays flanked with muskeg, whilst the western side has sandy beaches which fall quite rapidly into deep water. At the extremity of the arm is a circular depression with a maximum depth of 33 m separated from the rest of the arm by a slight sill at 20 m.

The total volume of the lake is estimated at 2236 km³ of which 2141 km³ forms the main basin, while only 95 km³ or 4% of the total is contributed by McVicar Arm. The differences in morphometry between the arms are well illustrated by comparison of their respective volumes and mean depths (Table 2). McTavish has by far the largest volume (747.8 km³), (although Keith Arm is considerably larger in area) and the greatest mean depth (114.5 m). McVicar Arm has the smallest area (2765 km²), volume (95.0 km³), and mean depth (34.3 m).

In McTavish Arm there is an extensive crypto-depression with a maximum depth of 285 m below sea level. Approximately 30% of the volume

of the arm, or 10% of the total volume of the lake, is below the level of the ocean.

WATER EXCHANGE AND WATER LEVEL

A gauging station was initially established on the Great Bear River in 1938, but it was only in 1963 that continuous recording was inaugurated (Anon. 1970). The mean annual rate of discharge is given as 571.7 m³/s which is 18.03 km³/yr; the yearly discharge is equal to 1/124th of the volume, indicating a water residence time (or flushing rate) of 124 yr.

The changes in lake level observed over the years at the gauging stations at Fort Franklin and Port Radium are quite small. The extreme maximum and extreme minimum recorded since 1963 are 119.11 m and 118.20 m above sea level, giving a total difference of 0.9 m. Changes within any one year are much smaller and rarely exceed 0.2–0.3 m; however, considerable temporary fluctuation may be produced by wind, amounting to 0.2–0.3 m difference in mean daily level.

Small level changes are also produced by seiches in both winter under the ice and in the summer open water season. Porsild (1932) made observations on the movement of water in and out of the narrow channel between Rich Island and the mainland in the vicinity of Fort Confidence; he measured a movement with a amplitude of 23 cm and a period of 2 h 58 min; this occurred in May when the lake was completely ice covered. He also noticed in July that a small inlet, connected to the main lake by a narrow channel, showed level changes of 5–10 cm with an apparent periodicity of 1 h 30 min or double that observed at Rich Island.

In 1961 a continuous water-level recorder was installed at Port Radium by the Department of the Environment, Water Survey (formerly Department of Energy, Mines and Resources). This gauge is in the protected waters of the harbor but there is no constriction between the harbor and the deep water outside and is therefore ideally situated for observing seiches.

Examination of the chart for the period July 2–9, 1963 (Fig. 2) showed a very well marked periodicity in water level. The most clearly defined waves are for the intervals between 1800 on the 3rd and 1800 on the 4th, 1900 on the 4th to 0600 on the 5th, and 0200–1300 on the 7th; all exhibit a frequency of 5 h 30 min. When computed over longer time periods the frequency of the seiche falls to about 5 h. The frequency of 5 h 30 min is very close to being double that observed by Porsild in 1928 in winter and 4 times the summer period. This would suggest that a seiche is formed with a period of 5 h and

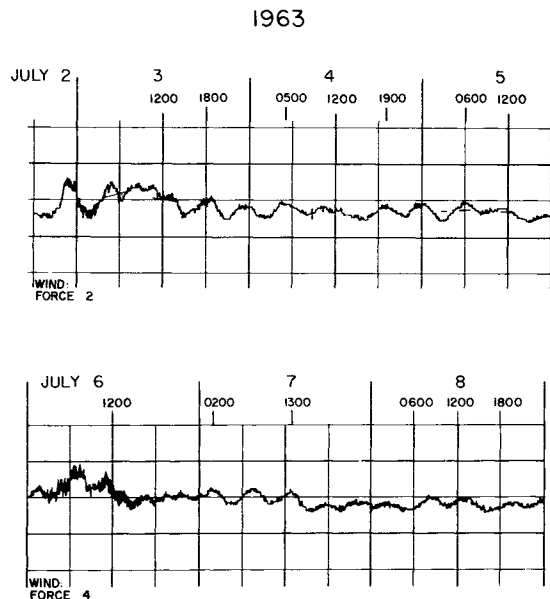


FIG. 2. Reproduction of level-gauge recorder sheet, Port Radium, Great Bear Lake, for period July 2–8, 1963, showing seiche formation.

30 min with binodal and quadrinodal frequencies at 2 h 45 min and 1 h and 22 min. However, no such harmonics can be recognized on the charts from Port Radium.

The size and complexity of the basin preclude any simple analysis of the seiches. None of the functions developed by Chrystal and given by Hutchinson (1957) for the frequency of oscillation provide even a reasonably close approximation to the observed period. The nearest is the equation for the truncated symmetrical concave quartic lake, which for a lake with the dimensions of Great Bear yields a value of 4 h 36 min.

The onset of more active seiche movement seems to be well correlated with increased wind speed, although even in periods of sustained calm a regular movement can be discerned.

While the amplitude of the seiches is relatively small, they do produce significant effects in winter. As Porsild noted, the ice thickness at Fort Confidence is much reduced; at Hloø Channel at the south end of Richardson Island, leading into Conjuror Bay, open water is maintained throughout the winter, and in summer quite strong currents are noticeable through this channel in both directions.

The existence of seiches in winter, occurring under at least 1.5 m of ice, would seem to indicate that barometric pressure is the main causative agent. If this is the case, it is likely also to be

a factor in setting up seiche movements in large lakes under the open water conditions.

TRANSPARENCY

The crystal clarity of the waters of Great Bear Lake is one of its most striking features. Both Richardson (Franklin 1828) and Miller (1947), using a white rag and a white enamel plate, respectively, recorded maximum transparencies of 27 and 29 m. These observations, both made in the area of deepest water off Port Radium, are in good agreement with present observations.

The greatest Secchi transparencies were found in McTavish Arm; the maximum reading obtained was 30 m, close to the 200 m contour, 35 km west of Port Radium (position 66°3'N, 118°49'W). In water over 400 m deep the greatest transparency observed was 23 m. In the coastal regions transparencies were mostly of the order of 17–18 m. In Cameron Bay, perhaps the most secluded bay in the Shield region, the transparency at the beginning of August was 5 m in the deepest part (12 m). The lowest value encountered in McTavish Arm was in Hornby Bay on the edge of the Shield where 4 m was observed.

In Smith, Dease, and Keith arms the transparency in the open waters of the arm is somewhat less than in McTavish, most of the readings being in the range of 12–16 m. At the extreme end of Smith Arm suspended material reduced transparency to 6 m, while in the bays of this arm, 5 m was not uncommon. In McVicar Arm the water is the least transparent in the lake, being slightly brown stained with humic material; much of this water originates from the Johnny Hoe River, but the eastern shore is adjacent to extensive muskeg swamps which also make a contribution. At the mouth of the Johnny Hoe River the transparency is 5 m; it rises to a maximum of 10 m in the open part of the arm. The minimum reading of the whole lake (1.5 m) was obtained in a shallow bay 4 m deep on the eastern shore.

WATER CHEMISTRY

Water from all areas within the freely circulating main basin shows a remarkable uniformity in its chemistry. This uniformity is maintained irrespective of location or depth and is undoubtedly due to the thorough mixing achieved during the 124-yr residence time, the very low degree of biological activity, and the absence of strongly developed stratification.

The water in the main lake is low in dissolved substances but not as dilute as many lakes en-

tirely within the Canadian Shield (Armstrong and Schindler 1971). Total dissolved solids varied between 78.4 and 81.0 ppm (Table 3), while conductivity varied between 149 and 157 $\mu\text{mho cm}^{-2}$ at 25 C. The pH was virtually constant between 7.8 and 7.9. The dominant constituent is bicarbonate (HCO_3^-) with values between 63.5 and 68.4 ppm followed by Ca^{++} (16 ppm), $\text{SO}_4^{=}$ (14.8 ppm), and Mg^{++} (6.9 ppm).

In the summer of 1964 in water 400 m deep the specific conductance at the surface was 150 μmho , 148 at 50 m, and 149 μmho at 400 m. Similarly in winter there was 2 μmho difference between water at the under ice surface and the bottom at 390 m, that is, 116 m below the sill separating the two deeps. Silicate also showed a remarkable degree of consistency over the same depths (Johnson 1966b).

The tributary streams (Table 3) are, in general, rather lower in dissolved substances than is the main basin. The waters originating on the Shield are particularly low; the Dease River with 32 ppm TDS is only slightly higher than the lowest value observed: 28 ppm for a stream entering Hornby Bay. Apart from the main component of HCO_3^- the major constituents of these streams are Ca^{++} and Mg^{++} . The Camsell River with a TDS of 58 ppm contributes the greatest volume of water; the most significant constituents are HCO_3^- , Mg^{++} and $\text{SO}_4^{=}$; Ca^{++} is conspicuous by its low value of 1.4 ppm.

The Johnny Hoe River, also a significant contributor, has a relatively high TDS (149 ppm); as usual bicarbonate, Ca^{++} , Mg^{++} , and $\text{SO}_4^{=}$ are the most significant ions present; all of these four substances occur at almost double the concentration at which they occur in the main basin. An even greater concentration of Ca^{++} , Mg^{++} , HCO_3^- and $\text{SO}_4^{=}$ is found in the rather anomalous Takaatcho River which enters Takaatcho Bay on the north side of McTavish Arm (212 ppm TDS).

The effects of the tributary streams are very local. In the secluded waters of Conjuror Bay 8 km from the mouth of the Camsell River toward the main lake (position: 65°41'N, 118°21'W), the presence of Camsell water is still apparent but considerable mixing with the main lake water has occurred. The same is true of the Johnny Hoe River in McVicar Arm; by the time the river water has reached the first narrows at the north of the most southerly bay (64°54.3'N, 121°14.7'W) a considerable dilution has occurred; values here are very much closer to those of the main lake than they are to those of the river. The effects of the Takaatcho River are limited to the bay into which they discharge and do not noticeably influence the main lake water.

TABLE 3. Chemical composition of water from Great Bear Lake and tributary streams. All values are given in parts per million unless other units are shown.

Region	McTavish-A	Smith-A	McVicar-A	Conjuror-B	Camsell-R	Dease-R	J.Hoe-R	Hornby-B	Takaatcho-R
Latitude	66°4.3'N	66°18.3'N	64°54.35'N	65°41.5'N	65°36.5'N	66°53.8'N	64°45'N	66°37.3'N	66°21'N
Longitude	118°5.0'W	128°19.3'W	121°18'W	118°20'W	118°2'W	119°00'W	121°22'W	117°36'W	119°37'W
Date of sampling	Mean Value	July 31, 1964	Aug. 26, 1963	July 20, 1963	July 20, 1963	Aug. 4, 1964	May 26, 1963	July 31, 1963	Aug. 12, 1963
pH (pH units)	7.8	7.9	8.1	7.5	7.7	7.5	8.2	6.8	7.5
Color (Hazen units)	0	15	15	5	5	20	45	10	50
Total alkalinity (CaCO ₃)	55.8	54.4	66.3	46.5	43.6	29.4	99.3	15.8	86.7
Conductivity (mho/cm ²) at 25 C	155.0	152.0	191.0	125.6	115.4	60.0	269.3	41.0	353.9
Hardness (CaCO ₃)									
Total	66.6	68.0	87.3	57.0	52.0	31.5	131.0	17.9	169.0
Noncarbonate	13.9	13.6	21.0	10.5	8.7	2.1	31.5	2.1	82.3
Calcium	16.2	16.1	19.9	12.8	1.4	6.7	31.4	3.2	38.8
Magnesium	6.9	6.8	9.1	6.1	5.7	3.6	12.7	2.4	17.5
Iron (dissolved)	0.13	<.01	0.01	0.19	0.01	0.03	0.03	0.02	0.5
Aluminum						0.06			
Manganese						0.015			
Copper						0.004			
Zinc						0.013			
Sodium	4.2	4.0	4.5	2.2	1.7	0.6	4.9	0.6	7.0
Potassium	0.8	0.8	0.8	0.7	0.9	0.5	0.9	0.3	0.3
Nitrate (NO ₃)	0.49	0.37	0.3	<0.01	Trace	0.5	0.2	Trace	0.2
Phosphate (PO ₄) Total	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Carbonate	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bicarbonate	68.0	66.3	80.8	56.7	57.8	35.8	121.0	19.3	105.0
Sulphate	14.8	14.1	21.9	10.9	9.3	1.6	31.5	1.9	89.4
Chloride	4.8	4.4	5.3	2.3	1.5	0.6	4.4	0.7	1.4
Fluoride	0.11	0.13	0.17	0.16	0.17	0.06	0.23	0.07	0.32
Silica (SiO ₂)	2.2	2.0	2.0	1.3	0.9	0.6	3.2	1.9	5.0
Total dissolved solids	78.4	81.3	104.0	62.7	57.6	32.3	149.0	28.3	212.0

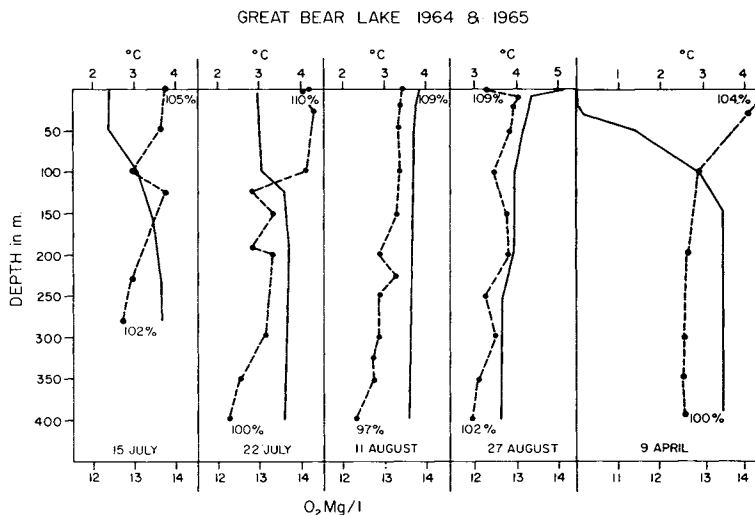


Fig. 3. Temperature and oxygen profiles for the deepest water in Great Bear Lake in the summer of 1964 and April 1965.

OXYGEN

The oxygen content of the water was close to the saturation level at all times of the year and at all depths. In the surface waters during summer, values of 13.0–14.0 mg/liter were invariably recorded, indicating 105–110% supersaturation according to temperature. With increasing depth there was a slight decrease in oxygen content, but even at 400 m it was 12.42–12.5 mg/liter, very close to 100% saturation (Fig. 3). The summer oxygen condition may be generalized as being supersaturated on the surface, declining to a saturated state at the greatest depths. These deepwater values are comparable with those obtained by Strøm (1933) from very unproductive lakes in Norway. Strøm (1932) also recorded a supersaturation of 116% in Tyrifjord during the summer months.

In April when it might be expected that oxygen values in the deep regions would be at their lowest (Mortimer and Mackereth 1958), it was found that the upper 10 m had a uniform oxygen content of 14.4 mg/liter (104% saturation), while from 10 to 200 m there was a slight fall to 12.6 mg/liter; below 200 m the water was uniform at 12.6 mg/liter which is saturation for the prevailing temperature of 3.5 C.

The high levels of oxygen in all parts of the lake at all depths throughout the year indicate a low level of biological activity; in such circumstances any attempt to calculate oxygen deficit, or ratio of oxygen in the hypolimnion to that in the epilimnion, would have little value.

TEMPERATURE AND CIRCULATION

The lake emerges from the winter covered by 1.5–2.5 m of ice; below the ice is 20 m of water in which the temperature is 0.06 C; from 20 m down to 200 m there is a zone of strong inverse stratification with cold water lying on top of warm. Below 200 m the water is isothermal at 3.52 C, the temperature of maximum stability for the bottom water at 446 m (Johnson 1964, 1966b; Eklund 1963, 1965). That some circulation is taking place below 200 m is indicated by the uniform level of oxygen saturation in addition to the isothermy.

Soon after breakup in mid-July the effect of fall cooling can still be seen in the upper 200–250 m of water (Fig. 3). As the lake continues to warm up the temperature difference between the surface and bottom waters narrows but can still be seen in late July. In warm years a density resorting process takes place, resulting in a stable temperature profile along the line of maximum stability (Eklund 1965, Johnson 1966b), the line interpreted by Strøm (1945) to be the line of maximum density of water with increasing depth. This stable structure developed in the relatively warm years of 1963 and 1964, but in 1965 surface temperatures did not rise above 3.5 C and the lake was virtually isothermal at 3.42 C in late August.

In 1963 and 1964 extensive areas with a surface temperature below 4.0 C were found in the central body of the lake at the time of maximum heat intake in late August (Fig. 4 and 5). A

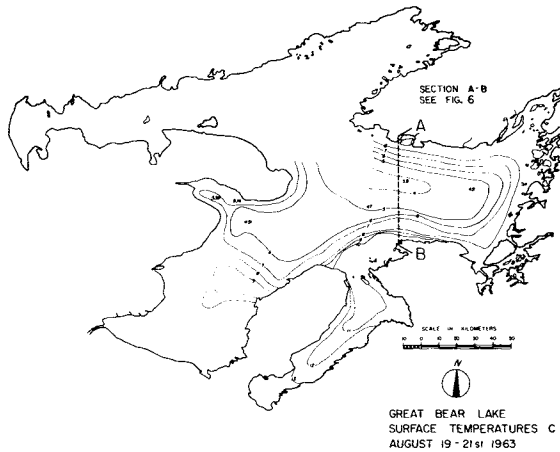


FIG. 4. Distribution of surface temperatures in Great Bear Lake, August 19-21, 1963.

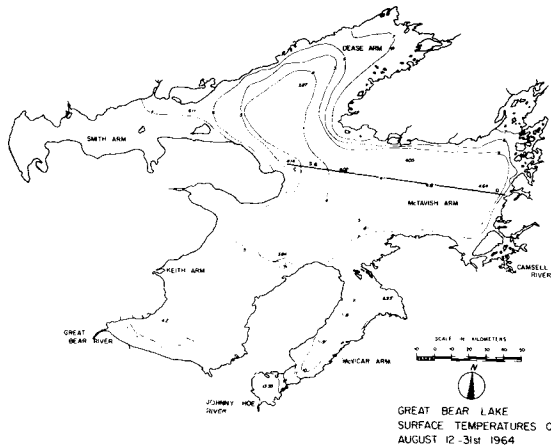


FIG. 5. Distribution of surface temperature in Great Bear Lake, August 12-31, 1964.

section, running north-south across McTavish Arm in 1963 (Fig. 6) shows what appears to be the remnant of the cold water (<4.0 C) in the upper 200 m. In the west-east section made in the cooler year of 1964, it appears that westerly winds are moving surface waters in an easterly direction and establishing a flow of cold bottom water from east to west (Fig. 7).

The more sheltered regions of the lake develop temperatures up to a maximum of 15.5 C. Both the Camsell and the Johnny Hoe Rivers discharge considerable quantities of waters at this temperature in midsummer. The Camsell River discharges into Conjuror Bay where the surface waters are warmed to a depth of 20 m; below this depth, to the unexpectedly deep bottom at 180 m, the water is in the region of 4 C.

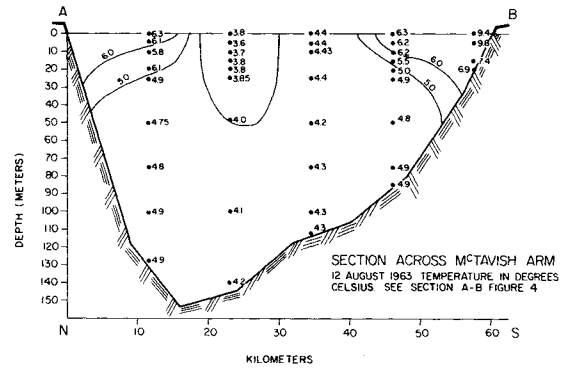


FIG. 6. North-south section across McTavish Arm, August 12, 1963. Section is along line A-B, Fig. 4.

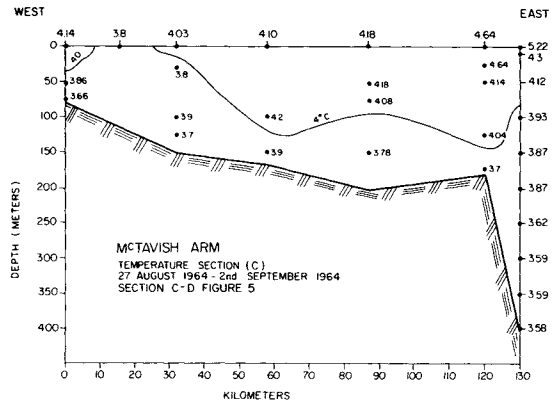


FIG. 7. West-east section down the center of McTavish Arm, August 27-September 2, 1964. Section is along line C-D, Fig. 5.

The most extensive region of warmth was the southern end of McVicar Arm which receives the waters of the Johnny Hoe River. Surface temperature here reached 15 C and even at 20 m the temperature was 11.5 C. As one proceeded north up the arm, surface temperatures decreased in a regular manner until the region of deepest water was reached (Fig. 4 and 5); in this region the lowest surface temperatures in the arm were recorded. However, a considerable difference between 1963 and 1964 was experienced: 11 C in 1963 and 7 C in 1964. North beyond the deep water, temperatures increase significantly due to the shallows protecting the eastern side of the entrance.

HEAT BUDGET

The irregularity of surface temperature distribution and the irregularity of the basin itself

TABLE 4. Composition of Great Bear Lake water and the average values for the whole world as given by Clarke (1908-24) and Livingstone (1963) and the mean values for 58 arctic lakes determined by Kalff (1968).

	Great Bear Lake			Whole world (Clarke 1908-24)	Whole world (Livingstone (1963))	Arctic lakes of Alaska (Kalff 1968)
	ppm	meq/liter	meq/liter (%)	meq/liter (%)	meq/liter (%)	meq/liter (%)
Cations						
Ca	14.6	.727	51.3	63.5	52.7	69.03
Mg	7.3	.600	36.0	17.4	23.7	13.89
N	3.4	.148	11.6	15.7	19.36	13.99
K	0.7	.018	1.1	3.4	4.15	3.09
Anions						
Cl	4.3	.121	8.6	10.1	15.6	10.37
SO ₄	10.8	.224	16.0	16.0	16.5	9.87
HCO ₃	64.4	1.055	75.4	73.9	67.87	79.76

make calculation of an accurate heat budget extremely difficult. An attempt has been made for McTavish Arm considered as a single unit. Heat input has been determined from the temperatures observed in late August 1964 and those observed in April 1965 when the heat content is at a minimum; the results are therefore based on heat lost rather than heat gained.

The period of ice melt extends beyond the season of maximum insolation by almost a month; thus, a highly significant fraction of the total heat input is absorbed as latent heat of fusion; to melt 1.5 m of ice at 0 C with a density of .917 and a latent heat of fusion of 79.7 cal g⁻¹ and no change in temperature requires 12,300 cal cm⁻². A further 2300 cal cm⁻² is required to raise the ice from its minimum temperature to 0 C; thus, a total of 14,600 cal cm⁻² is required to bring the surface water to 0 C.

Heating or cooling does not extend below 200 m as the lower layers are virtually isothermal throughout the year. The heat required to bring about the measured difference in temperature in the upper 200 m is 26,000 cal cm⁻². This gives a total heat budget of some 40,600 cal cm⁻². This heat input is derived almost entirely from solar radiation since the contribution from inflowing rivers is very small. If all the inflowing water were at 7.5 C, the total heat input would be increased by 250 cal cm⁻².

The calculation of summer heat income, i.e. the heat required to raise the temperature of the water above 4 C, has not been attempted since it is negligible.

Discussion

The special interest of Great Bear Lake lies in its northerly location and extreme oligotrophy; it

is the only lake of comparable size in the world that touches or even approaches the Arctic Circle. With an area of 31,153 km² it ranks fourth in North America following lakes Superior (83,300 km²), Huron (59,510 km²), and Michigan (57,850 km²). Great Bear (446 m) is also the fourth deepest lake in North America being exceeded only by Great Slave Lake, 614 m (Rawson 1950); Crater Lake, 608 m (Hasler 1938); and Lake Tahoe, 501 m (Hutchinson 1957).

In volume it is rather larger than its sister, Great Slave Lake, which was computed by Rawson (1950) to be 1580 km³ compared with 2236 km³ for Great Bear Lake; however, Great Bear Lake is dwarfed when compared with Lake Baikal which has almost the identical surface area (31,500 km²) but with 23,000 km³ of water, over 10 times the volume (Kozhov 1963).

The ionic composition of Great Bear Lake is close to the average values for the world's fresh waters given by Livingstone (1933) and Clarke (1908-24) and quite close to the standard composition of Rodhe (1949). It is also similar to the mean value of 58 Arctic lakes investigated by Kalff (1968) (Table 4). The most noticeable differences are the higher value in Great Bear Lake for Mg⁺⁺ and the lower values for Na⁺ and K⁺ compared both with world average and Kalff's figures for arctic lakes. There is a somewhat lower Cl⁻ content in Great Bear Lake which is possibly accounted for by its great distance from the sea. In a more restricted perspective Great Bear Lake has a much higher total dissolved solids content (80 ppm) than the majority of waters derived entirely from Shield drainages; for example, McLeod Bay of Great Slave Lake has a TDS of 22 ppm (Rawson 1950); the Dease River and a stream entering

Hornby Bay have 32 ppm and 28 ppm, respectively. Great Bear Lake in fact exhibits the dramatic increase in Ca^{++} and HCO^{-3} which Armstrong and Schindler (1971) showed was a characteristic of lakes lying on the Shield margin, compared with those on the Shield itself. The only waters that depart appreciably from the standard composition of Rodhe are those of the Takaatcho River in which the relative value of sulphate ion is abnormally high.

The main basin of Great Bear Lake is characterized by the high degree of uniformity in its chemical composition at all times of the year: conductivity and pH are almost invariable with season or depth and no change could be detected in silica content; only oxygen appeared to change from a supersaturated condition at the surface to saturation in the deepest waters.

This is in contrast to the results obtained from the majority of studies on ice-covered lakes. Mortimer and Mackereth (1958) found oxygen depletion and an increase in temperature, conductivity, and alkalinity in the sumps formed by the separate depressions in the bottom of Torneträsk, a Swedish arctic Lake. The increased temperature they ascribed to heat being given up by the sediments, while oxygen was considered to have been used up by the oxidation of carbohydrate which in turn yielded H^{+} ; this exchanged with adsorbed cations to release the equivalent amount of bicarbonate, thereby increasing the conductivity and alkalinity. Welch (1974) used the levels of oxygen depletion in arctic lakes in winter as a measure of the metabolism of the whole lake. He considered that the high oxygen content of the water immediately beneath the ice was due to its exclusion on freeing. Schindler et al. (1974a) showed that in Char Lake the oxygen content of the upper water layers remained close to 15 mg/liter throughout the winter, but in depths below 24 m there was a rapid decline to 5 mg/liter following freeze-up. Hobbie (1973) states that all arctic lakes examined, except for the permanently frozen Angiussaq Lake in Greenland (Barnes 1960), had deoxygenated water at the bottom in winter; in this exceptional case the bottom water in winter was 95% saturated.

In this respect Great Bear Lake seems to resemble Angiussaq Lake rather than other arctic lakes. Even in the sump, 116 m below the sill separating the two deeps, the region, according to Mortimer and Mackereth (1958) which was most likely to be affected, there was no oxygen depletion in April.

Although Kalff and Welch (1974) have shown that photosynthesis begins as soon as the light returns to Char Lake in February, it is possible to account for the supersaturated condition of the

water immediately below the ice by the oxygen freeze-out over the winter.

In the openwater period oxygen is again at a supersaturated level in the surface layers, and it is possible to account for this by the warming of the water. In the deepest water at this time of the year the oxygen level is very close to saturation.

In April, in depths below 200 m in Great Bear Lake, the water is isothermal at 3.52 C and it also has a very uniform oxygen content (12.6 mg/liter). The system is not only unstable it appears to be actually in circulation. In such conditions it is possible that the heat flux from the centre of the earth of $1.23 \times 10^{-6} \text{ cal cm}^{-2} \text{ s}^{-1}$ (Bullard 1954) or $3.2 \text{ cal cm}^{-2}/\text{mo}$ is sufficient to cause slight convection currents. As the temperature of maximum density of water at 450 m is 3.04 C, any heating above this temperature will cause an upward movement; at the same time any heating in the water above 200 m will cause a downward flow since it is below the temperature of maximum density.

Full circulation, as indicated by temperature, was observed only on one occasion; this was in 1965, the year with the slowest rate of heating. By August 23rd the surface temperature in the deepest region had reached only 3.5 C with the majority of the lake at 3.42 C. It seems that in warmer years deepwater stability is developed and the lake turns over only in the upper 225 m (Johnson 1966b). This, however, affects only the 3.6% of the lake below the depth of circulation.

The delicate balance involved in circulation can be seen in the temperature sections of McTavish Arm (Fig. 6 and 7). It appears that surface water is being moved eastward by westerly winds and warmed as it proceeds. This induces a westerly flow of cold water ($<4.0 \text{ C}$) along the bottom. A thermal bar (Tikhomirov 1963) is developed where the surface waters above and below 4.0 C meet; this stimulates sinking of the 4.0 C water and upwelling of the colder water (Rodgers 1965). A small contribution to the stability of the system will result from the temperature of maximum density between 50 and 100 m being 3.9–3.8 C.

The net effect of circulation is to maintain high oxygen values at the water-sediment interface in all parts of the lake. This high oxygen level ensures that the sediments are fully mineralized, effectively preventing the recycling of phosphates, iron, and manganese (Mortimer 1971). It is apparent that the absence of an anoxic layer reflects the extremely low biological productivity and hence extreme oligotrophy.

This extreme oligotrophy is confirmed by the high degree of transparency as measured by Secchi disc. With a maximum reading of 30 m

it is not quite so extreme as some North American Lakes; Hasler (1938) recorded 40 m in Crater Lake, Oregon; Martin (1955) observed 35 m in Chubb Crater, Ungava, Quebec and LcConte (1883) gave a value of 33 m for Lake Tahoe, Nevada. However, Great Bear Lake has the highest recorded transparency for arctic lakes; Schindler et al. (1974a) consider that 20–22 m may be an underestimate for Char Lake; Lake Hazen (McLaren 1964) had a reading of 20 m and Netilling Lake (Oliver 1964) had a Secchi depth of 13–20 m in the most transparent region. Rawson (1950) gave maximum values of 13–17 m in the deep water of the East Arm of Great Slave Lake.

In such clear waters the photosynthetic zone will extend to a considerable depth. Clarke (1936a) considers that photosynthesis is possible down to a depth of 130m in the clearest ocean water; however, Great Bear Lake is not of such extreme clarity. For Great Bear Lake, Johnson (1966b), following the methods of Sverdrup (1953) and Marshall (1958), estimated the critical depth, or that depth above which total photosynthesis is equivalent to total respiration per unit surface area, to be 142 m. This is the depth above which circulation must occur for an increase in phytoplankton production to take place. With a circulation depth of 225 m in Great Bear Lake in summer the critical depth is exceeded and increase in production is unlikely.

The penetration of light into a deep lake is also important in that it affects the vision of fish and possibly their ability to feed. Clarke (1936b) believes that the light penetrating coastal waters and lakes is mostly in the green region (5000Å) of the spectrum, whereas Hutchinson maintains that in deeper lakes penetration is mainly in the blue (4500Å). Clarke concluded that the sunfish *Lepomis* which was most sensitive to light in the yellow-green region (5300Å–5500Å), could respond visually to a light intensity 10 logarithmic units below that at the surface on a bright sunny day. If the Secchi depth is taken to indicate the depth at which the illumination is 5% (Yoshimura 1938) that of the surface, then one logarithmic unit in Great Bear Lake will be approximately 23 m, similar to that given by Clarke for the deep basin of the Gulf of Maine. Some response down to a depth of 234 m can thus be considered possible for a fish with visual characteristics similar to those of *Lepomis*. Lake trout (*Salvelinus namaycush*) and fourhorn sculpins (*Myoxocephalus quadricornis*) were taken from the greatest depths (400 m), but it seems unlikely that they would be feeding visually below 230 m; however, both species from deep water were found to have full stomachs. About 96% of the bottom area is therefore likely to be affected by incident

light in summer; below 230 m extremely stable conditions of no light and low temperature will prevail at all times.

It is of interest to compare Great Bear Lake with Great Slave Lake since they are similar in their size and northerly setting. Both have basically two basins, one more productive than the other largely on account of the origin of the water draining into them. In Great Bear Lake the large unproductive main basin is comparable with the East Arm of Great Slave Lake: both are largely dependent on Shield drainage. In Great Slave Lake the large western basin is supplied with five-sixths of its water by the very turbid Slave River. McVicar Arm, which is warmer and slightly higher in dissolved solids than the rest of Great Bear Lake, is largely supplied with water originating in muskeg.

The great volume of water carried by the Slave River and its discharge into the western basin has a profound effect on the residence time of the water in this part of the lake. It is here that the difference between Great Slave and Great Bear lakes is perhaps at its extreme. In Great Slave Lake the residence time of the water is 12.5¹ yr when the whole lake is considered, but this is not a valid figure when the two basins are so completely separated; for the western basin a figure of 7 yr is more realistic; for the East Arm a figure in excess of the 124 yr of Great Bear Lake is possible, on account of the smaller number of rivers discharging into it and its great depth and volume.

The great difference in water residence time, coupled with the high silt load deposited in Great Slave and virtual absence of silt deposition in Great Bear, separate the two lakes in a most positive way. Water temperatures, too, are considerably higher in Great Slave Lake. In McLeod and Christie bays surface temperatures reach 10 C even in the offshore regions (Rawson 1950); in the deeper parts of the East Arm temperatures seem comparable with those of Great Bear Lake.

Rawson estimates the heat income of Great Slave Lake, above that required to melt the ice, at 23,400 cal cm⁻². This is close to the comparable figure of 26,000 cal cm⁻² for Great Bear Lake. However, the distribution of this heat into summer and winter heat incomes is quite different; in Great Bear Lake the summer heat income is negligible, while in Great Slave Lake it is between 15,000 and 19,000 cal cm⁻², indicating in the more southerly lake, a very much smaller mass of water below 4 C at the start of the heating cycle. Schindler et al. (1974a) calculated the

¹Recalculated from Rawson's (1950) data. Rawson's figures of 125 yr and 70 yr appear to be in error by a factor of 10.

budget for Char Lake; they give a figure of between 15,000 and 19,000 cal cm⁻² for the total heat intake of which 14,000–15,000 is for melting ice. This is with an incident radiation figure of 4×10^5 kcal m⁻² yr⁻¹ about half that of Great Bear Lake (8.7×10^5 kcal m⁻² y⁻¹).

However, Schindler et al. (1974b) and Kalf (1970) believe that the low primary production of arctic lakes is a result of low nutrient input rather than low temperature. Schindler et al. conclude that the low nutrient status is due to low nutrient levels in the precipitation. If this is so, then it will be of great consequence in Great Bear Lake since the drainage basin is small compared with the lake surface area (5:1), and precipitation is low ensuring that the volume of water entering the lake each year on a unit area basis is small (0.6 m³/m² plus evaporation). Combined with this is the very low nutrient status of the Shield rocks (Schindler and Armstrong 1971) on which the majority of the precipitation falls.

Great Bear Lake has thus the characteristics of a polar lake: a single period of circulation at a temperature close to 4 C in summer; high oxygen values at all times of the year with supersaturation in the surface waters in summer and below the ice in winter; and, above all, a high oxygen content of the bottom waters in April. This last condition is matched only by one other arctic lake and that one is permanently ice-covered. This polar character is developed in a north temperate climatic region where the surrounding lakes are characteristically temperate dimictic in character (Keller Lake and McVicar Arm).

Most of these characteristics can be attributed to the low nutrient status and hence low biological activity, free circulation in the main basin, and above all the immense volume.

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