THE UNIVERSITY OF MANITOBA

NUTRIENT BUDGETS AND SEDIMENTATION IN CHAR LAKE, N.W.T., 74°42' N; 94°50' W.

by

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ABSTRACT

Supplies and losses of nitrogen, phosphorus, and organic carbon were measured at Char Lake, N.W.T. in 1972 and 1973. Parameters measured were inflows, precipitation, outflow and sedimentation.

Total supplies per square metre of lake area were 2.46 g organic carbon (C_o) yr^{-1}, 0.325 g N yr^{-1}, and 0.024 g P yr^{-1} as a two year mean. Only 12% of N and P and 16% of allochthonous C_o entered the lake in direct precipitation. Allochthonous C_o was found to be a minor component (10.5%) of the Char Lake C_o budget.

The lake was relatively inefficient in retaining nutrients. Only 63% of the N supply and 55% of the P supply were retained. Outflow losses of C_o were minor (8.9%).

Sediments were found to be unevenly distributed. They were thickest in the moss zone and at the maximum water depth (Z_m). Fine sediments were absent near shore and thin in water depths of 15 to 20 metres.

Low concentrations of C_o, N, and P were found in the sediments and these varied from place to place in the lake. The sediments were found to contain only 45% of the N retained by the lake, and 17% of the C_o not accounted for by other losses. Sedimented P accounted for 117% of the amount retained by the lake.

Factors affecting the supply, losses , and sedimentation of C_o, N, and P are discussed.

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B. Graham performed the X-ray diffraction analyses and lent me a C-H-N analyser. Dr. I. Lubinsky identified the mollusks from Char Lake sediments. I am grateful to them both.

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INTRODUCTION

Char Lake was the subject of an intensive productivity and carbon flux study from 1969 to 1973 as part of the International Biological Program. An allochthonous organic carbon (allochthonous C_o) budget was required to determine the importance of external C_o sources in the total C_o budget of the lake.

The purpose of this study was to measure the supply, storage (i.e. net sedimentation), and outflow losses of C_o at Char Lake. Nitrogen (N) and phosphorus (P) were also studied because of the importance of the supply of these elements in controlling planktonic primary productivity in lakes (Vollenweider, 1968). Char Lake has one of the lowest rates of planktonic primary production known (Kalff and Welch, 1974).

This is the first study in which supply, outflow losses, and storage of C_o, N, and P have been studied simultaneously in one lake. Combining these with studies from other project members enabled the construction of budgets for C_o, N, and P. Factors considered for the C_o budget are given in Figure 1.

Production estimates for Char Lake have been published in Welch and Kalff (1974) and Kalff and Welch (1974), allochthonous C_o estimates in Stocker (1972) and de March (1975), C_o outflow losses in de March (1975), respiration estimates in Welch (1974) and Welch and Kalff (1974), and a preliminary estimate of C_o storage in Rigler (1974). Dissolved inorganic carbon was measured by Schindler *et al.* (1974). The results of these studies are summarized in Table 1. N and P supply and outflow losses for one year (1971) were reported in Schindler *et al.* (1974). Some of the 1972 and 1973 results from the present study were published in de March (1975).

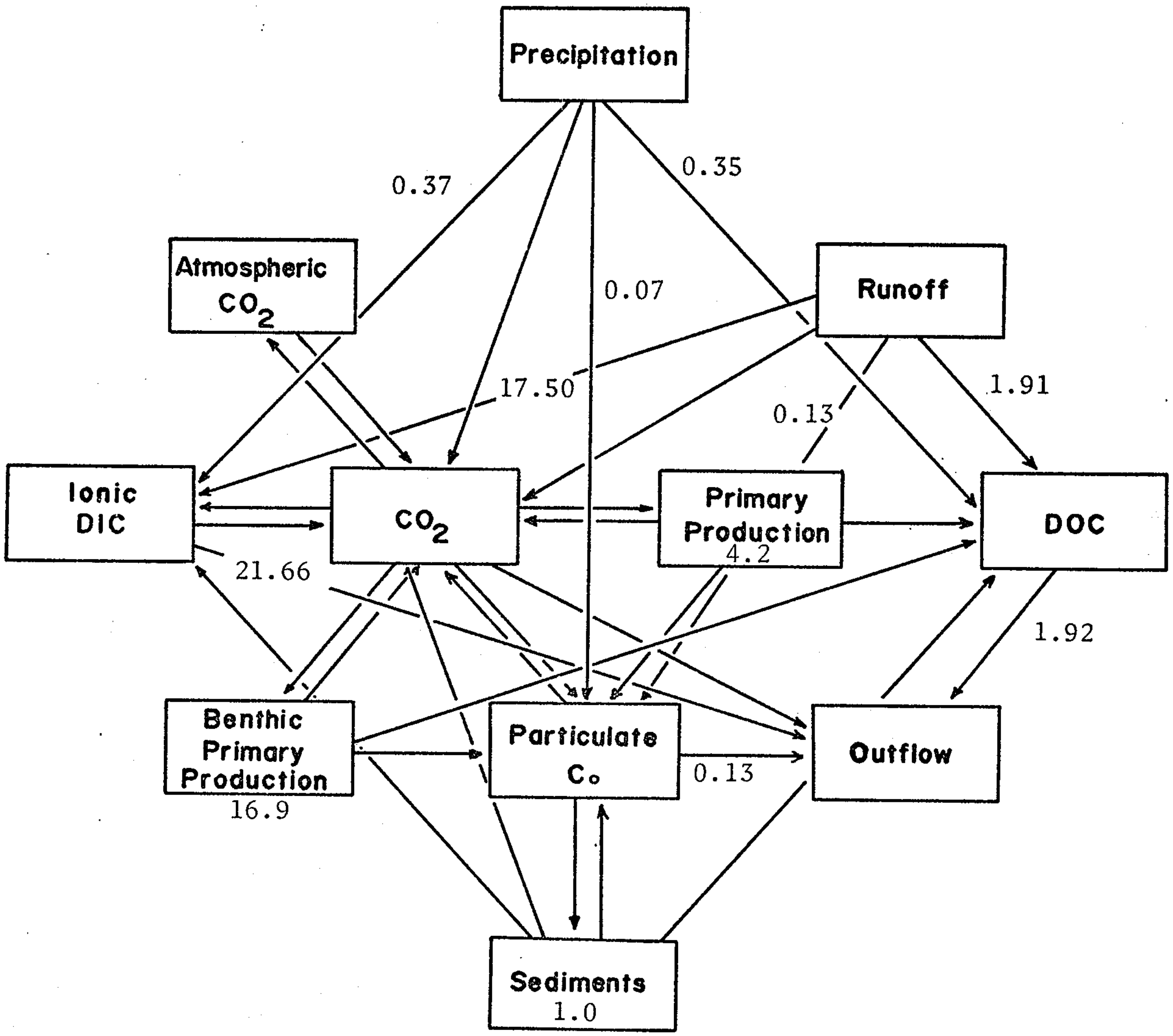
Table 1. A summary of sources and losses of organic carbon in Char Lake. All values are presented as g C_o m^{-2} lake area yr^{-1}.

Sources						=	Losses					
Allochthonous	+	Planktonic production	+	Benthic production	Total	=	Respiration	+	Outflow	+	Sedimentation	Total
0.9[1][a] or 2.5[2]	+	4.2[3]	+	16.9[4]	22 or 23.6[5]	=	15.9[6]	+	2.1[2]	+	5.8[7] or 1[8]	23.8 or 19[5]

1. Stocker (1972), large particles only.
2. de March (1975), DOC + FPOC.
3. Kalff and Welch (1974).
4. Welch and Kalff (1974).
5. Totals using the result of the present study.
6. Welch (1974).
7. Rigler (1974), estimate from sediment trap data.
8. Present study, total C_o in the sediments.

a. The actual values reported were 10 g m^{-2} yr^{-1} or a total of 480 kg. The latter value is equivalent to only 0.9 g m^{-2} yr^{-1}.

Figure 1. A simplified version of the carbon cycle in Char Lake, showing parameters that have been measured. All values are in g C m^{-2} lake area yr^{-1}. Production values are from Table 1.


Precipitation
Atmospheric CO2
Runoff
Ionic DIC
CO2
Primary Production 4.2
DOC
Benthic Primary Production 16.9
Particulate Co
Outflow
Sediments 1.0
0.37
0.35
0.07
17.50
0.13
1.91
21.66
1.92
0.13

Few papers have been published on sediments in polar lakes. Schindler et al. (1974) mentioned the chemistry of interstitial waters in Char Lake sediments, and Kalff and Welch (1974) gave an estimate of C_o concentrations in Char Lake surface sediments. Coakley and Rust (1968), Brunskill et al. (1973), and Livingstone et al. (1958) all reported sediment data, but in northern lakes which are not comparable to Char Lake because of their geographic location or their geological setting.

Many authors have used organic carbon as an indicator of past environmental conditions in lakes (e.g. Vallentyne and Swabey, 1955; Mackereth, 1966), but none have attempted to determine the total amount of C_o stored or an average sedimentation rate for C_o over the history of the lake. Rich and Wetzel (1972) reported a storage rate of 14.8 g C_o m^{-2} yr^{-1} for Lawrence Lake, but used only a single core to derive this figure.

One factor preventing such attempts is that lake histories are usually determined from cores obtained at the deepest point in the lake (Z_m) (e.g. Mackereth, 1966; Livingstone and Boykin, 1962). When a series of cores has been taken over an extensive area of a lake, they have been used for studies such as the mineralogical studies of Coakley and Rust (1968), or the turbidite studies of Ludlam (1974). An exception is Tessenow (1972, 1973a, 1973b, 1974a, 1974b) who studied the upper sediments of a small area of a bog lake in great detail, examining the factors affecting the sedimentation and migration of phosphorus.

It has long been realized (Ohle, 1962; Ludlam, 1974), but not been stressed often enough, that more sediment collects in the deeper parts of lakes than in the shallows. There are also physical and chemical differences between sediments of different depth zones of a lake (Whittaker, 1922; Coakley and Rust, 1968; Tessenow, 1973a, 1973b). Extrapolating over a whole lake from a single core that represents the unique conditions at Z_m is, therefore, not justifiable.

In this study a relatively large number of cores was obtained in order to map the distribution of sediments in the lake, and to estimate a 'true' sedimentation rate for the lake as a whole, rather than just at Z_m.

The Study Area

Char Lake is a polar lake (Hutchinson, 1957) at 74°42' N. latitude and 94°50' W. longitude on Cornwallis Island, N.W.T. It is situated approximately 1.5 km from the Arctic Ocean and 1.5 km from the Resolute Bay Airport (Fig. 2).

The lake is roughly circular in shape (Fig. 3), has an area of 52.6 ha., maximum depth of 27.5 m and a mean depth of 10.2 m (Rigler, 1972). The watershed (A' = 403.7 ha.) is underlain by Silurian limestones and dolomites of the Read Bay Formation (Thorsteinsson, 1958). The terrain is thinly mantled with frost - shattered rocks, mineral soils, and marine clays. Continuous permafrost underlies the watershed with the active layer penetrating to a maximum depth of 0.5 m in August. Plant cover, consisting of mainly Salix arctica, Saxifraga oppositifolia, Draba alpina, and Papaver radicum, is only 5 - 7% with an annual production of 1 to 8 g organic matter m^{-2} yr^{-1} (Arkay, 1972).

Four main streams and numerous temporary rivulets drain the watershed (Fig. 4). Streams 1, 2, and 3 drain a plateau and scarp along the northeast shore of the lake. Stream 1A drains a relatively level area on the north shore. The Department of Transport removed gravel

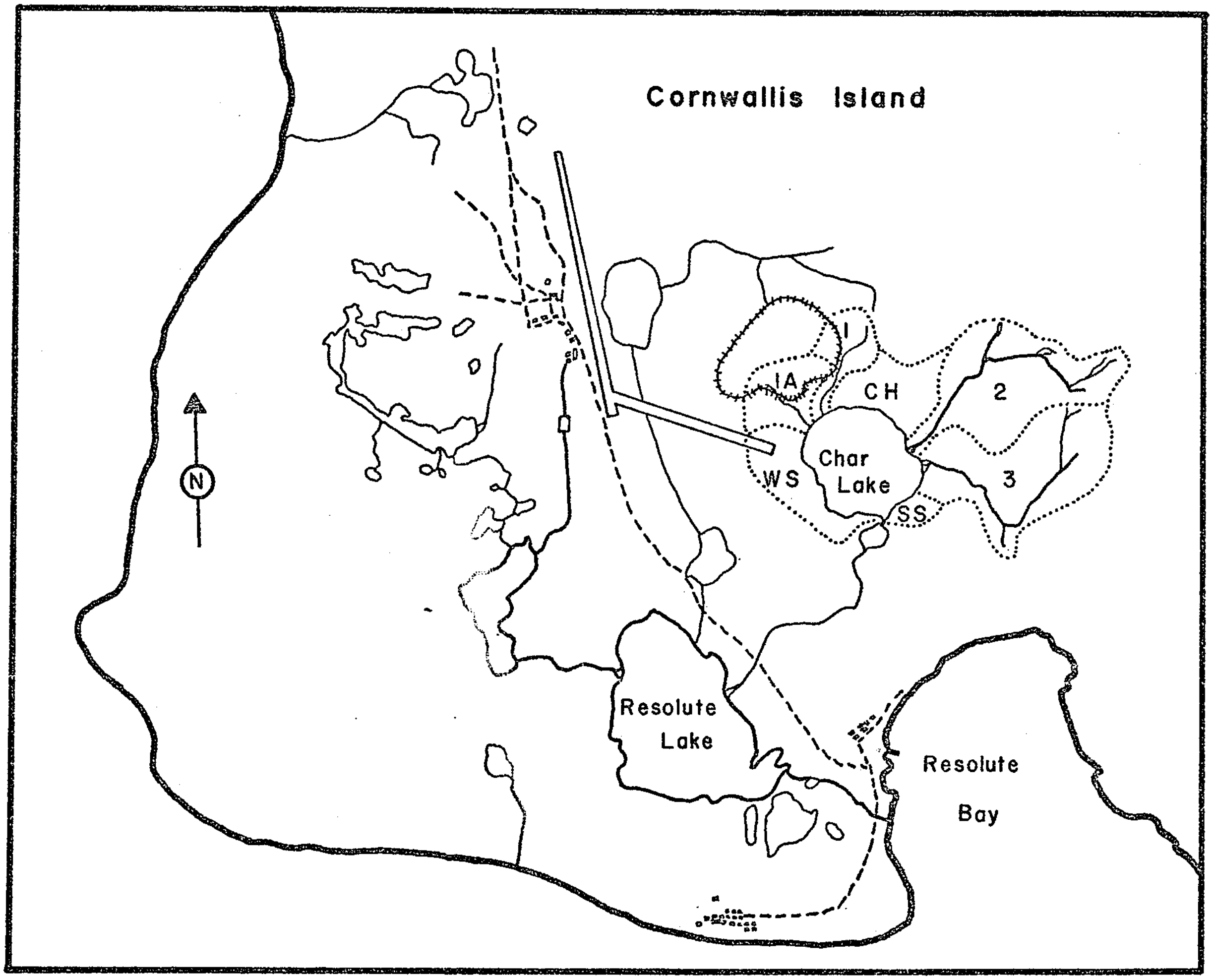
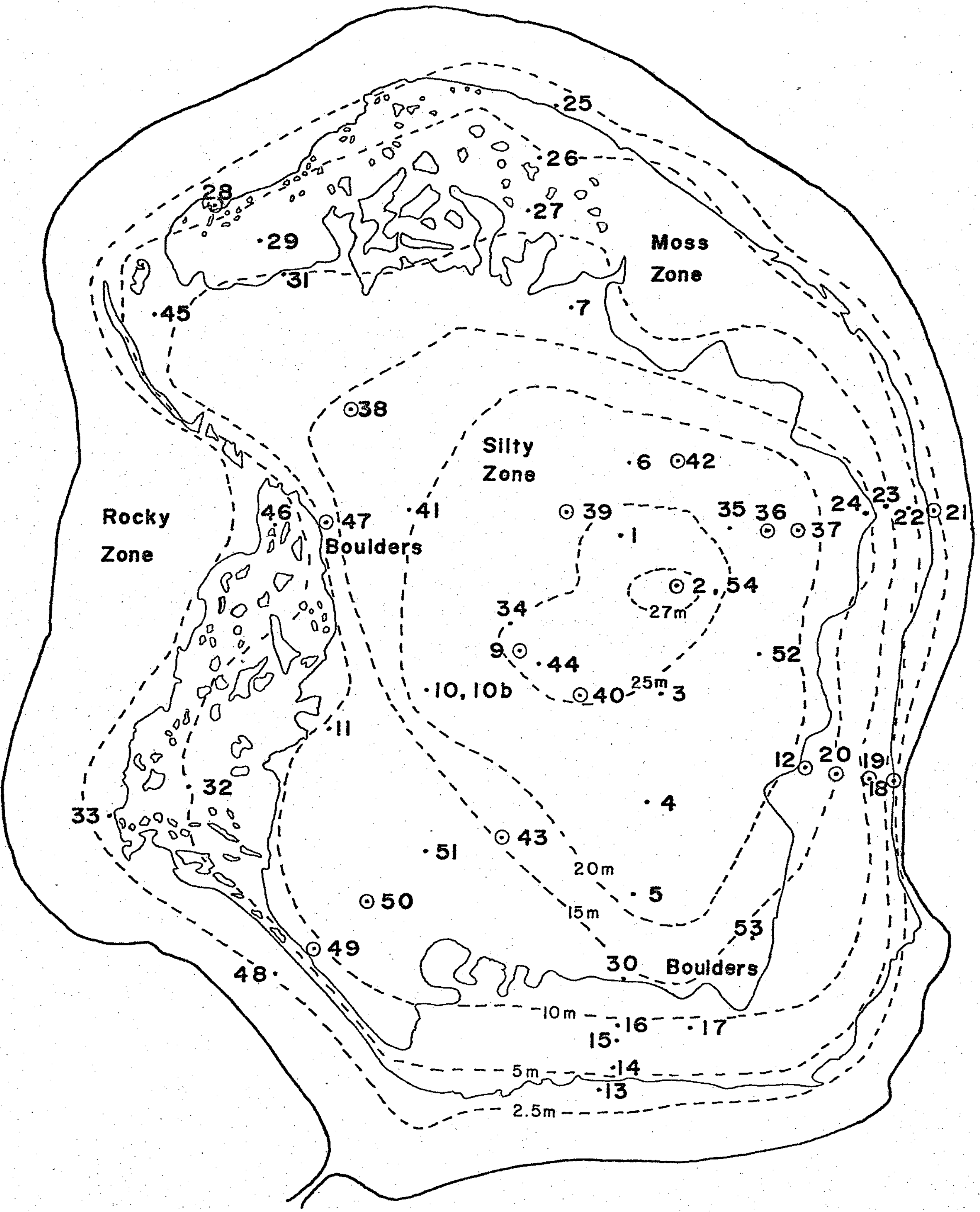


Figure 2 The Resolute Bay area. 1cm = 580 m. ++++++++++ Area of gravel removal. ------ Roads. ········Char Lake drainage basin. After Rigler (1972).

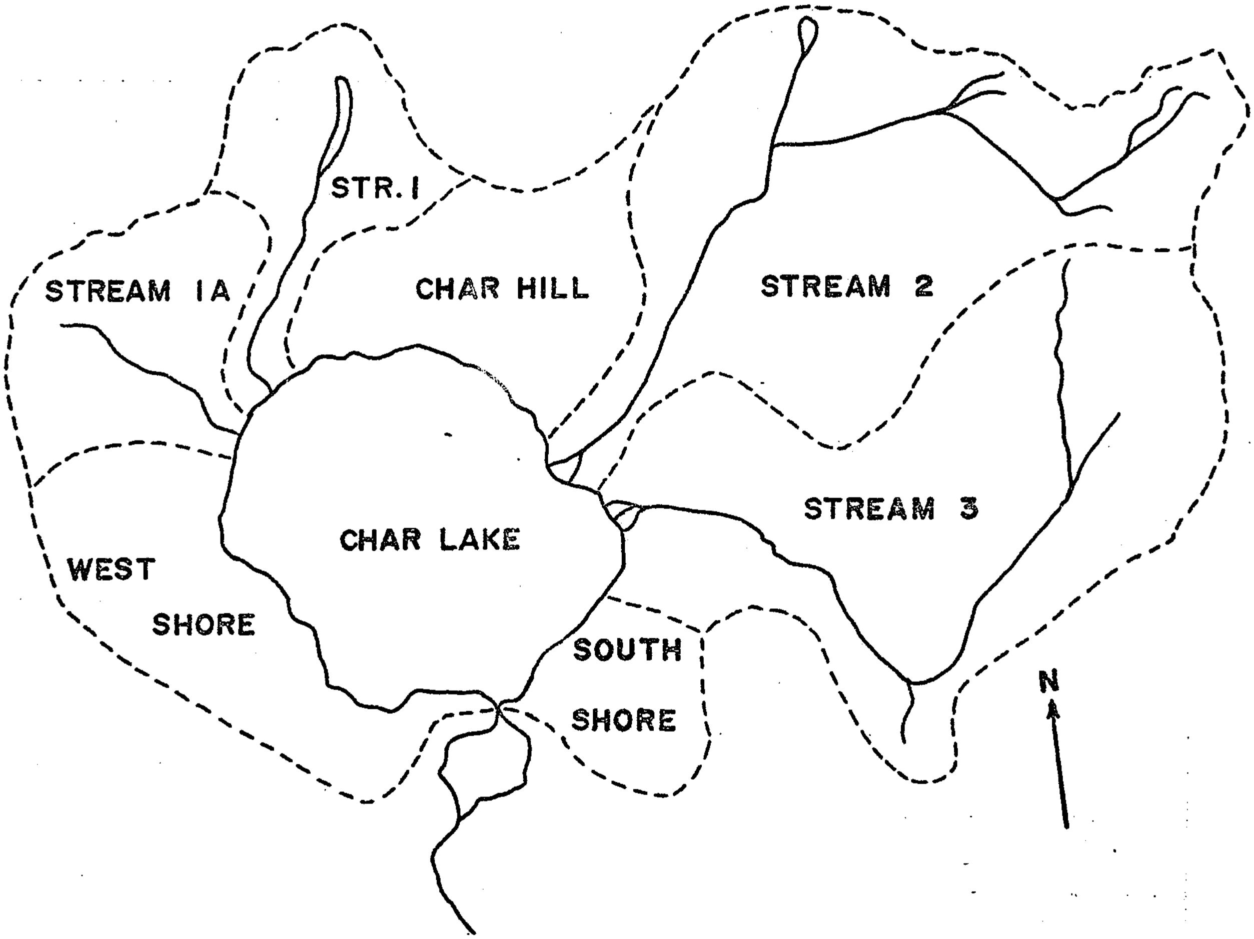
Figure 3. A bathymetric map of Char Lake showing the rocky, moss, and 'silty' zones. Positions of the sediment cores are also shown. After Welch and Kalff (1974).

CHAR LAKE



25
26
28
27
29
Moss
Zone
31
7
45
38
Silty
Zone
6
42
Rocky
Zone
46
47
41
39
35
36
24
23
22
21
1
37
Boulders
2, 54
27m
34
9
44
52
10, 10b
40
25m
3
11
12
20
19
18
32
33
4
43
51
20m
5
50
15m
53
49
30
Boulders
48
10m
16
17
15
14
5m
13
2.5m

Figure 4. A map of the drainage basin of Char Lake showing the major sub-basins and the major streams. After Stocker (1972).


STR. I
STREAM IA
CHAR HILL
STREAM 2
STREAM 3
CHAR LAKE
WEST
SHORE
SOUTH
SHORE
N

this area for runway construction from 1969 to 1973 (Fig. 2). Frozen ground from below the active layer was continually exposed to the sun and melting occurred in July and August.

The Resolute Bay area is a polar desert with annual precipitation averaging only 13.6 cm. About half of this falls as snow between September and May (McCann _et_ _al_., 1972).

The bottom of Char Lake can be divided into three major areas (Welch and Kalff, 1974) (Fig. 3). The rocky zone extends from the lakeshore to a depth of about 2.5 m and covers an area of 15.5 ha., or 29.4% of the lake area (Welch and Kalff, 1974). The only fine sediments are between the cobble sized rocks in the shallow parts of this zone, but are thicker and can be cored in the deeper parts.

The moss zone extends from the lower edge of the rocky zone to between 5 and 20 m. Generally the bottom is covered with a 10 to 20 cm thick layer of moss, only the upper portions of which are living. There are mossless patches within the moss zone, especially on the west side of the lake. The total area covered by the moss zone is 12.6 ha. or 23.9% of the lake area (Welch and Kalff, 1974). Mossless patches in the moss zone cover 2 ha. or 3.8% of the lake area (Rigler, 1972).

The remaining 22.5 ha. or 42.9% of the lake area constitutes the 'silty' zone (Welch and Kalff, 1974). Its surface is either bare silty sediment, algal mats or other growths of benthic algae.

Some areas (Fig. 3) have boulders with little fine sediment near them. They occur on steeper slopes of the lake bottom.

METHODS

I. Nutrient Budgets

Water samples from the four main streams, the lake (as a vertically integrated 10 m sample), and the outlet were collected daily during the period of maximum runoff and twice weekly thereafter. Smaller inflows were sampled at less frequent intervals. All water samples were filtered through Whatman GF/C glass fibre filters which had been ignited at 500°C for 10 hours. Filters were retained for analysis of particulate C, N, and P (particles $< \sim 1\ \mu$).

Snow depths and densities were measured on transects covering the whole drainage basin in 1972. In 1973 densities were measured at a number of points in the basin and the mean basin depths were extrapolated from snow depths on the lake. These measurements and snow samples for chemical analysis were taken at the end of May in both years. At this time, snow depths were at their maximum.

Bulk summer precipitation samples were collected in a $\frac{1}{4}\ m^2$ acrylic funnel on the shore of the lake near the outlet.

Water samples were analysed for conductivity (on a Beckman conductivity bridge, with results reported in μmhos cm^{-1} at 25°C), dissolved and fine particulate organic carbon (DOC and FPOC), nitrogen (TDN and FPN), and phosphorus (TDP and FPP) from May to August in 1972 and 1973.

Methods of analysis were according to Stainton _et al_. (1974) with the following exceptions. Samples for the analysis of TDN and TDP were sealed in ignited glass ampoules (1 hr. at 500°C) and autoclaved for later analysis. Because large amount of inorganic carbon (CO_3-C) were present in particulate samples, half of each filter for FPOC was analysed for total C in either a Carlo Erba Model 1100 C-H-N analyser or a Perkin Elmer Model 240 C-H-N analyser, and the other half for CO_3-C by the method described for sediments in Stainton (1973). FPOC was obtained by difference. Precisions of the methods are given in Stainton (1973) and Stainton et al. (1974).

To sample large particulate matter, screens of 6.35 mm mesh size were placed across one channel of each of the major streams near the point at which they entered the lake. Downstream from these were placed samplers of the inverted funnel type (Cushing, 1964) with nets of 1 mm mesh size. Nets and screens were cleared every few days in 1972.

Nutrient inputs to the lake were calculated as follows. The volume of water present as snow in each sub-basin was calculated from the average depth and density of snow. The volume of rainfall was added to the snow water volume and the total multiplied by the unweighted mean concentration of C_o, N, and P in stream water. The lack of weighting is partially compensated for by the fact that samples were taken 3.5 times more often during the period of maximum runoff than at other times.

II. Sediments

Fifty-four sediment cores from 25 to 104 cm in length were obtained either with a mini - Mackereth piston corer (Mackereth, 1958) using acrylic core tubes of 5 cm inside diameter, or by SCUBA and manual driving, using the same tubes. Cores were obtained in June, July, and August of 1972 and 1973. Fifty were obtained for the purpose of determining losses to the sediments of C_o, N, and P; seven from the lower rocky zone, seventeen from the moss zone, and twenty-six from the 'silty' zone.

Cores were extruded by forcing them up the tube with a piston powered by a manual water pump. Cores 2 to 33 were sectioned every 2 cm to 10 cm core depth, then at alternate 5 cm intervals to the bottom. Cores 35 to 53 had the 0 to 1 and 1 to 2 cm sections separated and then were sectioned at 2 cm intervals to 10 cm and at 5 cm intervals to the bottom.

Each core section of known volume was weighed to determine its wet density. After homogenization and drying at 105° C, the dry density (i.e. mass of dry material per unit of wet volume [d] was calculated. Water contents were calculated as the loss of weight on drying. After drying, sediment samples were ground to a powder in a mortar, then stored in glass vials.

For the following analyses, small samples (2 to 20 mg, depending on the analysis) were weighed out in pre - weighed aluminum pans on a Cahn Model G electrobalance. Samples were redried at 105°C and cooled in a desiccator before the final weight determination. All analyses were performed in duplicate and the results averaged.

Total C and N were measured on a Carlo Erba Model 1100 C-H-N analyser, CO_3-C by the method of Stainton (1973), and C_o was obtained by difference. P was determined by the method of Stainton et al.(1974).

A small number of samples was subjected to X-ray diffraction analysis for the qualitative determination of the major mineral components in the sediments.

The recent sedimentation rate at Z_m was estimated using the ^{210}Pb dating method (Kipphut, pers. comm; see also Koide et al., 1973). Sediment thicknesses through the zone dated (2 to 8 cm) were recalculated at the density of the top 2 cm to give a sedimentation rate at that density. This value was recalculated to give a rate at the mean compacted density of the sediment (mean density from 8 to 83 cm) .

No radiocarbon dates were obtained, thus, an age for the lake had to be determined from uplift data in the literature. Using the age of the lake calculated from data in Andrews (1968), Andrews *et al*. (1971), and Blake (1970), and the sedimentation rate from the ^{210}Pb dating, a maximum sediment thickness at Z_m was calculated. Maximum sediment thicknesses in the moss zone were extrapolated from the available data (this study).

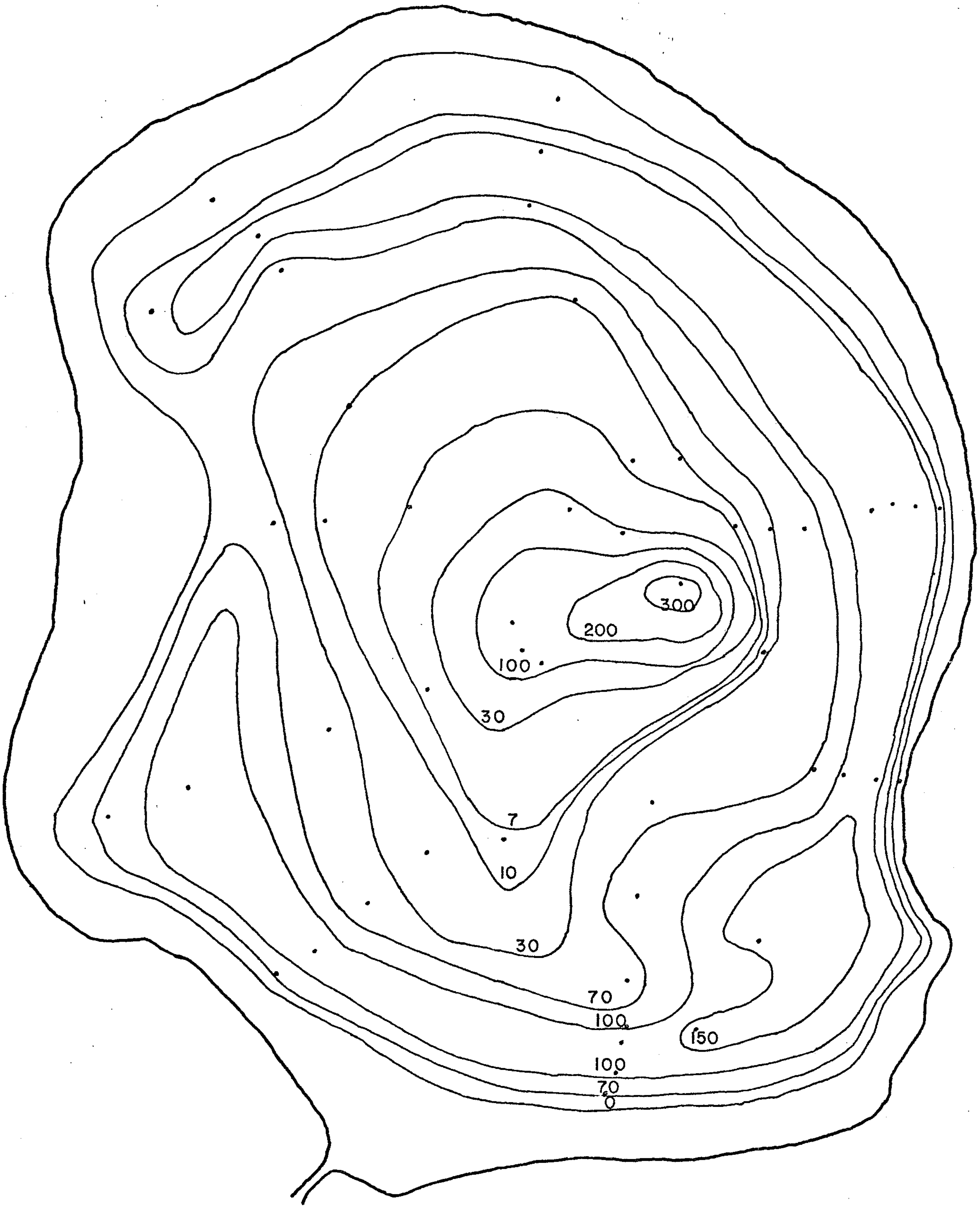
To calculate the masses of C_o, N, and P in the sediments, a map of sediment thicknesses (Fig. 5) was drawn using the 23 cores that reached the lacustrine - marine interface (see results). Areas between sediment thickness isopleths were measured by planimetry. Masses of each element were calculated using the mean concentration weighted by section thickness and the mean thickness and the area of sediment between isopleths. 'Doughnut' shaped areas were treated as rectangles with width equal to the mean radius of a torus of equal area. The volume below the minimum thickness of an area (for example the sediment from 1 to 2 m deep in the area between the 1 and 2 m thickness lines) was assumed to have a triangular cross section, and the elemental masses were calculated accordingly.

Concentrations of elements in sediments below the depth of cores which did not reach the marine sediments were assumed to equal the mean concentration of the lowest 30 cm of the core.

Dividing the total mass of C_o, N, and P in the sediments by the estimated age of the lake gave net sedimentation rates averaged over the whole period of lacustrine sedimentation. A mean sediment thickness was calculated from the area of the lake and the total wet sediment volume.

Figure 5. A map of lacustrine sediment thicknesses in Char Lake. Values given are in centimetres. Position of sediment cores are shown by dots.

CHAR LAKE



RESULTS

I. Precipitation

Total precipitation, including snowpack, was extremely low, only 15.84 cm of water in 1972 and 12.97 cm in 1973 (Table 2). At the Resolute Airport Weather Station the recorded precipitation was lower than the 13.6 cm average in both years (Atmospheric Environment Service, 1971, 1972, and 1973).

The stream watersheds and lake surface all received different amounts of snow because of their different topographies. These differences and stream basin areas were taken into account in calculating the water and nutrient budgets (Tables 2 and 3).

Based on my 1972 and 1973 precipitation data, and ignoring evaporation and evapotranspiration, the theoretical water renewal time for Char Lake is 9.2 years.

Concentrations of P and N in precipitation were low and similar to values reported for the area by Schindler *et al*. (1974). C_o concentrations were also low (Table 4).

Total atmospheric supplies of N, P, and C_o were small. Only small portions of these supplies (12% of N and P and 16% of C_o) fell directly on the surface of the lake (Table 3).

The terrestrial portion of the drainage basin retained only small percentages of N and P supplied by precipitation (Table 5).

II. Terrestrial Drainage

Concentrations of C_o, N, and P in the undisturbed streams were low (Table 6 and Appendix 1). There were variations between streams and between years, but these were relatively minor compared to the differences between the undisturbed streams and stream 1A, disturbed by