Canadian Technical Report of
Fisheries and Aquatic Sciences 962

August 1980

WATER CHEMISTRY OF TEN LAKES IN SOUTHERN NEW BRUNSWICK

by

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This is the one hundred and twenty-seventh Technical Report from
the Biological Station, St. Andrews, N.B.

Cat. No. 97-6/962 ISSN 0706-6457

Correct citation for this publication:

Peterson, R. H. 1980. Water chemistry of ten lakes in southern New Brunswick. Can. Tech. Rep. Fish. Aquat. Sci. 962, iii + 25 p.

CA8000550

ABSTRACT

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Monthly analyses of major ions were performed from May to September, 1978, on samples from ten lakes in southern New Brunswick, Canada. The lakes varied widely in buffering capacity. Mosquito Lake, Robin Hood Lake and Chisholm Lake had virtually no buffering capacity remaining (5-20 µeq./L HCO_3^-) and had mean summer pH's of 5.8-6.0. Creasey and Kerr Lakes had mean HCO_3^- levels of 40-50 µeq./L with mean pH's of 6.7-6.8. Bolton and Mill Lakes contained about 100 µeq./L HCO_3^- with mean pH's near neutrality. Stein and Wheaton Lakes contained about 150 µeq./L HCO_3^- with mean pH's of 7.1. Mud Lake was highly buffered with about 500 µeq./L HCO_3^- and a mean pH of 7.6. The relationship between HCO_3^- and Ca^{++} concentrations indicate a possible slight loss of alkalinity of about 10 µeq. HCO_3^-/L.

The concentrations of the various ions are discussed in relation to rain pH, weather vectors, rainfall patterns during the sampling, and local geology.

Key words: water chemistry, New Brunswick lakes, bicarbonate, pH, alkalinity, major ions, bedrock geology, acid rain

RÉSUMÉ

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De mai à septembre 1978, on a analysé à chaque mois les principaux ions dans l'eau de dix lacs du sud du Nouveau-Brunswick. Le pouvoir tampon de ces lacs était très variable. Celui des lacs Mosquito, Robin et Chisholm était presque inexistant (5 à 20 µé de HCO_3^-/l), et le pH moyen en été y était de 5,8 à 6,0. Dans les lacs Creasey et Kerr, ces valeurs étaient respectivement aux niveaux HCO_3^- de 40 à 50 µé/l et de 6,7 à 6,8. Les lacs Bolton et Mill contenaient environ 100 µé/l HCO_3^- et le pH près de neutralité. Stein et Wheaton, de 150 µé/l HCO_3^-, et le pH moyen était de 7,1 et dans le lac Mud, fortement tamponné, de 500 µé/l HCO_3^- et de 7,6. Le rapport entre les concentrations de HCO_3^- et de Ca^{++} dénote une baisse possible de l'alcalinité d'environ 10 µé de HCO_3^-.

La concentration des divers ions fait l'objet d'une discussion en relation avec le pH de la pluie, les facteurs météorologiques, la pluviosité au cours de la campagne et la géologie locale.

INTRODUCTION

In the last 10-20 yr concern has been expressed over the increased acidity of precipitation in many areas downwind of major industrial centers (Likens et al. 1979). For example, yearly dispersion patterns of acidic precipitation indicate that Scandinavia is probably the recipient of acid rain from heavily industrialized central Europe. As a result, Norwegian scientists undertook an intensive study (SNSF-project) in 1972 to examine the effects of acid precipitation on forests and fish (Braekke 1976). This study concluded that hundreds of lakes in southern Scandinavia cannot now support fish primarily because of acidification from atmospheric inputs. Approximately 70 Norwegian salmon streams have lost their stocks. Other areas where acid precipitation has caused deterioration of fish populations is the LaCloche Mountain area near Sudbury, Ontario (Beamish and Harvey 1972; Beamish 1974; Harvey 1975); the western Adirondacks in New York State (Schofield 1972); and probably in southwestern Nova Scotia (Farmer, pers. comm.) where several former salmon streams no longer contain this species. The lakes and streams in all these afflicted areas are characterized by having very dilute, poorly buffered waters due to the presence of insoluble granitic or other siliceous bedrock materials.

Some of the lake systems in southern New Brunswick appear to qualify as being sensitive to acidic inputs. Southern New Brunswick was scoured during the last glacial period (Gadd 1971) and as a result, many areas have a scanty, poorly developed soil overlying a granitic bedrock. Smith (1952) has characterized the Charlotte County, N.B. lakes as being soft and poorly buffered.

An annual mean precipitation pH of 4.6 has been suggested as the critical isopleth relating lake acidification to acid rainfall (Henriksen 1979). Lakes receiving precipitation more acidic than this typically show loss of buffering capacity. Maps of current rainfall pH isopleths indicate that the mean annual precipitation pH for New Brunswick is between 4.5 and 5.0 (Likens et al. 1976). The 4.6 isopleth in the map from Likens et al. (1979) roughly parallels the Maine-New Brunswick border. This is similar to the mean annual pH for rainfall (4.7 for 1978-79) in Nova Scotia (Underwood 1979). Sergeant and Zitko (1978) found the mean pH of rain water at St. Andrews, N.B. to be 3.9 during July-August 1977.

In contrast to the idea that a pH isopleth of 4.6 is critical, Davis et al. (1978) concluded, from historical data, that the mean pH of Maine lakes had decreased from 6.85 in 1937 to 5.95 in 1974 with 75% of the change occurring between 1950 and 1960. This decrease occurred despite the fact that the mean precipitation pH of the region was still above 4.7 in 1965-66 (Cogbill and Likens 1974). Depending upon mean [Ca^{++}] in Maine lakes this decrease may or may not be sufficient to indicate serious acidification in Henrikson's plots.

Since New Brunswick may now be the recipient of seriously acidic rainfall, it was decided to survey several lakes in the province. The chemistry of the surface water was analyzed monthly from May to October 1978 to establish some baseline data and to determine if possible acidification could be detected by indirect methods. Fish populations were sampled every 2 mo through the summer of 1978. The physical characteristics of the lakes are still to be measured. This report presents the water chemistry aspects of the survey.

SAMPLING METHODS

The water samples were taken just beneath the surface of the lake. Where it was not practical to take the water samples from a boat, they were taken by carefully wading out as far as possible in chest waders and filling the bottles at arm's length so as not to include any roiled water due to wading. In some instances, particularly in May when some ice cover persisted, samples were taken from a dock or rocky point projecting out into the lake.

Ca^{++}, Mg^{++}, Cl^-, K^+, $SO_4^=$, Na^+, and alkalinity were determined from 1-L samples taken in wide-mouth, polyethylene bottles which had been acid-washed and rinsed with deionized water. No preservative was added.

Phosphate was analyzed from water samples taken in 50-mL Sovirel containers with 0.5 mL of 30% H_2SO_4 as preservative.

Samples for nitrate determination were taken in 100-mL polyethylene bottles. The samples were kept on ice or refrigerated until analyzed.

Two 1-L samples were taken in polyethylene bottles for heavy metal determination. One sample was unfiltered, the other filtered through an acid-washed Millipore filter assemblage. The samples were acidified to pH <3.0 with 10% Aristar® nitric acid.

Measurements for pH were taken with a Radiometer Model 24 portable pH meter by immersing the electrodes in the lake directly, usually from the side of a boat. The meter was standardized with pH 4.0 and 7.0 buffers before and after measurement of lake pH, the electrodes being rinsed thoroughly with deionized water after immersion in the buffers.

Conductivities were measured *in situ* with a YSI Model 33 salinity-conductivity-temperature meter.

Ca^{++}, Mg^{++}, Cl^-, K^+, $SO_4^=$, Na^+, alkalinity, nitrate and phosphate analyses were performed by the Water Quality Branch, Inland Waters Directorate, Moncton, N.B., according to the IWD Analytical Methods Manual (Anon. 1979). One set of field titrations of alkalinity was also performed as outlined by Jeffries (1977) on each lake to compare with laboratory determined values. Aliquots were aerated to constant pH after each addition of titrant. End points were determined by the Gran technique (Stumm and Morgan 1970).

Heavy metals (Cu^{++}, Cd^{++}, Pb^{++}, Mn^{++}) were determined by standard flame and graphite furnace atomic absorption methods.

DESCRIPTIONS OF LAKES STUDIED

The 10 lakes selected for the survey are listed in Table 1 and their locations in New Brunswick shown in Fig. 1. The lakes were selected on the basis of several criteria: a) distance from the coast - a factor which will influence the concentrations of several ions, particularly Na^+ and Cl^-. The selection was not altogether satisfactory in this regard as none of the lakes was within the 18- to 20-km range of distances from the coast. b) distance from major centers of human habitation. Saint John is the largest urban center in southern New Brunswick; therefore the lakes were selected at variable distances from Saint John so that it might be possible to detect local influences on lake chemistry. As will be shown, the wind and precipitation patterns are such that minimal local effects would be expected in any of the survey lakes. c) relative areas of lakes and drainage basins. Headwater lakes, particularly those with low ratios of drainage basin to lake area, should be most sensitive to acidification - other factors being equal - due to a larger percentage of their inputs being of atmospheric origin. On this basis Chisholm, Mosquito, Creasey, and Wheaton Lakes should be most vulnerable, although Wheaton is not a sensitive lake for other reasons (Table 1). At the other end of the scale are such lakes as Robin Hood and Kerr Lakes, which receive the effluent of more headwater lakes. A more complete description of the physical characteristics of the 10 lakes will be given in a subsequent report, but a brief description of each lake, particularly with reference to the bedrock geology, will now be given. Many of the lakes studied lie upon formations of Devonian granite (Potter et al.; 1:50,000 geological maps of New Brunswick). Exceptions are the two lakes in the survey nearest the coast (Wheaton and Stein) and Mud Lake, the three of which lie in areas underlain by sedimentary formations. Correspondingly, these latter three lakes have a considerably higher ionic content, over and above the sea salt input. It has been assumed here that the drainage basins of the lakes surveyed are similar in geological characteristics to the formations in the particular areas generally. The detailed geology of the drainage areas of particular lakes may differ, although the results of the water chemistry agree with the generalizations drawn in the following descriptions.

MUD LAKE

Mud Lake (Fig. 2, Table 1) is a senescent lake draining into Skiff Lake by a short connecting stream. The lake basin has filled to a large extent with the remains of aquatic vegetation, which probably has a strong influence on the nature of the water chemistry. Lakeside vegetation is mainly cedar with several extensive cattail patches in the littoral zone. There is much drowned timber along the margins. An unpaved road skirts the western end of the lake, and two cottages were noted. At the shoreline the sediment was rock under the flocculent covering material. Mud Lake lies primarily in Silurian sedimentary formations consisting of slate to sandstone, conglomerate and limestone. The surficial deposits surrounding the lake are mainly heterogeneous tills, reflecting the underlying geology.

BOLTON LAKE

Bolton (Fig. 3, Table 1) is the largest of the lakes in the survey with a lake area of about 310 ha and a drainage area of 3700 ha. Bolton Lake drains into the Cheputneticook system via Bolton Brook. The lake margin is lined with large granite boulders which are also scattered over the bottom of the lake. Sweet gale (*Myrica gale*) grows along the shoreline. There is a sand beach at the access road where a small feeder stream enters the lake. The bedrock on which the lake lies is Devonian granite and the surficial geology consists of bedrock outcrops with some till and morainic deposits. There are two or three cottages and fishing camps on the lake.

WHEATON LAKE

Wheaton Lake (Fig. 4, Table 1) is 110 ha in area and is situated on a low point forming the eastern arm of Chamcook Bay. Its proximity to the coast influences the water chemistry greatly. Much of the lake drainage basin is thinly soiled with spruce-fir vegetation and a lot of rock outcrop. The northeastern portion of the drainage basin was burned in 1958 resulting in much young growth of poplar and maple. This fire may have had some influence on the water chemistry of the lake as well. The shoreline is rocky with patches of horsetails (*Equisetum*), reeds (*Sparganum*) and pickerel weed (*Pontederia cordata*), particularly near the inlet (at the end nearest the road) (Fig. 10) where considerable siltation has occurred. The bedrock underlying the lake consists of Silurian sedimentary rocks. Due to its unprotected location, the lake is usually disturbed by sea breezes. Two cottages were observed on the lake margin.

STEIN LAKE

Stein Lake (Fig. 4, Table 1) at 5 ha is the smallest of the lakes in the survey. It is situated in a basin of bedrock with rock bluffs rising on each side. The inlet (north) end is marshy with a large patch of aquatic grasses. Much dead standing or submerged timber and snags line the shore. The lake is in the early stages of senescence with the formation of quaking mats of dead vegetation at the outflow end. The lake bottom has accumulated a considerable depth of loose mud and flocculent material. Most of the drainage basin is Devonian granite but Devonian sediments underlie the southern margin of the lake. Most of the drainage basin is bedrock, but some outwash delta occupies the southwestern corner.

CREASEY LAKE

Creasey Lake (Fig. 5, Table 1) and Kerr Lake are both in the Bocabec River drainage. Creasey is a small (19 ha), shallow headwater lake whose outlet stream joins the outlet of Kerr Lake. The drainage basin is bedrock dominated by some glacial moraine deposits. The shoreline is treed with spruce-fir and three cottages are on the lake. Due to the shallowness of the lake (maximum depth of 3 m), there are considerable expanses of emergent vegetation. A narrow gravel beach extending from lake to a rocky bluff has formed along part of the eastern shore. The lake lies in a shallow pocket developed in Devonian granite.

KERR LAKE

Kerr Lake (Fig. 5, Table 1) is a larger lake (77 ha) than Creasey and of considerably greater depth (max. 12 m). There are many rock outcrops along the lake margin and jutting above the lake surface (Fig. 11). Much of the shore of the southern end is lined with sweet gale. The northern half of the lake lies on Devonian granite and the southern half lies on a slightly older gabbro-diorite unit. There are glacial moraines at both the northern and southern (outflow) ends of the lake. Kerr Lake receives the effluent of two other lakes, Navigation Lake and McCullough's Pond. It is one of the more highly utilized lakes for recreational purposes with several cottages on the margin.

MILL LAKE

Mill Lake (Fig. 6, Table 1) flows into Lake Utopia through a short interconnecting stream. A dam controls the outflow at the outlet. A gravel road runs along the western edge of the lake, and there are two or three cottages at the southern end. The eastern margin rises abruptly in a rock bluff. The underlying bedrock of most of the drainage basin is Devonian granite, but there is a wedge of Silurian slate-sandstone on the southeastern corner. The main feeder stream of the lake flows through a fairly extensive outwash delta, and this (northern) end of the lake is marshy. The rest of the shoreline is rocky with a gravel beach derived from morainic deposits at the southern end (Fig. 12).

MOSQUITO LAKE

Mosquito Lake (Fig. 7, Table 1) is the most isolated of the lakes surveyed, the access road being 32 km long and requiring a 4-wheel drive vehicle. The drainage basin consists of bedrock and morainic material (Fig. 13). Tree growth is scrubby and of spruce-fir and jack pine (*Pinus banksiana*) with some bare sandy patches. Large granite boulders occur along the lake margin and are visible in places extending above the lake surface. The bedrock is Devonian granite, and the ratio of drainage area to lake surface area (4.2) is low. Therefore Mosquito Lake should be one of the more sensitive lakes in the survey.

ROBIN HOOD LAKE

Robin Hood Lake (Fig. 8, Table 1) has the largest ratio of drainage area to lake area of any of the lakes in the survey (44.8). Robin Hood Lake is a fairly popular recreational area with five or six cottages on the lake. The margin of the lake consists mainly of rock outcrop and trees growing on sandy soil, except at the mouth of the inflow stream which is marshy (Fig. 14), and where there are extensive areas of submerged vegetation offshore. Most of the drainage area bedrock cosists of Devonian granite, but a small wedge of Silurian sedimentary formation does extend into the drainage area.

CHISHOLM LAKE

Chisholm Lake (Fig. 9, Table 1) is a very small lake (8 ha), situated in the New Brunswick highlands to the east of Saint John. It is a private lake owned by a fishing club that has a fishing camp on it. Chisholm Lake is a very shallow lake, probably the greatest depth being 2-3 m, with a shoreline vegetation composed of sweet gale and spruce (*Picea* sp.). The entire lake has a thick growth of submerged vegetation. Chisholm Lake is situated on much older bedrock formations than are the other lakes, being mainly Precambrian granite-diorite-gabbro complex with some Precambrian sedimentary rock. The lake bottom is coarse cobble overlain with considerable organic floc.

RAINFALL PATTERN DURING THE LAKE SURVEY

The weather for the summer of 1978 was characterized by lower than normal rainfall in July and August (Table 2, Fig. 15). This dry period was reflected in the total ionic concentration in the lakes which rose sharply throughout July and August as the water level fell (Fig. 16). This increase in ionic concentration is no doubt attributable to the combined effects of evaporation and relatively greater amounts of ground water input compared to atmospheric input during dry periods. The low spring concentrations are no doubt due to the large influx of water from snow and ice melt in April-May.

LOCAL INFLUENCES AND LAKE CHEMISTRY

Whether or not the influence of precipitation on water chemistry was due to local inputs, such as from the Saint John area or from more remote inputs was of some concern. Figure 17 shows cumulative wind vectors from weather data recorded at the Saint John airport for the months of May-September 1978, during which time the lake survey was carried out. A south-southwesterly-southerly flow of air strongly dominated the southern New Brunswick weather systems for these months. The location of each of the lakes surveyed is also indicated in Fig. 17. It is probable that none of these lakes should be very much affected by Saint John atmospheric effluents as these would flow primarily to the north and north-northeast sectors from Saint John. Robin Hood Lake would probably receive more than the other nine lakes. In the winter months, the main wind direction was northwest and north-northwest, so that the lakes would not be affected to any great extent during the winter months either. The rainfall during the summer months was mainly associated with a southerly flow of air (Fig. 18) as would be expected. It would probably be of interest in future surveys to study some lakes in the north to north-northeast quadrant from Saint John. Not many lakes occur north to north-northeast of Saint John, however, nor would the bedrock type lead one to consider the area particularly sensitive to acidification.

LAKE TEMPERATURES, CONDUCTIVITIES, AND pH'S

Most of the lakes in the survey had similar surface temperature regimes through May-September (Table 3). Temperatures were variable in May, depending on whether any ice cover remained in the lake. Chisholm Lake was almost entirely ice covered in May, with only 30-50 cm of open water along the margin. Mixing had probably not occurred in Chisholm Lake in May, but probably had in the other lakes. Kerr Lake also had considerable floating ice in May. Surface temperatures typically rose into the low to mid 20's in July and August, then began to fall again in early September. The surface temperature regime of Bolton Lake was exceptional in that warming occurred more slowly, so that temperatures in June and July were 4-6°C below those of other lakes. The rate of cooling in the fall appeared similar to that of other lakes. The slow warming is no doubt due to the large size of Bolton Lake so that warming during the spring turnover is more gradual.

The conductivities (Table 4) measured during the May sampling were probably erroneous as the meter was functioning erratically. Values calculated from ionic levels may be closer to correct values. Most of the other field measurements seem reasonable except those for Creasey Lake in August and September, and the measurement for Mill Lake in July. Some of the problems with the early measurements may have been due to irregularities from melting ice; however, the water samples and conductivities were usually taken in close proximity. The mean conductivities are probably very near the true yearly means. In general, the late summer values are higher than those for June-July, due to the increase in ion concentrations during the dry summer months. Mud, Mill, Stein, and Wheaton Lakes, which have considerable sedimentary bedrock in their drainage basins, have higher conductivities than the rest of the lakes which are situated on granite-diorite bedrock. Some of the high conductivities of Stein, and particularly Wheaton Lake, are due to high Na^+ and Cl^- concentrations from oceanic sources The high conductivity of Mud Lake, however, is due to high Ca^{++} and HCO_3^- levels. The higher conductivities of Kerr and Creasey Lakes compared to Bolton are also a reflection of higher salinities in the former lakes. Hayes and Anthony (1958) give values of 30 and 29 for condivities of Creasy and Kerr Lakes, respectively - very close to my mean values of 26 and 28, respectively.

The pH's of the lakes (Table 5) were lower in May-June than later in the summer due to the acidity of the snow and ice melt water draining into the lakes at this time of year. The pH's of the three more dilute lakes (Chisholm, Robin Hood and Mosquito) were lowest with mean levels of 5.8-6.0. Creasey, Kerr, and Bolton Lakes were intermediate with mean pH's of 6.7-7.0. The four lakes with highest conductivities were Mud, Mill, Stein, and Wheaton, all having mean pH's greater than 7.0.

CHLORIDE

Chloride ions present in freshwater lakes are considered to be derived entirely from oceanic sources (Gorham 1957, 1958; Watt et al. 1979). In accordance with this, it is commonly found that Cl^- levels are higher in lakes nearer the coast. Clearly, this is true for the lakes in the survey (Table 6A, B; Fig. 19) where Cl^- levels range from about 200 μeq./L in Wheaton Lake (0.4 km from the coast) to about 30 μeq./L in Mud and Bolton Lakes (about 60 km from the coast). The line of best fit derived by Conway (1942) for North American fresh water in general is included in Fig. 19. The agreement is fairly good, although the data indicate a somewhat greater decline in Cl^- with increasing distance for the first 20 km from the coast. Local variations in wind and rainfall patterns may account for variations from the general trend.

The May sample from Chisholm Lake contained a large fraction of melt water as the sample was taken at the edge of the ice cover. As a result of this ice-water dilution, chloride concentrations (as well as those of other ions) in this sample were much lower than concentrations in subsequent samples from Chisholm Lake. As a result of this dilute sample, some of the calculations made in regard to chloride and sodium ions have been performed both with and without the Chisholm Lake data. Complete series of ion analyses (May-late Sept.) were obtained from six other lakes - Mosquito, Creasey, Kerr, Mill, Stein and Wheaton. All of these six lakes, except Mill Lake, show similar seasonal trends in Cl^- concentrations. This trend consists of a decrease in $[Cl^-]$ from May to June by about 20%, a rise in concentration of some 20% from June to July, and no change from July until late September when the concentration goes up by another 20% (Table 6; Fig. 20, middle panel). This seasonal trend in Cl^- concentration is interesting because it differs from the trends exhibited by the other major ions including Na^+ (also mainly of oceanic origin). The concentrations of other ions increase throughout the summer, then decrease in late September, following the pattern for total ion concentration (Fig. 16) for reasons discussed in a previous section. Since Cl^- is the main anion in plant cell sap, we speculate that perhaps the decrease in concentration from May to June may coincide with increase in phytoplankton and/or macrophyte biomass which removes Cl^- from the water. The possibility of a systematic analytical artifact cannot be excluded entirely either. Since the water samples were not filtered to remove phytoplankton, increase in macrophytic biomass seems a more reasonable explanation. The marked increase in Cl^- in late September would coincide with die-off of macrophytic vegetation. This Cl^- uptake would necessitate exchange with either anions (possibly HCO_3^-) or uptake of an equivalent amount of cation. Results of future surveys will be interesting to see if similar trends occur.

Since Cl^- is presumed to be entirely of oceanic origin, the proportion of the various other ions derived from the ocean is calculated from Cl^- concentrations and molar ratios of the various ions to Cl^- for sea water

SODIUM

As with Cl^-, Na^+ is mainly of oceanic origin (Gorham 1958). Accordingly, the lakes nearer the coast were enriched in Na^+, as they were in Cl^- (Fig. 21). However, the lakes sampled are apparently enriched in Na^+ (w.r.t. Cl^-) when the equivalent ratios of these waters are compared to that of sea water (Fig. 22) if mean values are considered. The Na^+:Cl^- ratio for Wheaton Lake is near that of sea water, but the ratio increases linearly with increasing distance from the coast. This pattern can be explained by assuming that about 20 μeq./L of Na^+ is derived from other sources, and this is relatively constant for all lakes (Table 7, last column). Since the total amounts of Cl^- and Na^+ decrease with distance from the coast, the addition of a constant 20 μeq./L of Na^+ accounts for the increasing ratio. This assumption may not be required, however, if Cl^- is sequestered for most of the summer into an inaccessible compartment, such as plant biomass - as discussed in the section dealing with Cl^-. Since cell sap contains KCl, rather than NaCl, sodium is not taken up as indicated by the different seasonal pattern (Fig. 20). Accordingly, the apparently extra oceanic Na^+ fraction should disappear or become small when Cl^- is released in the fall, or before it is sequestered in the spring. In agreement with this concept, the calculated extra oceanic Na^+ fraction was usually low in the May and late September samples (Table 7, in parentheses; Fig. 20, bottom panel). Na^+:Cl^- equivalent ratios for these months are nearer the seawater value (0.857) for most lakes (Fig. 19, bottom panel).

POTASSIUM

Potassium concentrations varied from 3-23 μeq./L in the lakes sampled (Table 8). Mud Lake was notable for its high K^+ concentrations. Most K^+ is of terrestrial origin, the estimated amount from oceanic sources ranging from 1-4 μeq./L; although in the case of Wheaton and Stein Lakes, this may amount to nearly 50% of the total K^+. The fact that K^+ does not follow the seasonal fluctuations that Cl^- does is interesting. If the hypothesis that Cl^- is being sequestered into macrophyte vegetation were correct, one might expect K^+ to follow a similar pattern. It must be kept in mind, however, that the K^+ dissolved in the surface waters is but a small fraction of the changes in Cl^- levels. Potassium is bound tightly to organic materials, and much of the required K^+ may have been stored in roots or derived from lake sediments.

SULFATE

Sulfate concentrations were of particular interest, since much of the increased acidity of precipitation in eastern Canada has been attributed to sulfuric acid (Summers and Whelpdale 1976). However, the sulfate concentrations in surface waters of the lakes show, if anything, an inverse correlation with pH (compare Tables 9 and 5). This is not unexpected, since there is no reason to expect more sulfate input in one region of the study area than in any other - as discussed in the section dealing with wind and precipitation patterns. The average sulfate concentration in precipitation is in the order of 60-70 μeq./L (Sergeant and Zitko 1978). Therefore, precipitation is probably the major contributor of $SO_4^=$ to these lakes; however, some of this $SO_4^=$ is derived from sea salt. The estimated input from oceanic sources (Table 9) ranges from 4% in the more inland lakes to over 20% for Wheaton Lake. Some of the high $SO_4^=$ levels in Mud and Stein Lakes may be biogenic, originating from the accumulated flocculent sediments covering the lake bottom. Smith (1952) reported $SO_4^=$ levels of 100 μeq./L for Kerr and Creasey Lakes for mid-October - values practically identical to the late September concentrations for these lakes in 1978.

MAGNESIUM

Significant amounts of Mg^{++} in the lake surface water is of oceanic origin, ranging from 70% for Wheaton and Mosquito Lakes to 15% for Mud and Bolton Lakes (Table 10). Stein Lake is exceptional in having a high Mg^{++} content of apparently extra-oceanic origin. The amount of Mg^{++} derived from terrestrial sources correlates well with the bedrock type. Those lakes situated on granite bedrock (Chisholm, Robin Hood, Mosquito, Creasey, Kerr) have low Mg^{++} levels, while those with some sedimentary rock in the drainage basin (Mud, Mill, Stein) have high Mg^{++} levels from non-oceanic sources. Wheaton Lake is somewhat anomalous in that the non-oceanic Mg^{++} fraction appears low, when its bedrock type is taken into consideration.

CALCIUM

The calcium bicarbonate system provides the primary buffer system in fresh water (Gorham 1958; Henriksen 1979). Therefore, the levels of these ions in lakes and streams are important when assessing possible impacts of acid precipitation. In general, those lakes which had a high non-oceanic Mg^{++} fraction also have high Ca^{++} concentrations (Fig. 22). Ca^{++}, however, differs from Mg^{++}, even for Wheaton Lake, in that it is almost entirely derived from non-oceanic sources (Table 11). Mud Lake is notable for its high Ca^{++} level. Calcium tended to concentrate throughout the summer as did most ions.

BICARBONATE

Bicarbonate ion levels present in the lake are critical in assessing lake sensitivity to acid inputs. The concentrations of bicarbonate are similar to those of Ca^{++} (Table 12), as would be expected, given the common sources of these ions. None of the lakes receives significant bicarbonate from oceanic sources. True alkalinity is difficult to measure, particularly in stored samples, so that one series of field measurements was also carried out in late August (titration curves in Fig. 24). These results are compared with the early September laboratory measurements (Table 13). Fixed endpoint determinations overestimate the bicarbonate levels by 32 μeq./L (Henriksen 1979). For the field measurements, the fixed endpoint determinations averaged 18 μeq./L higher than the total inflection point method, and 13 μeq./L higher than the laboratory values which were performed 2 wk later. It is probable that most of my values (Table 2) overestimate the true bicarbonate concentrations by 15-20 μeq./L.

Clearly Robin Hood, Mosquito, and Chisholm Lakes are the lakes most susceptible to damage by acidic precipitation, as their concentrations of HCO_3^- buffer are very low (5-25 μeq./L). Kerr and Creasey are somewhat better buffered at 40-50 μeq./L of HCO_3^-. Mill, Stein, Wheaton and Bolton Lakes all have 100-150 μeq./L of HCO_3^-, while Mud Lake is very highly buffered (>500 μeq./L).

Bicarbonate concentrations in the lakes are linearly related to the Ca^{++} concentrations (Fig. 25), the line of best fit having the equation $[HCO_3^-] = -22.03 + 0.93[Ca^{++}]$. Equations for this relationship for the experimental lakes area in Ontario, and for northwestern Norway were: $-29 + 1.32[Ca^{++}]$ and $-32 + 1.42\ [Ca^{++}]$, respectively, these equations being corrected for the 32 μeq./L of HCO_3^- overestimated by the total fixed endpoint determinations. A similar correction for my data (assuming the estimate of true HCO_3^- levels is correct) would lead to an intercept of about -40 μeq./L. The slope of the equation for New Brunswick lakes is also somewhat lower than the other two equations. A slope >1.0 indicates that anionic species other than bicarbonate contribute to alkalinity, and a slope =1.0 indicates "calcium bicarbonate" is the only buffer in the system. A slope <1.0 (as for my data) presumably indicates that Ca^{++} is not the only cation associated with alkalinity. Mg^{++} may be constituting the additional cationic component - amounting to about 7% for my data.

HEAVY METALS

Heavy metal loadings in the lakes were very low for all metals measured (Table 14). Manganese ions were present in the highest concentrations of any of the metals determined, with Cu^{++}, Pb^{++}, and Cd^{++} following. There was no correlation among any of the heavy metals determined with lake pH's. The only significant correlation was a positive one between Cu^{++} and Pb^{++}. There was no obvious correlation with numbers of roads or cottages on any particular lake, perhaps because development around any of these lakes is minimal. These data will not be discussed further, but are presented as a source of baseline data for these lakes.

ION BALANCES

The balance between cations and anions appears satisfactory for most lake analyses (Table 15). The only major discrepancy is the Bolton Lake analysis in June, where the total cations analyzed were 109 µeq./L in excess of the total anions. This is attributed to a (probably erroneous) low HCO_3^- determination. This low alkalinity measurement was not included in the mean HCO_3^- levels for Bolton Lake.

OTHER MEASUREMENTS

Silica, total dissolved nitrogen and phosphorus were also measured in each water sample. These will not be discussed, but are included in Appendices I-III.

DISCUSSION

The water chemistry of the lake survey is obviously related to the bedrock upon which the lake is situated (Fig. 23). Lakes with extensive sandstone formations in the drainage basins, such as Mud, Wheaton, Stein and Mill Lakes have higher concentrations of Ca^{++} and HCO_3^- than do lakes situated almost entirely on granitic formations. Variations occur within this latter group, however, Mosquito, Robin Hood and Chisholm Lakes are much less buffered than are Kerr, Creasey and Bolton Lakes. This may be related to the composition of the bedrock or to the characteristics of the drainage.

Obviously Mosquito, Robin Hood and Chisholm Lakes must be considered most susceptible to acid stresses of the ten lakes in the survey. The buffering capacity of Mosquito Lake in particular is near zero, so that the pH could change rapidly if acid stress is of influence on the lake chemistry. This lake also has a low ratio of drainage area to lake area so that atmospheric inputs may be relatively more important.

The sea salt influence on water chemistry is also obvious with lakes near the coast, Wheaton Lake, in particular, having high concentrations of Na^+ and Cl^- derived almost entirely from sea spray (Fig. 26). Significant quantities of Mg^{++} and $SO_4^=$ are also of oceanic origin. The ions involved in lake buffering capacity, however, are entirely derived from terrestrial sources as noted previously (Gorham 1958; Kramer 1976). Na^+ and Cl^- concentrations may be important in permitting fish to resist the effects of low pH more successfully, since ion losses are probably the primary effect of low pH on fish populations (Leivestad et al. 1976; Swarts et al. 1978). Ca^{++}, however, is probably of more importance in this regard.

Ions which are most likely contributed in part from the atmosphere, in addition to H^+, are $SO_4^=$ and and NO_3^-. It may be noted that $SO_4^=$ is more uniform in its distribution among the various lakes than are the other ions, being almost as high in concentration in the more dilute lakes as in the more highly concentrated lakes (Table 9). The total $SO_4^=$ in a lake is probably from four different sources - oceanic, geological, atmospheric and biogenic. The amounts derived from sea salt have been estimated, but the relative importance of the other three sources is conjectural. It is probable that a considerable proportion of the Mud Lake $SO_4^=$ is of biogenic sources, considering the amounts of decaying plant material present in the lake. This may also be true of Stein Lake. On the other hand, the $SO_4^=$ content of Mosquito Lake may be largely of atmospheric origin. The $SO_4^=$ derived from geological and oceanic sources would be balanced largely by Mg^{++} and Ca^{++} ions, whereas those from atmospheric sources would be balanced by H^+. Inspection of the residual Mg^{++} and Ca^{++} ions in Mosquito Lake (after subtraction of HCO_3^- concentration) would lead one to estimate about 40-50 µeq./L of $SO_4^=$ to be of atmospheric origin.

There are little historical data on sulfate levels in these lakes, but what little that does exist suggests no increase in sulfate loading in recent years. The sulfate concentrations reported by Smith (1952) for Kerr and Creasey Lakes in 1941 are identical to those obtained in our survey. Similarly the pH's recorded by Smith for Kerr and Creasey Lakes in the early 1940's are virtually identical to those measured in the 1978 survey. At most, a 0.2-0.3 drop in pH might be conjectured, but changes of this magnitude are well within the range of seasonal fluctuations and may not be significant. Historical data on lakes, such as Mosquito and Robin Hood, which have little buffering capacity remaining, would have perhaps given better indication of pH change.

Considering the weather patterns which bring precipitation to the area, it is probable that any atmospheric inputs to the lakes in the survey are derived primarily from sources outside the province.

Direct estimation of the degree of lake acidification over the last decade or so is difficult due to lack of historical data. Such data as exist suggest minimal acidification, unlike the changes apparent in the Halifax area (Watt et al. 1979). Indirect methods may be used, such as inspection of pH and Ca^{++} relationships, or Ca^{++} - HCO_3^- balances (Henriksen 1979). If the data for the New Brunswick lakes are plotted on the pH's vs. Ca^{++} graphs of Henriksen, the points fall in the population of lakes he classifies as "unacidified." However, comparison of the equations relating $HCO_3^-$to Ca^{++} for for New Brunswick lakes with those given by Henriksen would indicate a probable loss of alkalinity in the order of 10 µeq./L. Such decreases in alkalinity, particularly in well buffered lakes, would result in little pH change. A decrease of 10 µeq./L for the lakes such as Creasey or Kerr Lakes might be expected to result in a pH change of about 0.1 pH unit, whereas a similar decrease for Robin Hood Lake would result in a pH change of 0.4-0.5 pH units.

If it is true that the precipitation acidity of southern New Brunswick has exceeded the critical level within the last 5-10 yr, then the pH's of lakes such as Mosquito and Robin Hood may be expected to change rapidly as a response to the increased loading.

ACKNOWLEDGMENTS

I wish to acknowledge the assistance of J. D. Martin, Ms. J. L. Metcalfe, D. A. Hennessey, R. G. Saunders, Ms. J. Dick, J. J. Melanson, Dr. P. G. Daye and Dr. D. J. Wildish in collecting samples from the various lakes. Mr. P. Connell and Mr. B. King kindly granted us access to Chisholm and Robin Hood Lakes, respectively. Mr. M. Redmond and his staff of the N.B. Dept. of Natural Resources loaned us a boat and motor for several sampling trips. The Water Quality Branch, Dept. of the Environment, Moncton, N.B. generously performed most of the chemical analyses. Dr. S. Ray of the St. Andrews Biological Station analyzed the samples for heavy metals. Drs. T. L. Pollock, W. D. Watt and J. K. Elner, Messrs. D. J. Hamilton and D. E. Barnett reviewed the manuscript. Dr. J. Kerekes provided valuable discussion.

Messrs. P. W. G. McMullon and F. Cunningham prepared the figures. Mrs. B. McCullough typed the manuscript and Ms. R. Garnett edited it.

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Table 1. Geographical data on lakes sampled.

Lake	Lat.	Long.	Distance from coast (km)	Approx. elevation (m)	Drainage area (ha)	Lake area (ha)	Ratio drainage area lake area
Mud	45°50'	67°32'	66.1	210	430	42	10.2
Bolton	45°42'	67°35'	60.0	170	3700	310	11.9
Chisholm	45°33'	65°28'	14.8	350	52	8	6.5
Robin Hood	45°21'	66°19'	18.1	60	3000	67	44.8
Mosquito	45°16'	66°34'	14.2	150	380	91	4.2
Creasey	45°14'	67°01'	6.0	110	110	19	5.8
Kerr	45°13'	67°02'	4.4	60	1050	77	12.2
Mill	45°12'	66°46'	7.7	30	1880	150	12.5
Stein	45°11'	67°04'	1.6	60	150	5	30.0
Wheaton	45°10'	67°00'	0.4	15	410	110	3.7

Table 2. Monthly rainfall totals (mm) for summer 1978, and "normal" totals for years 1941-70 as recorded at the Saint John airport.

Year	May	June	July	Aug.	Sept.	5-mo total
1978	60.2	115.0	43.1	19.2	136.5	374.0
"Normal"	101.9	94.5	89.4	98.8	102.6	487.5

Table 3. Monthly surface water temperatures (°C) for the various lakes in the surveys. Most temperatures were measured between 0900 and 1600 h.

Lake	May 3-5	June 12-19	July 17-20	Aug. 9-17	Sept. 5-7	Sept. 22-27	Oct. 31
Mud	-	22.0	23.0	24.0	19.0	12.0	-
Bolton	-	12.0	17.5	24.0	19.5	13.0	-
Chisholm	0.6	16.2	23.5	23.0	13.8	13.1	-
Robin Hood	-	16.0	22.3	23.5	16.2	13.3	-
Mosquito	5.0	17.0	24.0	23.5	17.0	13.6	-
Creasey	6.1	22.0	24.0	24.5	14.2	14.7	-
Kerr	4.6	19.0	20.5	22.0	16.7	15.5	7.5
Mill	9.5	18.0	22.0	23.0	20.0	14.0	-
Stein	7.9	19.0	22.0	21.5	19.5	14.0	8.2
Wheaton	-	22.0	23.0	24.0	19.0	12.0	-

Table 4. Monthly surface water conductivities (μmho/cm^2) for the various lakes in the survey. Asterisks indicate values considered to be erroneous and are not included in calculation of the means. Values in parentheses are calculated from the ionic composition of surface water samples.

Lake	May 3-5	June 12-19	July 17-20	Aug. 9-17	Sept. 5-7	Sept. 22-27	Mean
Mud	-	50	55(61)	65	55	60	58
Bolton	-	25	30(22)	25	23	25	24
Chisholm	23*(9)	12	28	16	21	25	18
Robin Hood	-	15	22	20	20	20	19
Mosquito	35*(23)	20	21	22	-	25	22
Creasey	13*(25)	-	22	35*	14*	30	26
Kerr	12*(27)	-	22	31	30	30	28
Mill	53*(30)	30	42*(33)	35	35	35	33
Stein	23*(37)	-	32(39)	42	40	28*	40
Wheaton	29*(51)	50	55(61)	65	55	60	57

Table 5. Surface pH's of lakes surveyed for May-late September 1978. Asterisks indicate values which appear to be out of line with the majority of the readings, and are not included in the mean.

Lake	May 3-5	June 12-19	July 17-20	Aug. 9-17	Sept. 5-7	Sept. 22-27	Oct. 31	Mean
Mud	-	7.6	7.5	8.0	7.7	7.4	-	7.6
Bolton	-	7.1	7.4*	6.8	6.7	7.2	-	7.0
Chisholm	5.8	5.9	6.2	6.1	6.0	6.2	-	6.0
Robin Hood	-	5.6	-	5.8	5.7	6.1	-	5.8
Mosquito	5.2	5.6	5.8	5.8	5.9	5.9	-	5.8
Creasey	6.4	7.2*	6.6	6.8	7.0	6.9	-	6.8
Kerr	6.0	6.8	6.4	6.5	7.0	6.7	6.9	6.7
Mill	6.5	7.2	7.2	6.9	7.0	7.3	-	7.1
Stein	7.0	7.3*	6.9	7.2	6.8	7.1	7.0	7.1
Wheaton	6.8	7.4*	6.8	7.2	7.2	7.2	7.0	7.1

Table 6A. Monthly chloride concentrations (μeq./L) in surface water samples from the various lakes. All Cl^- is assumed to be derived from oceanic sources (sea spray).

Lake	May	June	July	Aug.	Sept.	Late Sept.	Mean
Mud	–	–	34	28	40	38	35
Bolton	–	28	31	25	23	35	28
Chisholm	34*	82	99	90	90	99	82(92)
Robin Hood	–	51	–	56	54	62	56
Mosquito	71	56	70	85	76	120	80
Creasey	87	59	85	85	96	107	86
Kerr	90	70	76	90	90	107	87
Mill	107	90	99	104	99	90	98
Stein	102	82	85	99	96	120	97
Wheaton	209	180	217	198	198	254	209
Monthly mean for 7 lakes for which measurements were made in all sampling periods	100	88	104	107	106	128	105.5
Normalized mean	0.92 ± 0.24	0.89 ± 0.17	0.93 ± 0.16	0.94 ± 0.15	1.007 ± 0.100	1.20 ± 0.15	

Table 6B. Normalized values of Cl^- for the various lakes (with respect to the mean values). Values in parentheses for Chisholm Lake exclude the May value.

	May	June	July	Aug.	Sept.	Late Sept.
Chisholm	.41*	1.00(.89)	1.21(1.08)	1.10(.98)	1.10(.98)	1.21(1.08)
Mosquito	.89	.70	.88	1.06	.95	1.50
Creasey	1.01	.69	.99	.99	1.12	1.24
Kerr	1.03	.80	.87	1.03	1.03	1.23
Mill	1.09	.92	1.01	1.06	1.01	0.92
Stein	1.05	.84	.88	1.02	.99	1.24
Wheaton	1.00	.86	1.04	.95	.95	1.22
Mean	1.01	.82	.97	1.01	1.00	1.20

Table 7. Monthly sodium concentrations (μeq./L) in surface water samples from the various lakes. Amounts calculated to be derived from oceanic sources are given in parentheses. Total concentrations are the sum of the two values. Lower set of figures are normalized values as explained in Table 6B.

Lake	May	June	July	Aug.	Sept.	Late Sept.	Mean
Mud	-	-	28(29)	32(24)	31(34)	33(32)	31(30)
Bolton	-	24(24)	23(26)	27(21)	28(20)	18(30)	24(24)
Chisholm	6(29)*	21(70)	11(85)	19(77)	19(77)	2(85)	13(71)
Robin Hood	-	26(44)	-	22(48)	28(46)	12(53)	22(48)
Mosquito	9(61)	30(48)	23(60)	14(73)	22(65)	0(78)	16(64)
Creasey	8(75)	36(51)	18(73)	23(73)	22(82)	0(91)	18(74)
Kerr	6(77)	27(60)	26(65)	14(77)	19(77)	0(87)	16(73)
Mill	4(92)	40(77)	24(85)	28(89)	41(85)	36(77)	27(82)
Stein	3(88)	26(70)	31(73)	19(85)	27(82)	0(100)	23(81)
Wheaton	12(179)	37(154)	5(186)	26(170)	30(170)	0(187)	21(172)
Chisholm	.42	1.08	1.14	1.14	1.14	1.04	
Mosquito	.88	.98	1.04	1.09	1.09	.98	
Creasey	.90	.94	.99	1.04	1.13	.99	
Kerr	.93	.98	1.02	1.02	1.08	.98	
Mill	.88	1.07	1.00	1.07	1.16	1.04	
Stein	.88	.92	1.00	1.00	1.05	.96	
Wheaton	.99	.99	.99	1.02	1.04	.97	
Mean	.84 (.91)	.99 (.98)	1.02 (1.00)	1.05 (1.03)	1.10 (1.09)	.99 (.98)	

Table 8. Monthly potassium concentrations (μeq./L) in surface water samples from the various lakes. Amounts calculated to be derived from oceanic sources are given in parentheses. Total concentrations are the sum of the two values.

Lake	May	June	July	Aug.	Sept.	Late Sept.	Mean
Mud	-	-	22(1)	20(0)	22(1)	22(1)	22(1)
Bolton	-	7(1)	7(1)	8(0)	8(0)	9(1)	8(1)
Chisholm	2(1)*	4(1)	11(2)	8(2)	6(2)	3(2)	6(2)
Robin Hood	-	4(1)	-	4(1)	4(1)	4(1)	4(1)
Mosquito	4(1)	4(1)	7(1)	6(2)	7(1)	6(2)	6(1)
Creasey	3(2)	4(1)	3(2)	6(2)	8(2)	6(2)	5(2)
Kerr	3(2)	4(1)	9(1)	6(2)	6(2)	6(2)	6(2)
Mill	6(2)	13(2)	8(2)	11(2)	8(2)	8(2)	9(2)
Stein	3(2)	2(1)	3(2)	3(2)	3(2)	3(2)	3(2)
Wheaton	4(4)	3(5)	4(6)	4(4)	4(6)	4(4)	4(5)
Monthly mean for 7 lakes	3.7(2.0)	4.8(1.7)	6.4(2.3)	6.3(2.3)	6.0(2.7)	5.1(2.3)	

Table 9. Monthly sulfate concentrations (μeq./L) in surface water samples from the various lakes. Amounts calculated to be derived from oceanic sources are given in parentheses. Total concentrations are the sum of the two values.

Lake	May	June	July	Aug.	Sept.	Late Sept.	Mean
Mud	-	-	86(4)	118(2)	119(4)	102(4)	106(4)
Bolton	-	70(3)	67(4)	67(2)	71(2)	79(4)	71(3)
Chisholm	24(3)*	54(8)	52(10)	60(9)	71(8)	73(10)	56(8)
Robin Hood	-	57(5)	-	61(6)	61(6)	61(6)	60(6)
Mosquito	56(7)	46(6)	54(8)	54(9)	59(8)	52(12)	54(7)
Creasey	71(9)	81(6)	92(8)	91(9)	96(10)	92(10)	87(9)
Kerr	68(9)	76(7)	77(8)	74(9)	79(8)	92(10)	78(8)
Mill	62(11)	68(9)	69(10)	72(11)	77(10)	96(8)	74(10)
Stein	87(10)	92(8)	96(8)	96(10)	94(10)	102(12)	94(10)
Wheaton	56(21)	59(18)	61(22)	63(20)	63(20)	53(26)	59(21)
Monthly means for 7 lakes (Total $SO_4^{=}$)	70	77	82	84	88	93	

Table 10. Monthly magnesium concentrations (μeq./L) in surface waters of the various lakes. Amounts calculated to be derived from oceanic sources are given in parentheses. Total concentrations are the sum of the two values.

Lake	May	June	July	Aug.	Sept.	Late Sept.	Mean
Mud	-	-	40(6)	35(6)	39(8)	37(8)	38(7)
Bolton	-	29(5)	28(6)	36(5)	30(4)	24(6)	29(5)
Chisholm	1(7)*	10(16)	10(20)	15(18)	16(18)	10(20)	10(16)
Robin Hood	-	6(10)	-	14(11)	11(10)	2(12)	8(11)
Mosquito	5(14)	7(11)	7(14)	8(17)	7(14)	0(14)	6(14)
Creasey	16(17)	21(12)	16(16)	24(17)	23(18)	14(20)	19(17)
Kerr	20(18)	26(14)	29(14)	23(18)	23(18)	14(20)	22(17)
Mill	20(21)	13(18)	31(20)	38(20)	34(20)	31(18)	28(20)
Stein	40(20)	51(16)	49(16)	55(19)	56(18)	54(24)	51(19)
Wheaton	11(41)	21(35)	18(42)	27(39)	21(38)	8(50)	40(18)
Monthly means for 7 lakes	36	39	43	48	46	42	

Table 11. Monthly calcium concentrations (µeq./L) in surface waters of the various lakes. Amounts calculated to be derived from oceanic sources are given in parentheses. Total concentrations would be the sum of the two values.

Lake	May	June	July	Aug.	Sept.	Late Sept.	Mean
Mud	-	-	497(2)	533(1)	648(1)	597(2)	569(2)
Bolton	-	119(1)	133(2)	124(1)	124(1)	128(2)	126(1)
Chisholm	19(1)*	40(3)	51(4)	57(3)	56(4)	56(4)	46(3)
Robin Hood	-	41(2)	-	45(2)	48(2)	48(2)	46(2)
Mosquito	32(3)	39(2)	25(2)	37(3)	43(2)	41(4)	36(3)
Creasey	77(3)	73(2)	91(4)	82(3)	96(4)	91(4)	85(3)
Kerr	87(3)	92(3)	103(2)	92(3)	96(4)	96(4)	94(3)
Mill	121(4)	132(3)	156(4)	161(4)	146(4)	156(4)	145(4)
Stein	161(4)	167(3)	196(4)	201(4)	201(4)	221(4)	191(4)
Wheaton	177(8)	173(7)	197(8)	193(7)	197(8)	195(10)	189(8)
Monthly mean for 7 lakes	100	106	121	122	124	127	

Table 12. Monthly bicarbonate concentrations (µeq./L) in surface waters of the various lakes. The June value for Bolton Lake is considered erroneously low. Values <10 are taken to be zero for averaging.

Lake	May	June	July	Aug.	Sept.	Late Sept.	Mean
Mud	-	-	434	460	579	559	508
Bolton	-	10*	70	100	160	84	104
Chisholm	<10	32	<10	64	30	18	24
Robin Hood	-	<10	-	52	40	12	26
Mosquito	28	<10	<10	<10	<10	<10	5
Creasey	38	58	<10	56	50	34	39
Kerr	70	50	24	52	64	44	51
Mill	70	106	62	136	132	104	102
Stein	148	144	126	162	196	202	163
Wheaton	154	138	109	138	183	175	150
Monthly means for 7 lakes	74	77	58	88	95	84	

Table 13. Results of various estimates of HCO_3^- concentrations derived from field and laboratory alkalinity titrations. The values in the first column are estimates from field titrations using the fixed end-point (pH=4.50) method. The values in the second column are derived from the same data, but using the total inflection point method. The third column is laboratory measurements. The measurements for the first two columns were taken Aug. 22-23, and water samples for the last column were taken Aug. 5-7.

Lake	Fixed end-point method	Total inflection point method	Laboratory determinations
Mud	575	540	579
Bolton	150	160	160
Chisholm	33	30	30
Robin Hood	32	10	40
Mosquito	30	10	<10
Creasey	100	50	50
Kerr	90	65	64
Mill	145	132	132
Stein	210	197	196
Wheaton	200	185	183
Means	156	138	143

Table 14. Concentrations of four heavy metals (μeq./L) in unfiltered surface water samples taken from the various lakes; nm = not measurable.

A.

Lake	May				July				Sept.			
	Cu^{++}	Cd^{++}	Pb^{++}	Mn^{++}	Cu^{++}	Cd^{++}	Pb^{++}	Mn^{++}	Cu^{++}	Cd^{++}	Pb^{++}	Mn^{++}
Mud	-	-	-	-	0.19	0.001	0.008	0.59	nm	nm	0.002	0.56
Bolton	-	-	-	-	0.16	0.011	0.022	1.36	0.012	0.002	0.008	0.88
Chisholm	0.23	0.001	0.010	0.15	0.025	0.001	0.012	0.30	0.038	0.002	0.019	0.85
Robin Hood	-	-	-	-	0.041	nm	nm	1.31	0.041	0.002	0.019	0.85
Mosquito	0.022	0.001	0.010	1.64	0.079	-	nm	0.82	0.019	0.001	0.014	0.85
Creasey	0.012	0.001	0.003	0.41	0.075	0.015	0.012	0.38	0.012	0.002	0.007	0.53
Kerr	0.025	nm	0.003	0.52	0.044	nm	nm	0.32	nm	nm	0.006	0.73
Mill	0.038	0.002	0.005	0.57	0.038	0.006	nm	0.77	0.034	0.002	0.011	1.25
Stein	0.034	nm	0.003	0.59	0.057	nm	nm	0.36	0.009	nm	0.009	0.26
Wheaton	0.031	nm	0.004	0.70	0.021	0.004	0	0.86	0.041	nm	0.014	1.07

B.

Lake	Mean concentrations of heavy metals and mean pH				
	Cu^{++}	Cd^{++}	Pb^{++}	Mn^{++}	pH
Mud	0.070	0.002	0.005	0.58	7.6
Bolton	0.086	0.006	0.015	1.12	7.0
Chisholm	0.098	0.001	0.017	0.20	6.0
Robin Hood	0.041	0.001	0.010	1.08	5.8
Mosquito	0.040	0.001	0.008	1.10	5.8
Creasey	0.033	0.006	0.007	0.44	6.8
Kerr	0.023	nm	0.003	0.69	6.6
Mill	0.037	0.003	0.005	0.86	7.1
Stein	0.033	nm	0.004	0.39	7.1
Wheaton	0.031	0.001	0.006	0.88	7.2

Table 15. Cation excess (μeq./L) of the non-oceanic component in the various lakes surveyed. The June, Bolton Lake value (*) is probably due to erroneously low HCO_3^- determination.

Lake	May	June	July	Aug.	Sept.	Late Sept.	Mean
Mud	-	-	67	7	-9	28	23
Bolton	-	109*	54	21	-35	16	14+
Chisholm	-6	-11	21	-25	-4	-20	-8
Robin Hood	-	10	-	-28	-10	-7	-9
Mosquito	-34	24	-2	1	10	-15	-3
Creasey	-5	-5	5	-12	3	-15	-5
Kerr	-22	23	31	9	1	-20	4
Mill	19	24	56	30	20	31	30
Stein	-25	10	23	20	-3	-26	0
Wheaton	-6	39	45	49	8	-21	19

+: June value omitted from mean.

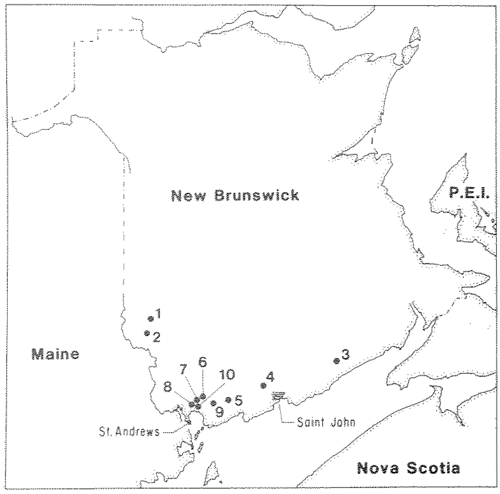

Fig. 1. Locations of each of the ten lakes surveyed are showed on the map of New Brunswick. The lakes corresponding to each number are as follows: 1. Mud; 2. Bolton; 3. Chisholm; 4. Robin Hood; 5. Mosquito; 6. Creasey; 7. Kerr; 8. Stein; 9. Mill; and 10. Wheaton.

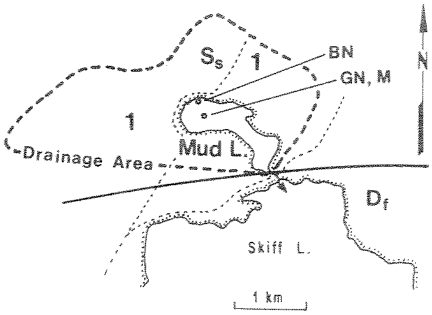

Fig. 2

Fig. 2-9. Diagrams of the lakes and their drainage basins.

1 - heterogeneous till, generally 3 m, drumlins to 50 m
2 - moraine, mainly gravel, bedrock-controlled topography
4 - outwash delta
R - bedrock
  - drumlin ridges
D_f - Devonian granite
D_m - Devonian mafic volcanic
SD_{fv} - Silurian-Devonian granite volcanic
S_{mv} - Silurian mafic volcanic
SDS - Silurian-Devonian sedimentary
S_s - Silurian sedimentary (slate to sandstone and conglomerate, some limestone
EO_s - Cambrian-Ordovician sedimentary
P_{rfv} - Precambrian granite volcanic
P_{rv} - Precambrian volcanic

GN - gill net locations
BN - beach seining locations
M - collection of water samples, plus measurements of temperature, pH and conductivity

Heavy solid lines - separate differing geological formations
Heavy dotted lines - outline of drainage basin
Light solid lines - inlet and outlet drainages
Light dotted lines - highways and roads
Arrows - direction of water flow.

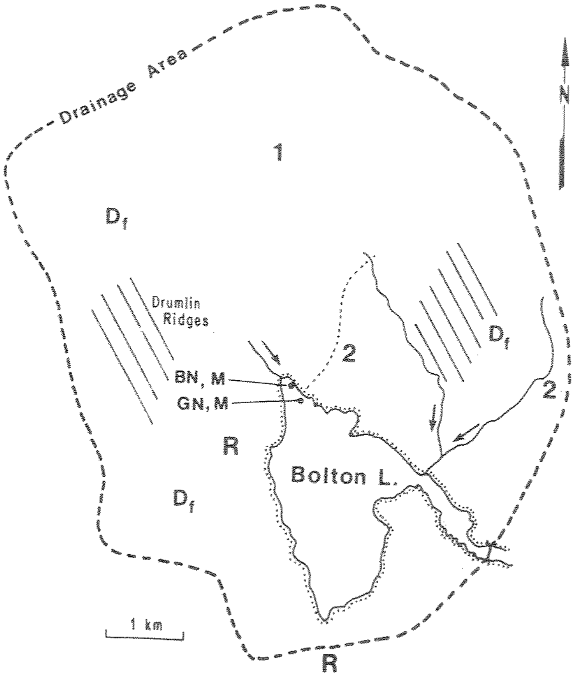

Fig. 3

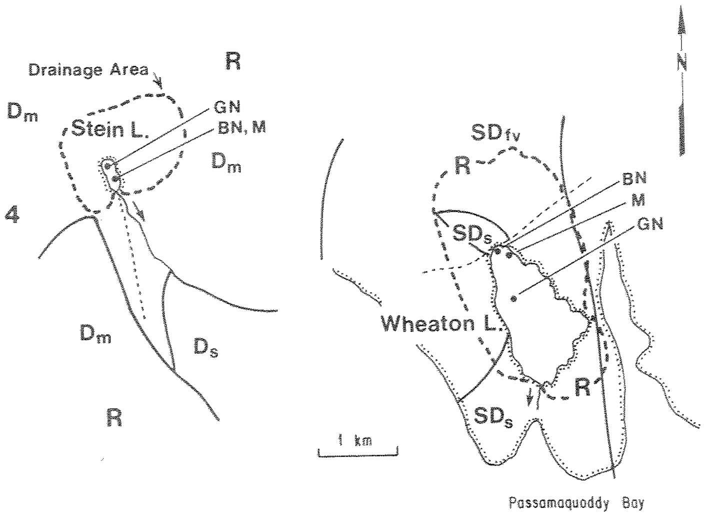

Fig. 4

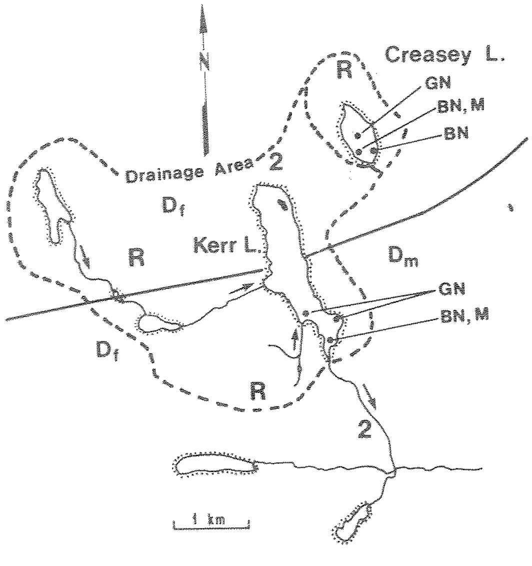

Fig. 5

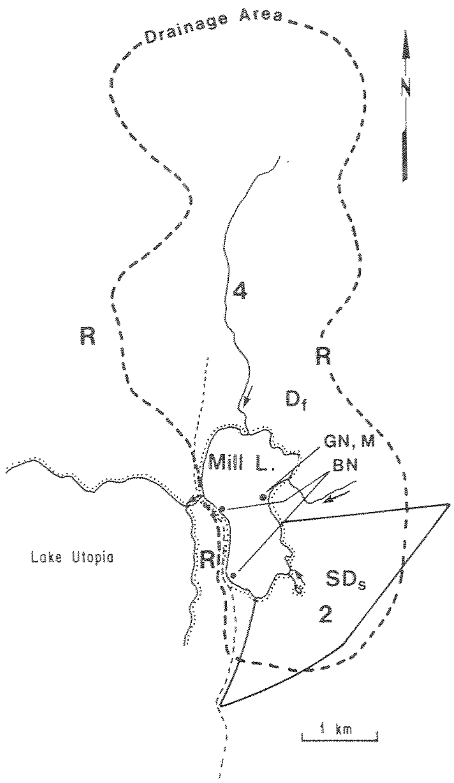

Fig. 6

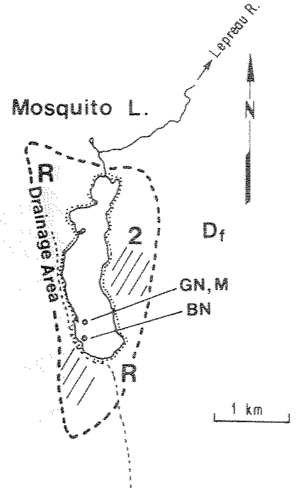
Lepreau R.
Mosquito L.
N
R
Drainage Area
2
Df
GN, M
BN
R
1 km

Fig. 7

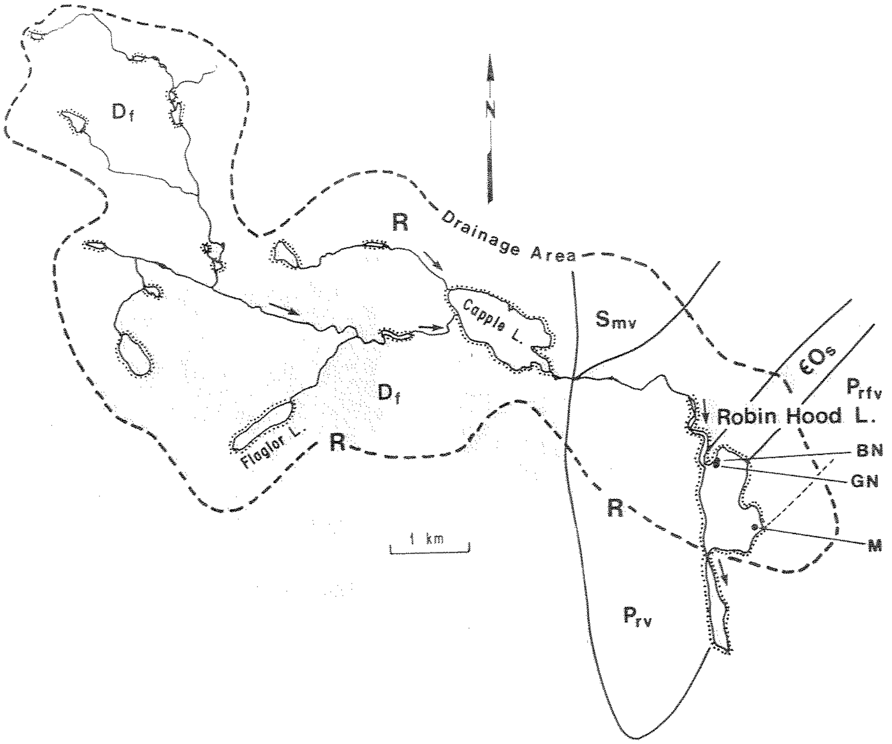
Df
N
R
Drainage Area
Capple L.
Smv
€Os
Prfv
Df
Robin Hood L.
Flaglor L.
R
BN
GN
R
M
1 km
Prv

Fig. 8

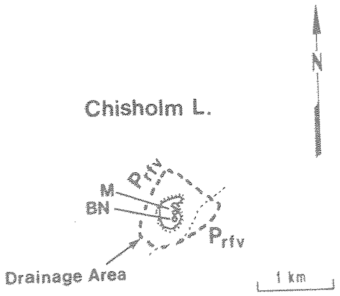

Fig. 9

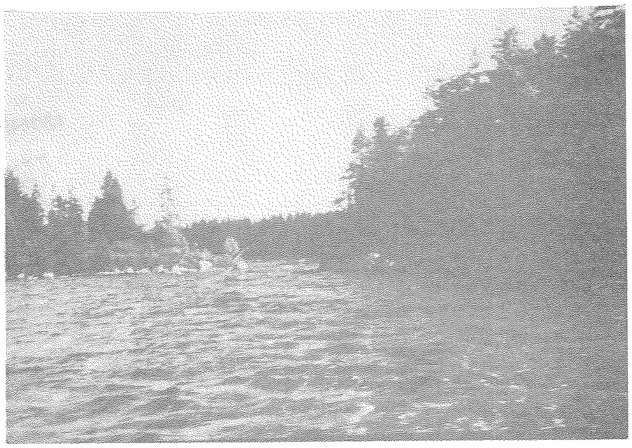

Fig. 11

Fig. 10-14. Photographs of typical littoral and shoreline conformations for five of the study lakes. Fig. 10 - Wheaton; Fig. 11 - Kerr; Fig. 12 - Mill (note extreme low water level due to evaporation and draw-down into Lake Utopia); Fig. 13 - Mosquito; Fig. 14 - Robin Hood (lake inlet at upper left).

Fig. 10

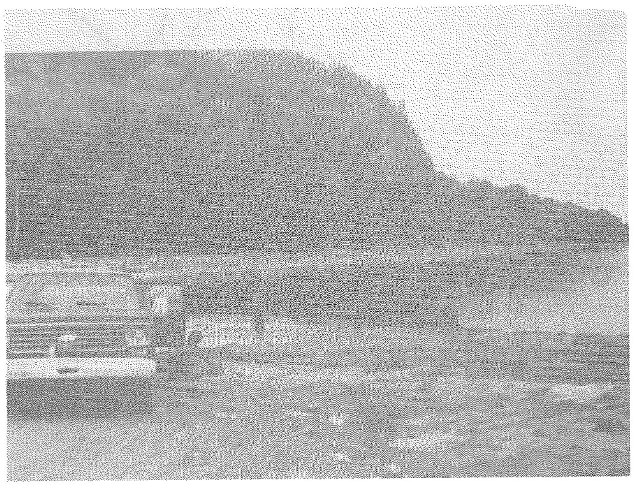

Fig. 12

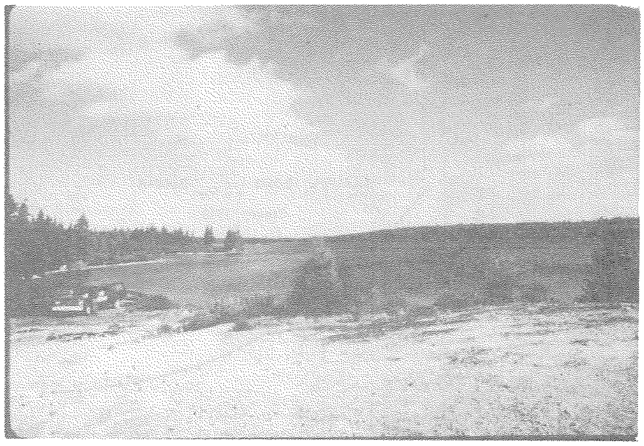

Fig. 13

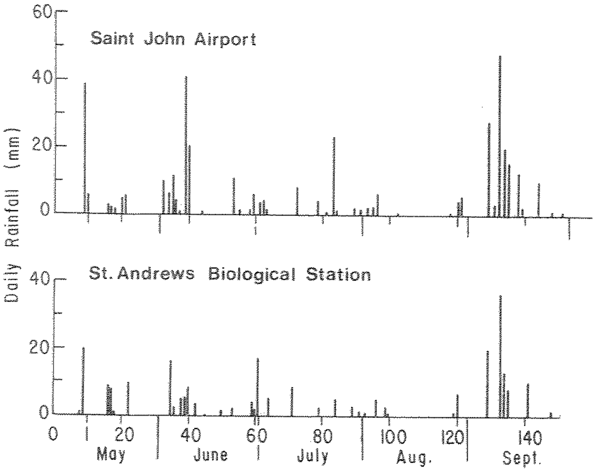

Fig. 15. Rainfall patterns through May-September, recorded at the St. Andrews Biological Station and the Saint John airport. St. Andrews' records may be underestimates due to evaporation as collectors were not serviced on weekends.

Fig. 14

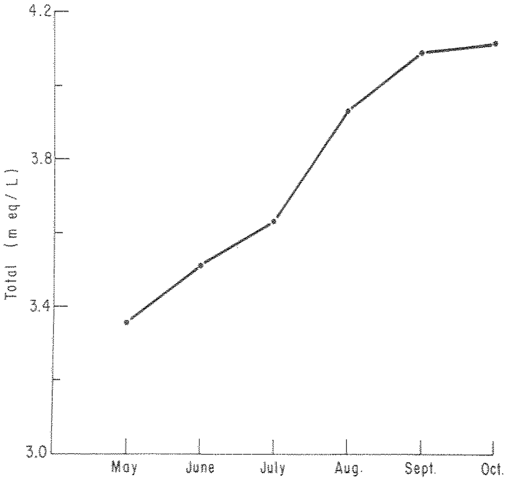

Fig. 16. The total ionic composition of surface water samples (each point a mean for seven lakes) as it varied through the summer of 1978. Increase in ionic concentration is due primarily to concentration through evaporation and low precipitation levels through the summer.

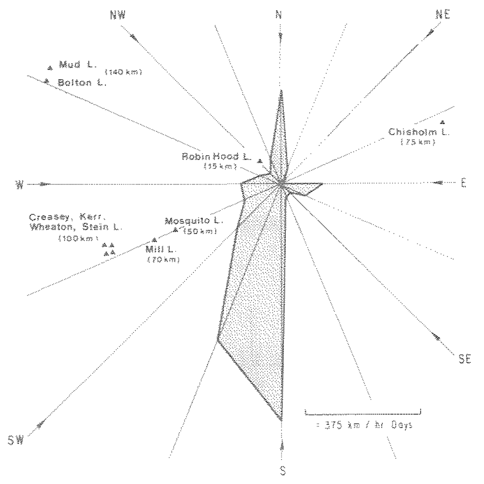

Fig. 17. Cumulative wind vectors at the Saint John airport for May-September 1978 are shown for various compass sectors. Mean wind velocity from any direction may be calculated by dividing the length of a vector by the number of days from May through September (153). Saint John is situated at the "hub" of the compass lines. Location of each lake in the survey is shown in relation to Saint John with distances given in parentheses.

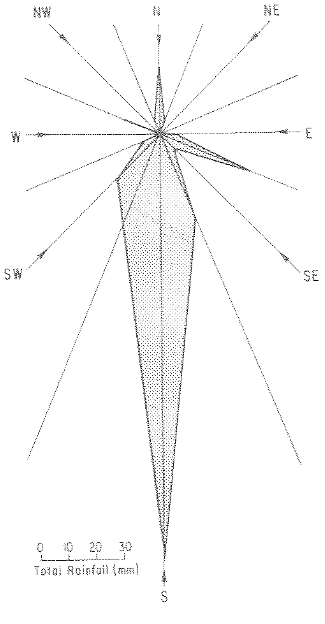

Fig. 18. Cumulative rainfall at the Saint John airport from May through September associated with weather systems from various compass sectors.

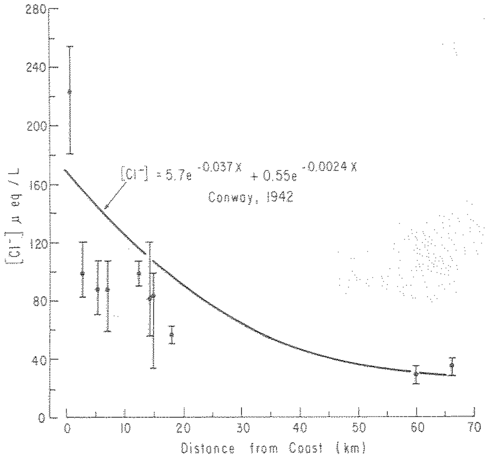

Fig. 19. Chloride concentrations in lake surface water samples as a function of lake distance from the coast. The solid line is derived from Conway's (1942) equation for North American fresh water in general. Vertical bars indicate ranges. Each point is a summer mean.

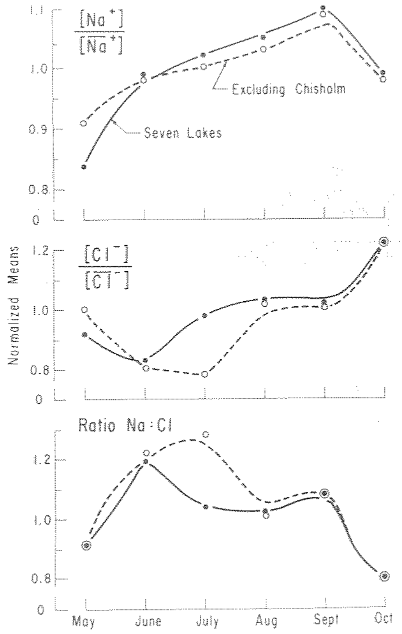

Fig. 20. Top Panel - normalized mean Na^+ concentration in surface water samples from May to September (mean for seven lakes); Middle Panel - as with Top Panel, but for Cl^- concentrations; Bottom Panel - equivalent ratios of $[Na^+]:[Cl^-]$ for the various sampling periods. Ratio for sea water is 0.857.

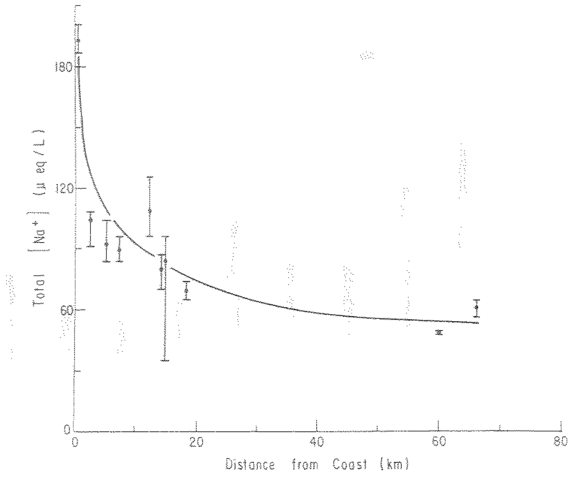

Fig. 21. Sodium concentrations in lake surface water samples for lakes at varying distances from the coast. Vertical bars indicate ranges. Line fitted by eye.

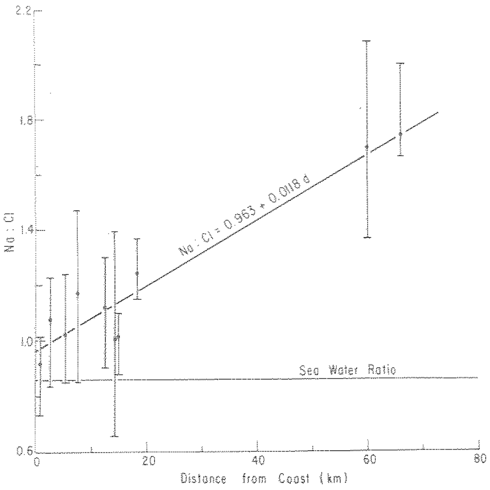

Fig. 22. Equivalent ratios of $[Na^+]:[Cl^-]$ plotted as a function of distance from the coast. Points represent summer means, bars indicate ranges.

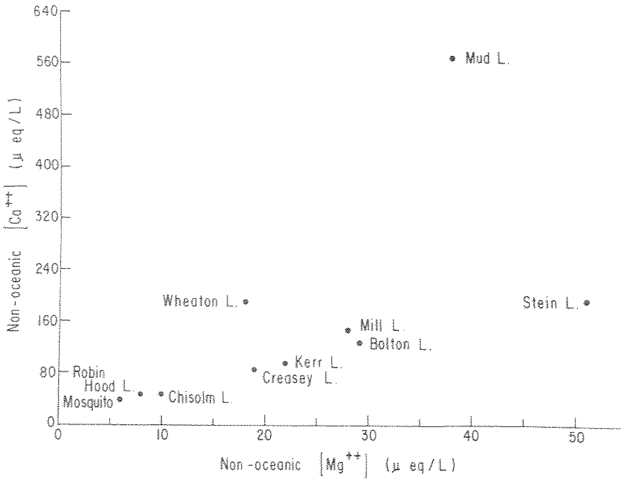

Fig. 23. Calcium concentrations calculated to be derived from non-oceanic sources are plotted vs. non-oceanic Mg^{++} concentrations. Each point is a summer mean for each lake.

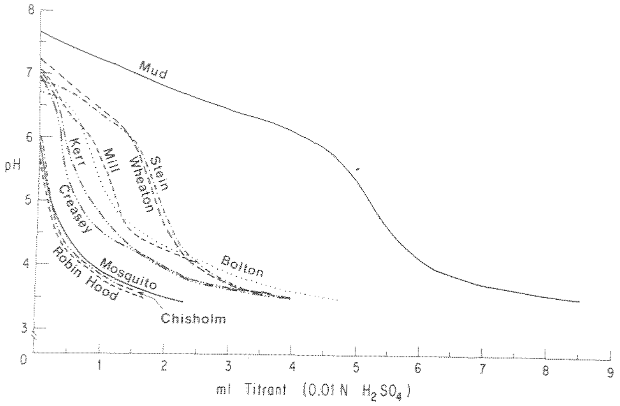

Fig. 24. Alkalinity titration curves for each of the ten lakes surveyed. Titrations were performed in the field with the samples aerated to constant pH after each addition of acid.

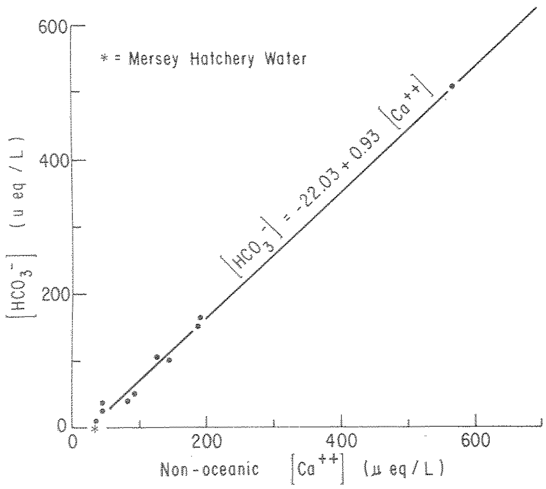

Fig. 25. Bicarbonate concentration is plotted as a function of the non-oceanic Ca^{++} fraction for the various lakes surveyed. Points are summer means. The value for the Mersey River water at the Mersey hatchery is included for comparison as it is a watershed considered to be acid stressed.

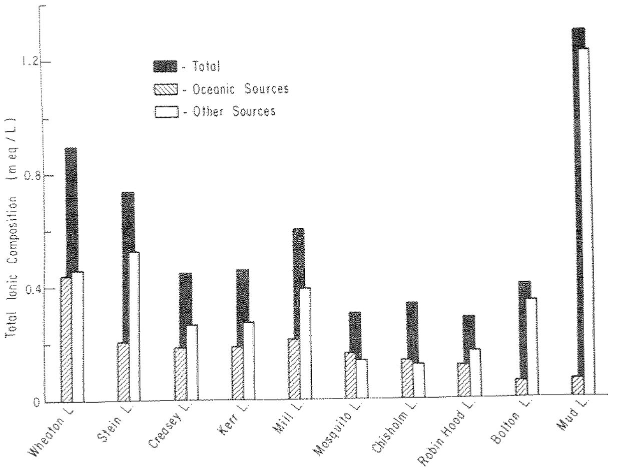

Fig. 26. The ionic composition of the lakes surveyed, as derived from oceanic sources, from other sources, and total composition (sum of the previous two). Lakes are ordered so that distance from the coast increases as one progresses from left to right.

APPENDIX I

Dissolved nitrogen (NO_3^- and NO_2^-) concentrations (μg/L) in surface water samples from the various lakes

Lake	May	June	July	Aug.	Sept.	Late Sept.
Mud	-	400	10	<10	<10	<10
Bolton	-	150	30	<10	<10	<10
Chisholm	50	<10	40	<10	<10	<10
Robin Hood	-	<10	10	<10	<10	<10
Mosquito	100	<10	10	<10	<10	<10
Creasey	80	<10	50	<10	<10	<10
Kerr	30	10	60	<10	<10	<10
Mill	50	1400	10	200	<10	<10
Stein	<10	<10	10	20	<10	10
Wheaton	50	<10	10	<10	<10	<10

APPENDIX II

Phosphorus concentrations (μg/L) in surface water samples from the various lakes. * indicates not included in determination of means

Lake	May	June	July	Aug.	Sept.	Late Sept.	Mean
Mud	-	10	12	12	9	9	10
Bolton	-	11	11	4	8	7	8
Chisholm	1	11	16	14	74*	14	11
Robin Hood	-	5	-	1	2	3	3
Mosquito	<1	2	2	1	1	3	2
Creasey	<1	10	6	7	5	8	6
Kerr	<1	6	5	4	12	4	5
Mill	4	11	18	6	13	10	10
Stein	12	5	21	1	<1	4	7
Wheaton	1	9	6	10	11	13	8

APPENDIX III

Silica concentrations (mg/L) in surface water samples from the various lakes. Determinations were made on September samples only

Lake	Sept.	Late Sept.
Mud	1.0	0.1
Bolton	0.9	1.1
Chisholm	0.1	0.1
Robin Hood	1.3	1.4
Mosquito	0.2	0.1
Creasey	1.6	1.5
Kerr	1.4	1.2
Mill	1.3	1.6
Stein	1.1	1.4
Wheaton	0.7	0.2