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ISLE ROYALE NATIONAL PARK

1984

ECOSYSTEM RESPONSE TO ATMOSPHERIC DEPOSITION

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EFFECTS OF ATMOSPHERIC ACID DEPOSITION
ON WATERSHED/LAKE ECOSYSTEMS OF ISLE ROYALE
AND MICHIGAN'S UPPER PENINSULA

Robert Stottlemeyer
Department of Biological Sciences
Michigan Technological University
Houghton, MI 49931

1984 PROGRESS REPORT
(GLARSU Report #9)

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Contributors were

Darcy Rutkowski
David Hanson, Jr.
Charlene Friesen
Mike Larson

HANSON

INTRODUCTION

There are five major objectives within the National Acid Precipitation Assessment Program (NAPAP) relating to the question of deposition effects on aquatic systems. Three of these relate to the ongoing study of Isle Royale and the Upper Peninsula of Michigan. They are as follows:

What is the extent of "sensitive" and "acidic" lakes, streams, groundwaters, and wetlands in the United States.

What factors control the susceptibility of surface and groundwaters to acidic deposition and how can these factors be used to predict future aquatic acidification or recovery under different deposition rates.

What are the relationships between surface water acidification and biological processes, biological populations, and aquatic communities, and how can these relationships be used to predict ecological changes.

In addition within NAPAP's Terrestrial Effects Program there are four additional major objectives of which three have a direct bearing on national parks, and are considered objectives for the ongoing Isle Royale/Upper Peninsula research. These are the following:

Does acidic deposition affect the structure and function of watersheds and the resulting outputs to aquatic systems.

Are soils affected by acidic deposition and, if so, what is the degree of current and expected damage.

Does acidic deposition affect forest productivity and, if so, what is the degree of current and expected damage.

In July 1984 Interior's broad obligations within NAPAP were outlined in a series of objectives. The National Park Service's obligation within Interior's program is to "conduct acid rain monitoring and research activities to develop a sound technical basis for management decisions on cultural resource and land and water management practices and for remedying adverse impacts of acid deposition on NPS resources," and "carry out research and meet deadlines as

established by appropriate Task Groups within the National Acid Precipitation Assessment Program."

To this end in February 1984 Project Descriptors were prepared for the four NPS watershed ecosystem effects studies underway. These study sites are located at Sequoia-Kings Canyon, Rocky Mountain, Olympic, and Isle Royale National Parks. The FY 1984 Deliverables for the Isle Royale/Upper Peninsula studies are as follows:

Snowpack dynamics and nutrient content in small watershed ecosystems of the Lake Superior Basin.

Input/output mineral nutrient budgets for moderately buffered and "sensitive" lake/watershed ecosystems.

Comparison of anion mobility in boreal forest and northern hardwood forests of Isle Royale National Park.

Primary productivity and standing crop in sensitive and less sensitive lakes, Isle Royale National Park and Michigan's Upper Peninsula.

This progress report, prepared during the fall of 1984, primarily addresses the above four topics. In addition, data are included regarding some of the complementing baseline studies such as forest biomass and its distribution among canopy layers. Also included are some of the aquatic survey data collected primarily during 1979-1980 which were used to select the sites picked in 1982 for more intensive watershed ecosystem effects research.

It should be mentioned perhaps that the intensive field season on Isle Royale is the period from June to early October, and much of the data collected this season just ended has not been sufficiently analyzed for presentation at this time. Thus a lot of the discussion regarding the data sets is just descriptive. Also the point is rapidly being reached in this study where the amount of data (2.5 years worth in most instances) is sufficient for meaningful integration and analyses. This too has not been properly executed in the following document, but it is one of the major objectives prior to release of the next progress report in the fall of 1985.

During 1984 some additional lake survey work was done on Isle Royale, in the Huron Mountains near the location of our most sensitive lake/watershed ecosystem, Trout Lake, and in

the vicinity of Pictured Rocks. Some of the results of this recent survey are included with the data collected in 1980 - 82 on Lake Superior basin lakes and streams (see section on Upper Peninsula Survey of Lake and Stream Sensitivity). Three permanent lakes (not under direct influence of beaver dams) were found having alkalinities under 100 eq. These are Theresa on Isle Royale, and two seepage lakes near Pictured Rocks National Lakeshore. All, however, are colored with measurements exceeding 35 platinum-cobalt units. Additional lakes such as Canyon near Trout Lake in the Huron Mountains and sites in the Kingston Plains area adjacent Pictured Rocks were found to have alkalinities between 100 - 200 μ eq. These too are highly colored.

We feel, based upon the extensive lake and stream surveys conducted principally from 1979 to 1981, that the three sites now being intensively studied are quite representative of lake/watersheds in this region which have surface stream water input and output during all or a significant portion of the year. Seepage lakes are not common in the central and western portions of Michigan's Upper Peninsula or on Isle Royale. Minerotrophic systems with perennial surface streams are the rule. Periodic beaver invasions are also the rule, and the resultant changes in organic debris within the aquatic system probably have a profound effect on stream water quality. This was the object of an earlier three-year stream study on Isle Royale, but the results have not yet been analyzed.

For the future a Scope of Work statement outlining the areas for emphasis during FY 1985 is currently being prepared. It will be completed by December. The emphasis now is shifting from the monitoring implementation stages and strategy to more process oriented studies.

PRELIMINARY INPUT/OUTPUT BUDGETS FOR SELECTED INORGANIC ION SPECIES

Site Descriptions

The two Isle Royale sites, Wallace Lake and Sumner Lake, have watersheds that are almost coterminous. The sites are located in the northeast section of the park adjacent Moskey Basin. They are vegetated by mature boreal forest (see next section "Vegetation Plot and Biomass Analyses"). The uniformity of the forest canopy varies somewhat due to old-growth dieback and replacement and winter blowdown. Preliminary vegetation maps have been prepared for the watersheds, and they suggest that the 1936 fire reached at least a small portion of the Wallace watershed. This has

been confirmed by other scientists who have established vegetation plots in the vicinity of the experimental watersheds (R. Janke, Dept. of Biological Sciences, Mich. Tech. University). There are no man-made facilities or disturbances on the ground in either watershed. A significant portion of lake water input comes from a perennial surface stream (Wallace l, Sumner l) in each watershed, with seasonal inputs coming from a number of small ephemeral surface streams. A perennial stream drains each lake. A fraction of the Sumner l perennial stream input into Sumner Lake is from Newt Lake, a small lake with no perennial surface stream inputs.

A considerable portion of all watersheds is exposed precambrian metamorphosed volcanics which have been glaciated. Soils are predominantly glacial till and alluvial deposits of highly variable quality and quantity (see following section "Anion Mobility in Forest Soils" for detailed descriptions).

Trout Lake watershed has been selected as a replacement for the Central watershed. The latter site is located on the Keweenaw Peninsula, and is a sensitive (mean alkalinity about 100 μ eq) system with perennial surface stream water inputs and outputs. Unfortunately, the site is not protected and after collection of one year's data it was significantly altered by a heavy timber cut. This forced the selection of another site of similar sensitivity to complement the Isle Royale sites. Trout Lake, an undisturbed lake/watershed ecosystem located in the Huron Mountains of Michigan's Upper Peninsula, was selected in the summer of 1983 as the replacement. It is protected by inclusion as part of the private Huron Mountain Club. It is vegetated primarily by a mature forest with more northern hardwood components. Lake alkalinity averages less than 200 eq thus it complements the Isle Royale sites and helps round out the spectrum of sites studied. It also provides the opportunity to compare a boreal forested ecosystem (Isle Royale) to a northern hardwood system. Like its Isle Royale counterparts considerable portions of the Trout Lake watershed are exposed glaciated bedrock, in this case early precambrian metamorphosed granite (Canadian Shield). Surface streams provide much lake input, but flow very little if at all during summer months. Lake surface outflow is perennial, but during late summer the flow rate is such that it seeps beneath the till short distances before re-emerging above the outflow stream gaging station.

Differences in lake and stream water chemistry among these three lake/watershed ecosystems is thought to be primarily

due to differences in quality of glacial till, but variation in hydrologic conditions could also be an important factor. The cause of observed differences is the subject of ongoing research.

Methods

Precipitation chemistry has been monitored since May 1979 using bulk collectors on the southwest end of Isle Royale. This monitoring station continues to operate supplemented by a NADP station operated for six months during the summer. Bulk precipitation chemistry has been monitored in the immediate vicinity of Wallace Lake also since May 1979. A complete data set was not, unfortunately, obtained at this site during 1980. During 1982 an Aerochem Metrics event collector was operated at Wallace paired with a bulk collector for comparison purposes. At present bulk collection continues in the watershed. Due to the proximity of the Sumner lake/watershed ecosystem and its similarity in elevation precipitation is not monitored in this watershed.

Samples are collected weekly during the time of island occupancy, and less frequently during the period November to April. Continuous Belfort collectors and hygrothermographs are operated at both Wallace and Windigo all year, and these reveal that the vast majority of precipitation falling in bulk collectors during the "off season" is snowfall. The less frequent winter sampling protocol therefore probably does little to effect precipitation sample quality. The instruments at the Wallace site serve as a backup to an Campbell remote area weather station which has been in operation since summer 1984. A continuous recording rain gage and hygrothermograph along with a bulk precipitation collector are also maintained at the Trout Lake site. Sampling intensity averages every two weeks which is also the winter schedule. Meteorological instruments are being individually automated at this site beginning this winter.

Lake input streams and outflow streams are all equipped with Stevens digital recording stage height recorders. All lake outflow stations are presently equipped with Stevens recording thermographs which we hope to replace with thermistors and dataloggers this year. On a seasonal basis lake outflow stations are equipped with Industrial Instruments recording pH meters. All Isle Royale stations are sampled every Tuesday while the island is occupied. Manning autosamplers are used at lake outflow stations during November and April. Due to access problems and cold weather the period December through March is sampled on a periodic basis only.

For each field sample instantaneous discharge is noted from stake heights in the Parshall flumes, and stream temperature and time recorded. Samples are collected in 500 ml amber polyethylene bottles. Specific conductance, pH, alkalinity, color, and on occasion NH_3 are determined at the Boreal Research Station as soon as the samples assume room temperature. Presently all field data are directly entered into microcomputer files maintained on Isle Royale or at MTU. A subsample of water is filtered through a 0.45 micron filter, and 60 mls retained for laboratory chemical analyses. This sample is refrigerated and sent to the lab at MTU. Inorganic cations and anions are determined on an automated ion chromatograph, and the results fed into a laboratory microcomputer with an additional file maintained on the University's mainframe. A selected sample subset is ran for SiO_2 using colorimetric methods.

Results for 1984

H^+ ion continues to dominate the cationic strength of precipitation (weighted mean pH is 4.5 - 4.6 depending on whether bulk or w/d sampler). In the five years of sampling no significant trend has been observed at Windigo, the site of longest continuous precipitation quality record probably in northern Michigan. Estimates of weighted mean precipitation concentrations for selected ionic species during FY 1984 are as follows:

Ion	mg/l
Ca	0.28
K	0.18
NO_3	0.97
SO_4	1.37

Map/Slide
1.5 mg/l
2.1 mg/l

Converting these preliminary values into input (kg/ha) we have the following values for FY 1984.

Ca	2.80
K	1.80
NO_3	9.80
SO_4	13.70

The mean concentration of Ca and K increased over that observed in 1982-83 (see 1983 progress report), but NO_3 and SO_4 concentrations decreased. The mean annual input values⁴ (kg/ha) for Wallace and Sumner for the June 1982 - August 1984 period are as follows:

Ca	2.49
K	1.39
NO ₃	14.24
SO ₄	22.10

Figs. 3 - 11 show in detail the annual cycles of precipitation quality for the bulk collectors at Windigo and Wallace on Isle Royale, and for comparison purposes the NADP/NTN station operated at MTU. Data are only shown for the period of this study. These figures warrant some description and discussion. Data from Trout Lake suggest little difference in precipitation quality, but some anticipated increase in quantity due to its location relative to Lake Superior. Since we only have one year's data for this site the data are not presented or discussed at this time.

Discussion

The monthly distribution of precipitation for most of the study period is shown in Fig. 2 for the NADP station at MTU. This is quite representative for the study sites. The high monthly inputs for fall 1983 are atypical, and account for the high stream runoff relative to precipitation input seen in Fig. 1. Precipitation inputs for the water year (October to October) 1984 come to 100cm which is about 42% above the long-term average of 70cm on Isle Royale. Note also in Fig. 2 the record dry period during April which accounted for the very high sublimation of the snowpack. This minimized the increase in spring stream discharge for 1984.

Figs. 3 - 6 show a mean "floating point" plot of major precipitation ionic species for the period of study. These values are not weighted by precipitation amount. Plots of the individual sample values are shown in Appendix A. Values for Ca and K in bulk collectors are typically higher than for the event NADP collector. With but one exception concentrations tend to be quite high during late spring, early summer, and late summer. This is due probably to a combination of high winds and seasonal land use practices to the west of this region. Supporting this hypothesis is the fact our values for Ca for even bulk collectors tend to be less than those observed due west in north central Minnesota (Verry 1983). In general weighted concentrations of major cations tend to be about 40% higher in rainfall than in snow. Mean K values for our NADP station compare favorably with those generally observed in Minnesota. Our weighted mean values for Ca in all collectors is several orders of magnitude greater than the long-term weighted mean for

Fig. 1

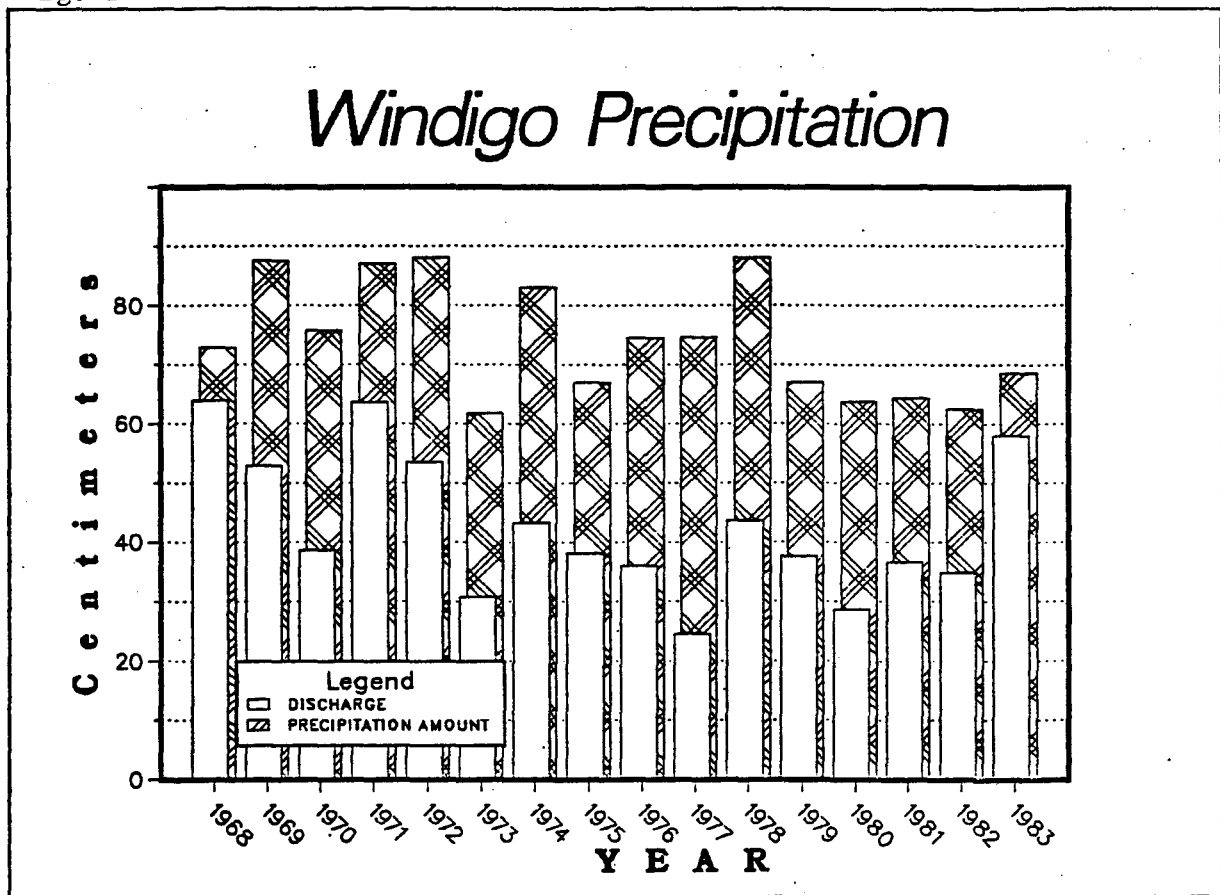


Fig. 2.

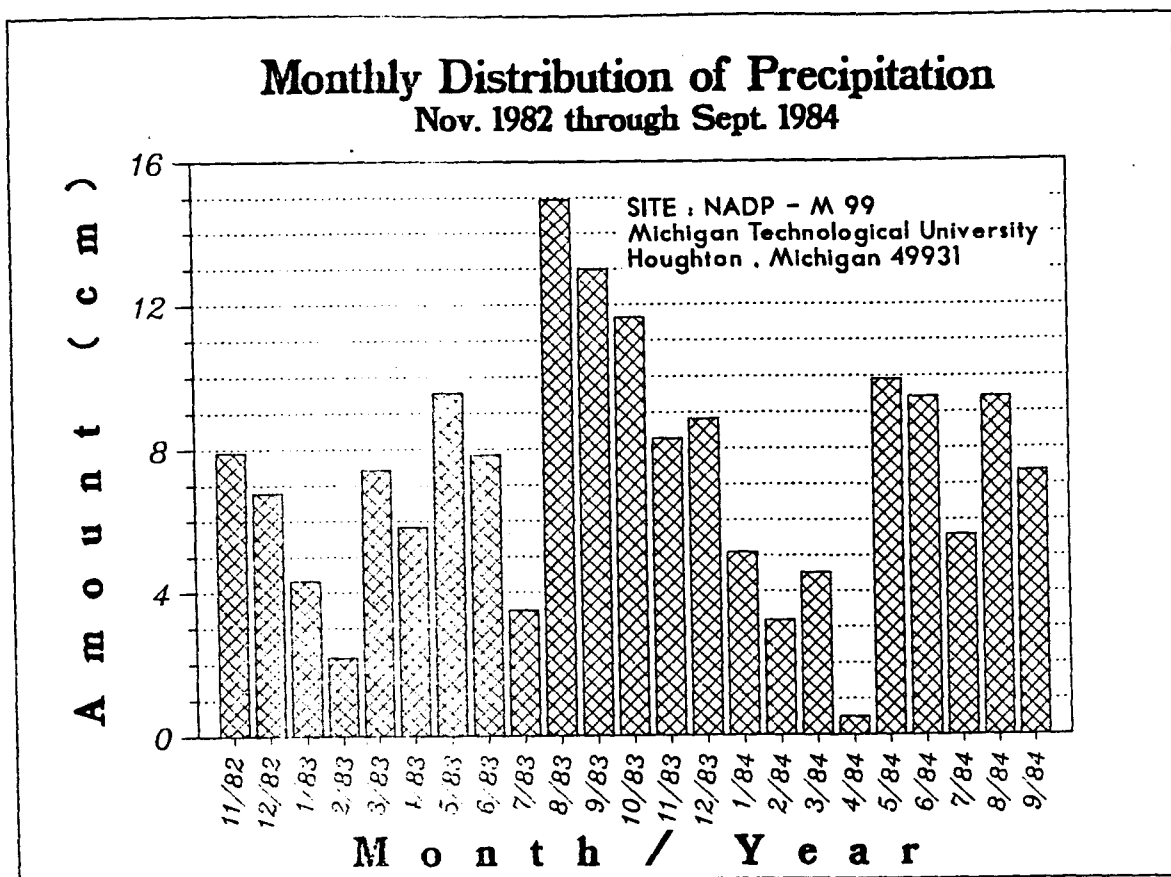


Fig. 3.

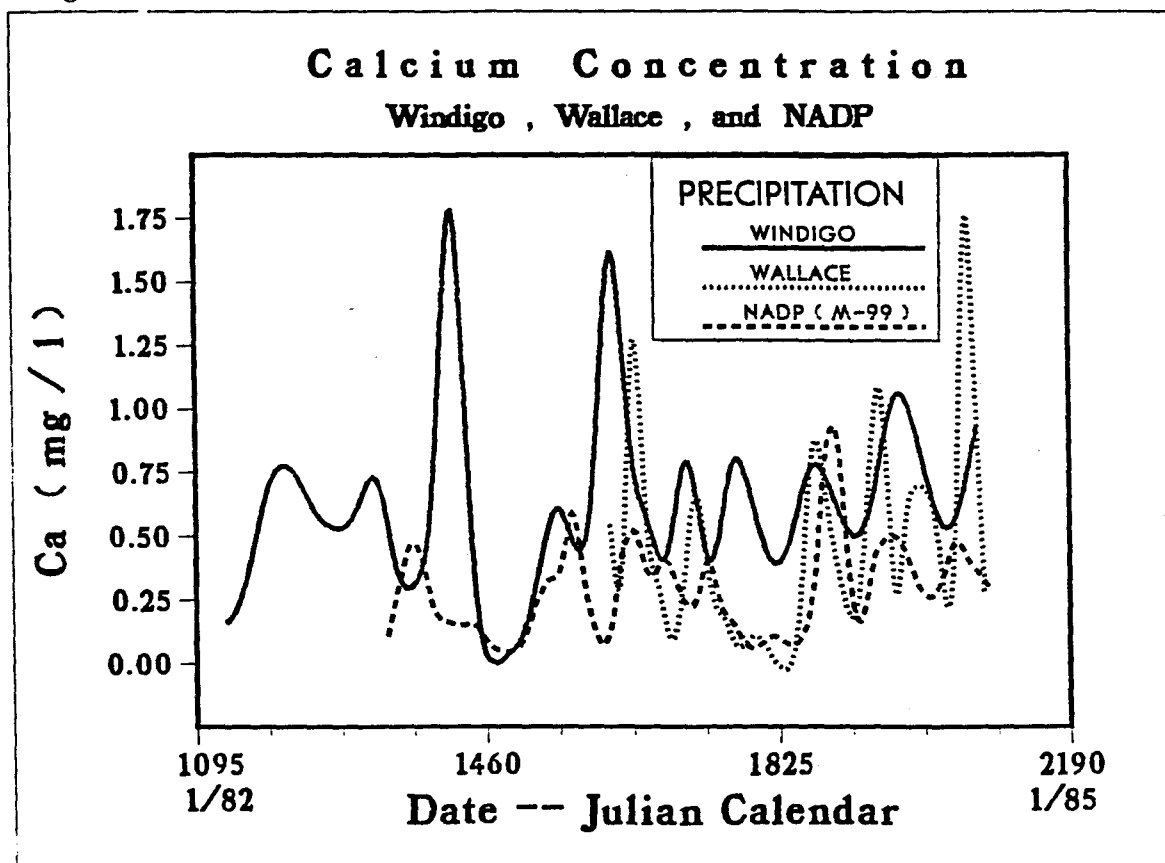


Fig. 4.

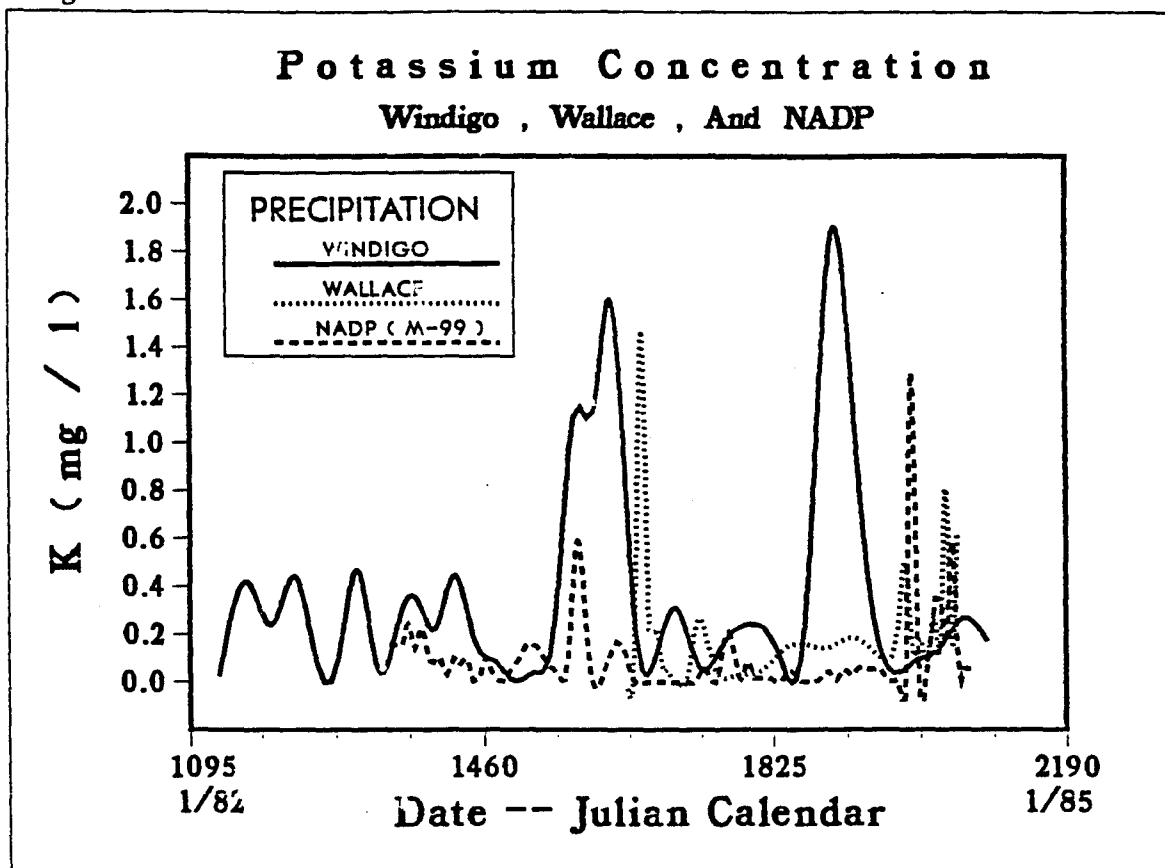


Fig. 5.

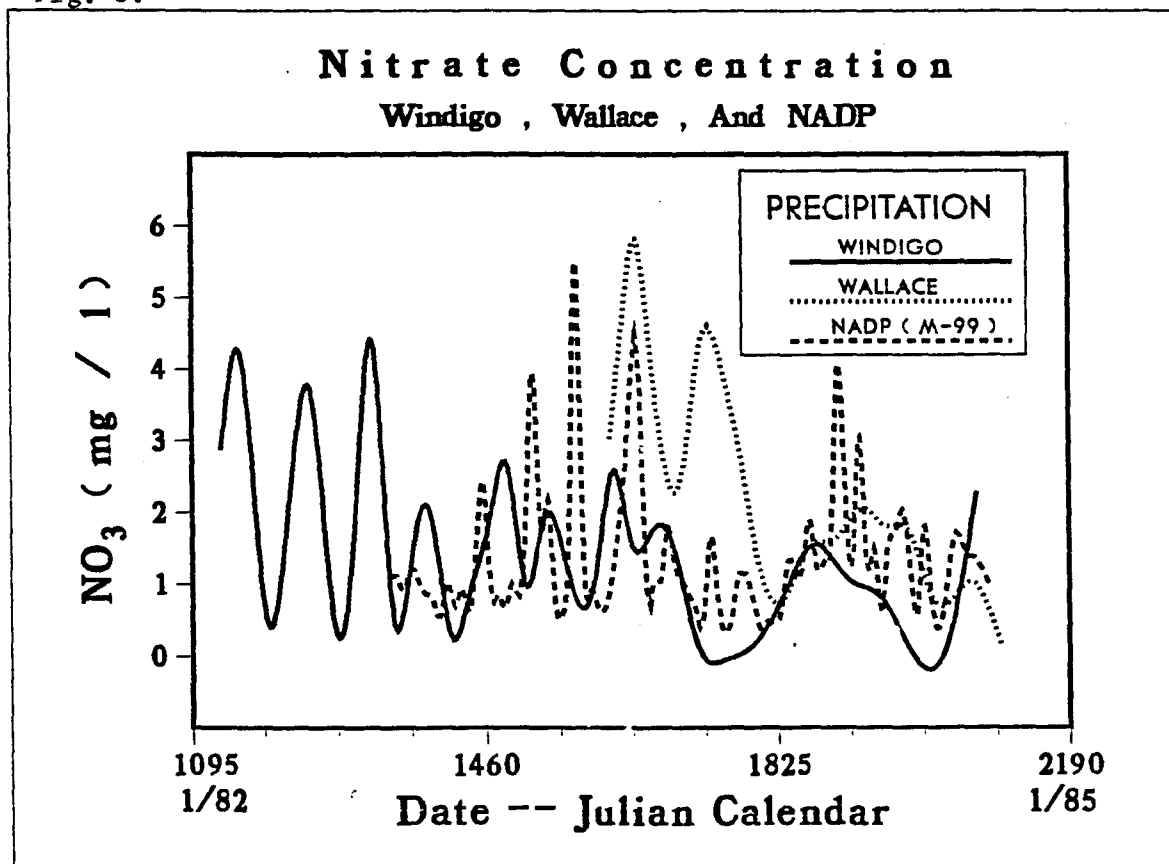


Fig. 6.

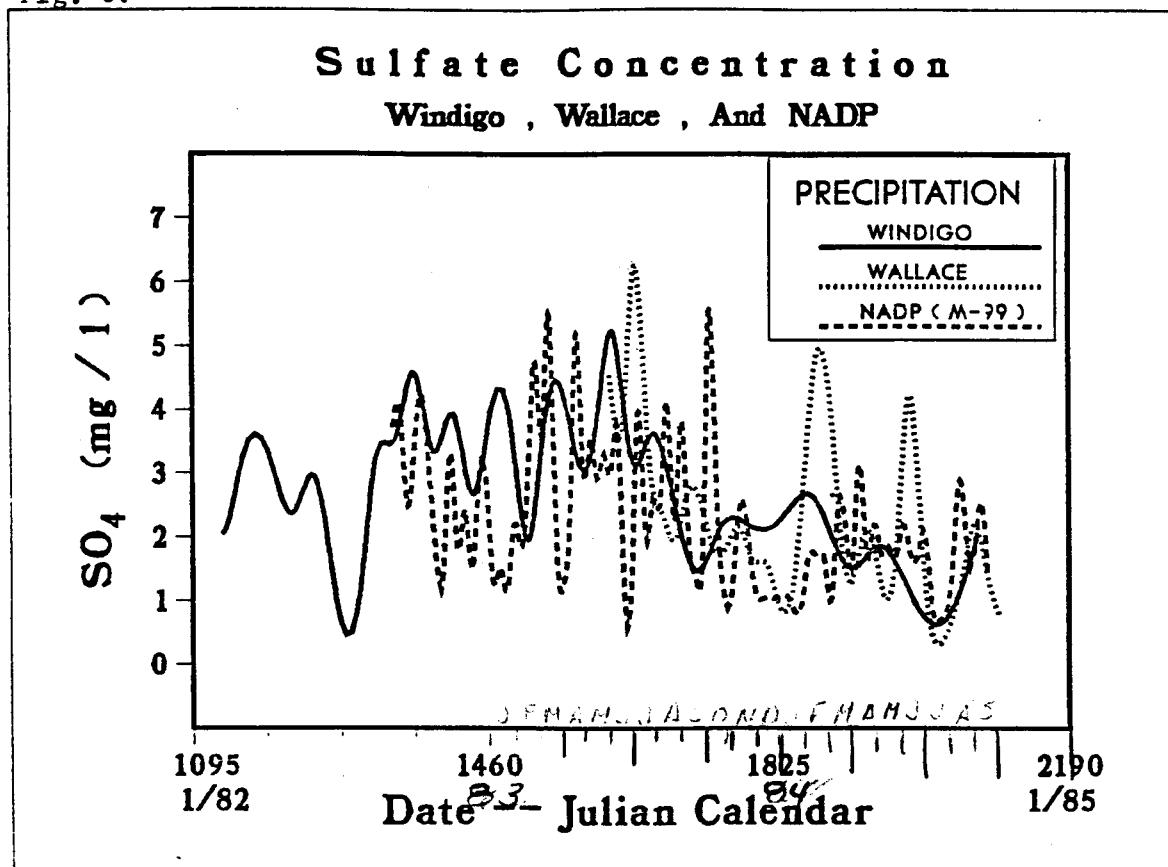


Fig. 7.

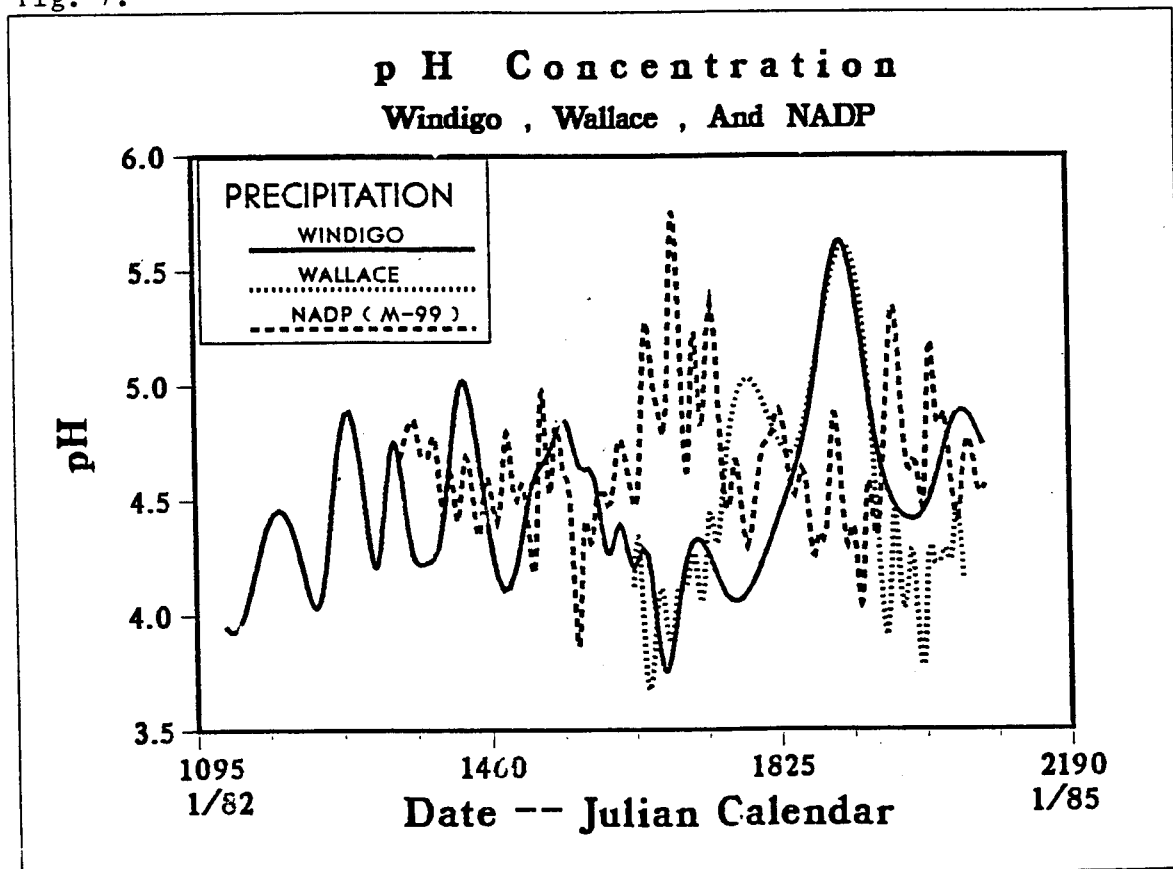


Fig. 8.

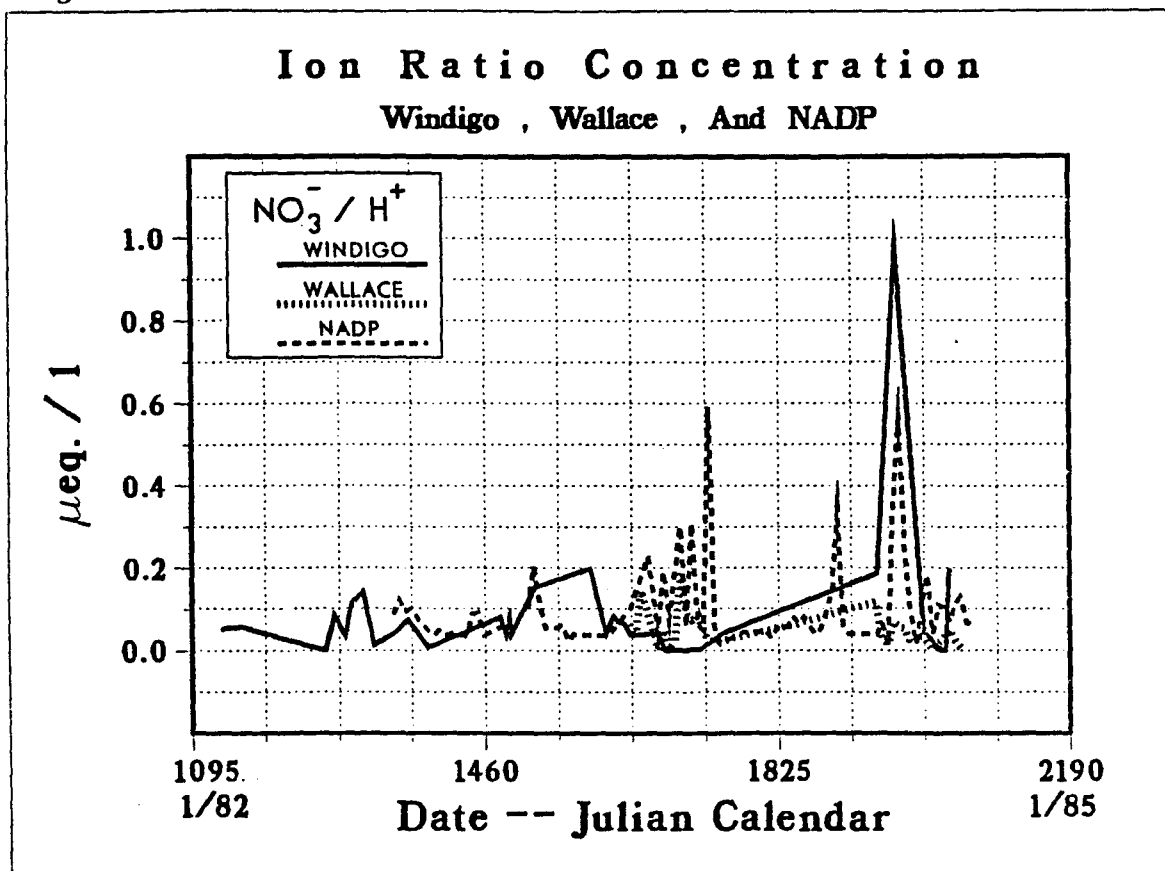


Fig. 9.

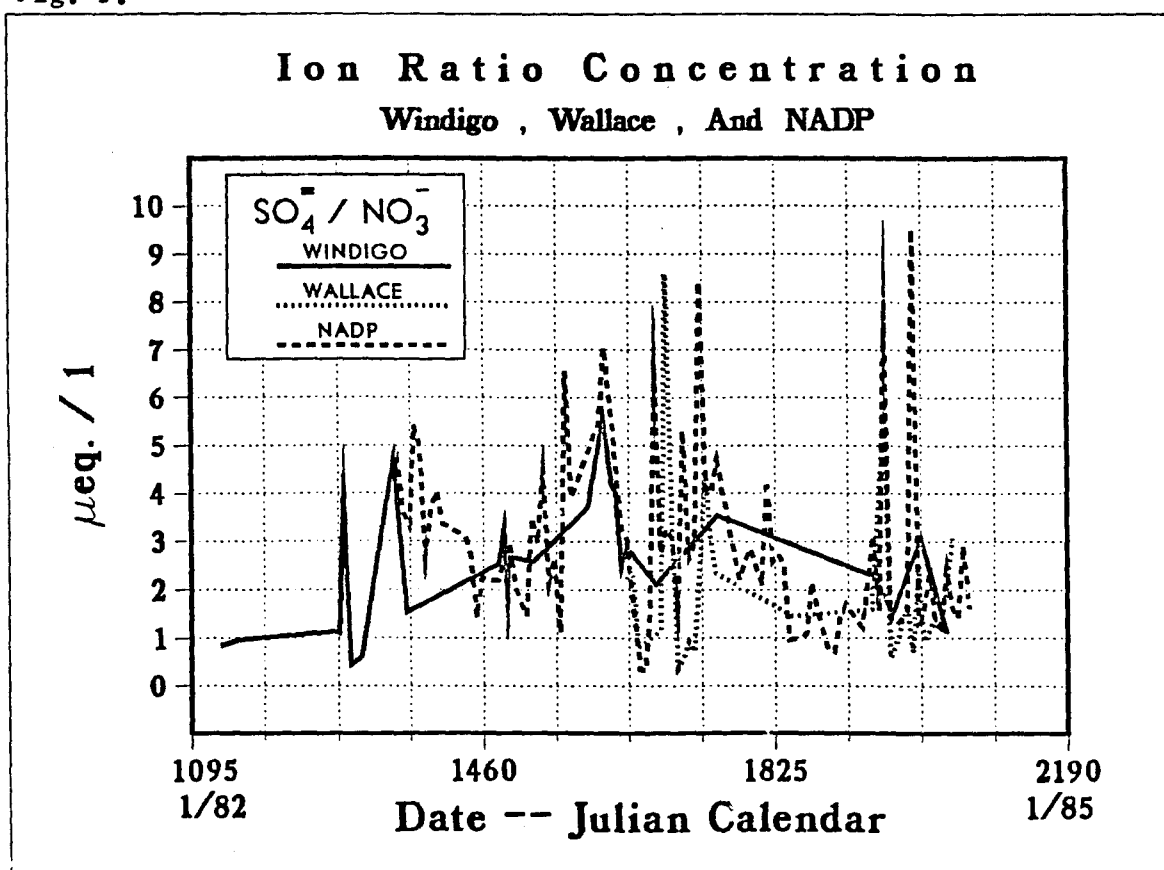


Fig. 10.

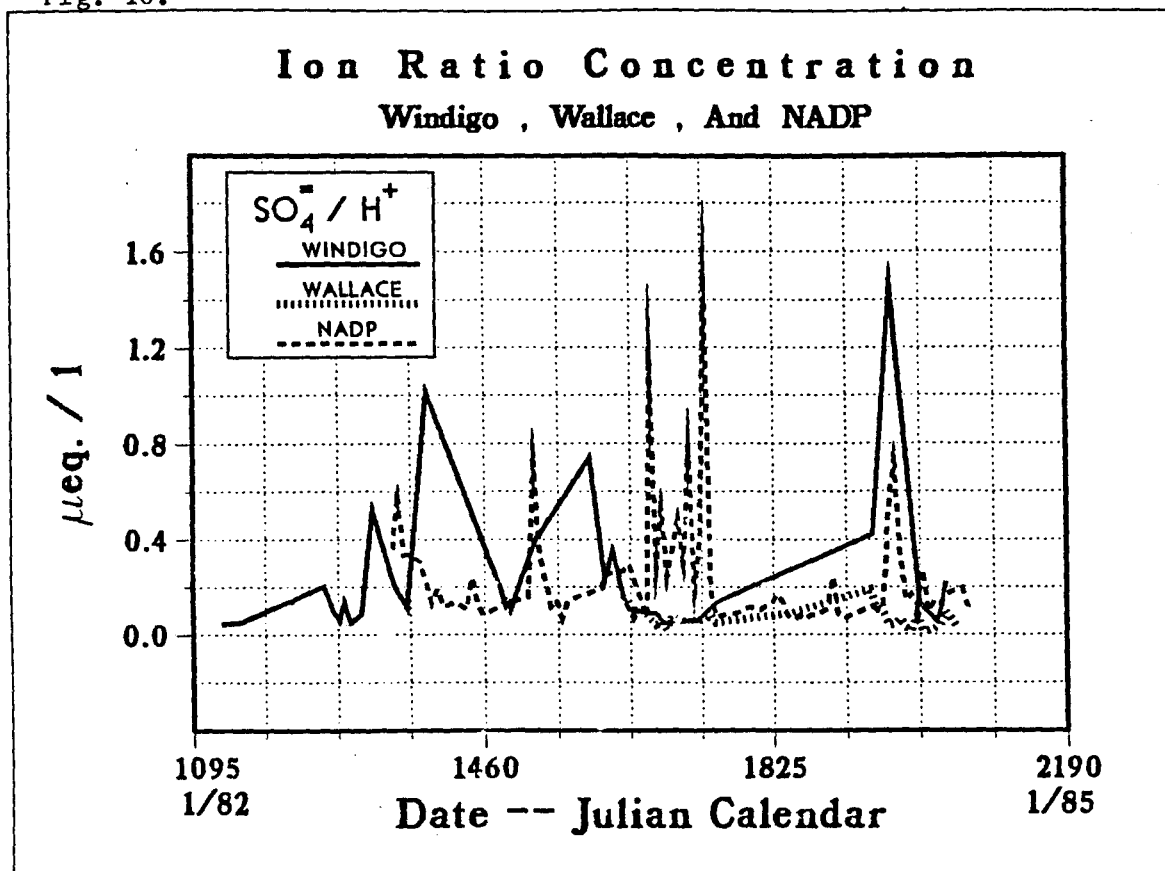
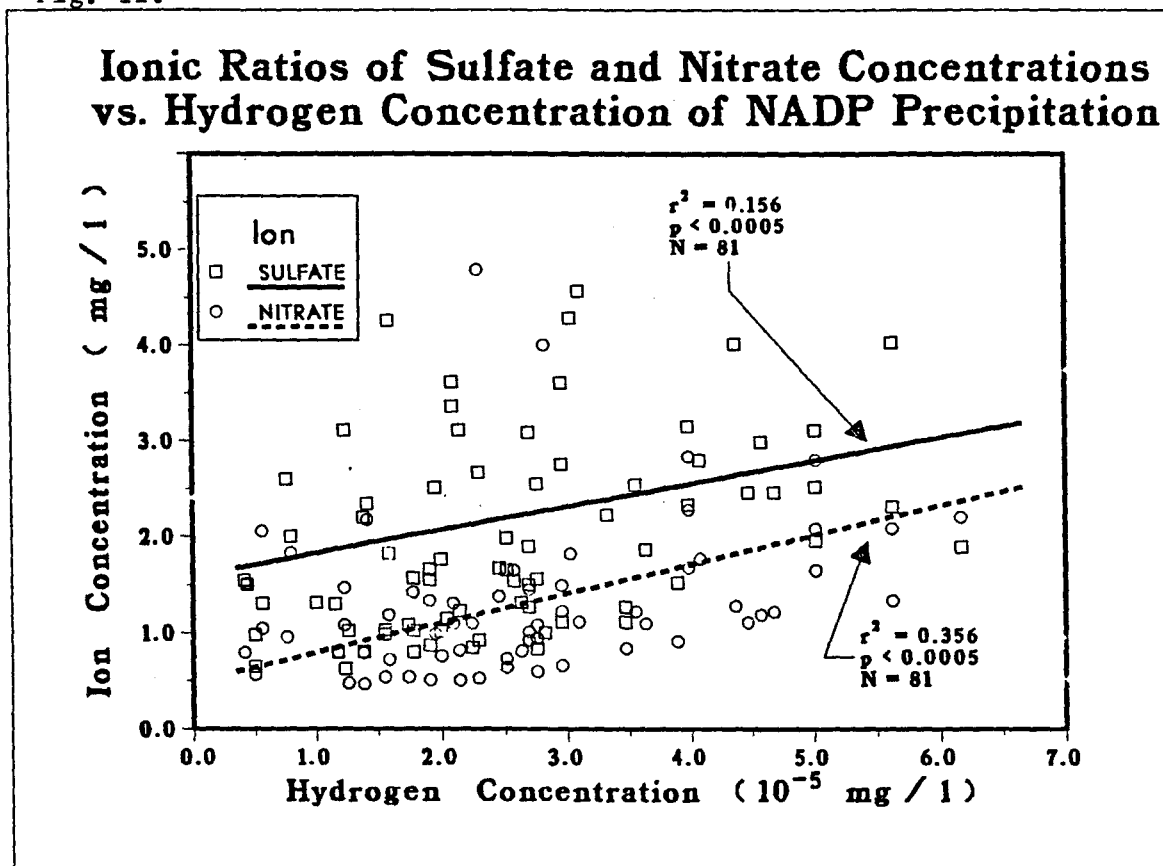


Fig. 11.



Hubbard Brook. Conversely, our weighted values for K are quite similar to the long-term Hubbard Brook record (Likens et. al. 1977).

Trends in NO_3 and SO_4 are much more difficult to discern (Figs. 5-6). The complete record for Wallace was inadvertently left out in these plots. NO_3 in particular is extremely variable with bulk collectors often showing values at or below those found in the event NADP collector. To date our NO_3 values are somewhat below the weighted mean found in Minnesota in recent years, but are comparable to the long-term average for Hubbard Brook. With the possible exception of the summer of 1983 seasonal trends in NO_3 concentration are not very apparent. On the other hand SO_4 does show a more pronounced seasonal trend at least relative to NO_3 , and the sulfate/nitrate ratio clearly demonstrates this seasonal variation (Fig. 10). This appears in all three collectors, but clearly is most pronounced in the NADP collector. Weighted SO_4 values are nearly identical to recent data from Minnesota, but are at least one-third less than the long-term record at Hubbard Brook. To better insure comparison of results it should be mentioned that we split all samples collected in NADP M-99 and run through our chemical analyses.

pH values for the three stations show an interesting dichotomy with the levels dipping at both Isle Royale stations during the summer of 1983 but rising at the NADP site on Lake Superior's south shore (Fig. 7). The opposite is true for the winter period of 1984. This could be the influence of some potential point sources in the Thunder Bay area just to the northwest of the eastern portions of Isle Royale. On an equivalent basis both NO_3 and SO_4 increase relative to H^+ during the summer months (Figs. 8 - 9). The correlation of H^+ to both NO_3 and SO_4 is poor (Fig. 11) for the NADP site. This appears to be the rule nationally for almost all NADP sites. The correlations between H^+ and SO_4 is especially low.

This is a rather shallow interpretation of the precipitation data. However, since the record is rather short there is perhaps not too much value in a detailed assessment at this time.

As for stream discharge the inorganic outputs from the coterminous Wallace and Sumner Lake watershed ecosystems on Isle Royale, which are on identical bedrock formations, appear to reflect watershed edaphic differences. Selected ionic outputs (kg/ha) for these two lakes from October 1983 to September 1984 are as follows:

Wallace

Ion	Kg/Ha
Ca	101.9
K	3.1
NO ₃	1.2
SO ₄	23.4

Sumner

Ca	84.3
K	1.5
NO ₃	0.3
SO ₄	21.1

The most striking differences between these two lake/watershed systems are the outputs of Ca and NO₃. Mg values for Sumner are also significantly higher than for Wallace. To date the only explanation for this must be edaphic conditions (see section on Anion Mobility and Forest Soils). Ionic outputs from Wallace reflect the changes in input this year, but Sumner appears less responsive for outputs of Ca and NO₃. Ca output from Wallace exceeds input by almost 40x, and output from Sumner exceeds input by 34x, a shift for the two watersheds from 1983. K output exceeds input for Wallace by an order of magnitude, while output approximately equals input for Sumner. NO₃ output from both systems is much reduced over inputs which is typical for Upper Midwest systems it appears. Wallace output was only 12% of input and Sumner was only 3%. The Wallace drainage has a much higher frequency of *Alnus* in it which could account for the higher NO₃ release, but data on stream input into the lake must be looked at first before this assumption can be substantiated. In general, these outputs of NO₃ are much lower than those observed in other streams on Isle Royale and in the Upper Peninsula and elsewhere. But the lakes incorporated in these systems are very shallow (see following section) and are ideal places for high biological incorporation of this often limiting nutrient.

SO₄ output from both watersheds is quite similar. Output of this anion exceeded input this year by about 1.6x. These values are quite comparable to those observed for streams in this region which generally have a net loss ratio of about 1.4 - 1.5. However, the fact that SO₄ is on the whole leaving a lake/watershed system, even with watersheds that are completely vegetated, clearly keeps open the possibility

of this anion leaching essential cation species from upper forest soil horizons. How much of this output is coming from precipitation and how much from the decomposition of organic matter is not presently known. It is not thought that bedrock or till is a significant contributor. The average annual output (kg/ha) for the two watersheds for the period of study is as follows:

Wallace

Ion	Kg/Ha
Ca	93.5
K	2.1
NO ₃	1.6
SO ₄	25.4

Sumner

Ca	101.9
K	1.2
NO ₃	0.3
SO ₄	26.2

Values for Trout Lake have not been calculated yet. Figs. 17 - 22 show unweighted concentrations of selected cations and anions for the lake outflow stations in Wallace, Sumner, and Central watersheds. The latter watershed study had to be discontinued due to disturbance, but preliminary data analyses suggest that Trout Lake is similar to Central. As all three of the above watersheds have identical geologic substrates and quite similar vegetation, it appears that the concentration differences indicated in Figs. 17 - 22 probably reflect edaphic differences. Fig. 17 shows the pronounced increase in Ca with decreasing summer discharge. This is particularly evident for Sumner and to a much lesser extent for Wallace. On the other hand K (Fig. 18) shows much greater increases in Wallace during summer low flow. These differences are also evident in their respective annual discharges.

The high NO₃ levels in Wallace relative to Sumner are shown in Fig. 19. Of note are the high levels seen during winter in Central Lake. Again the relative concentrations are reflected in the annual discharge values for Sumner and Wallace. Comparing Fig. 20 with Fig. 22, we can see that the dominant anion in Central Lake is SO₄ while in Sumner and Wallace the dominant anion is HCO₃.

Fig. 17.

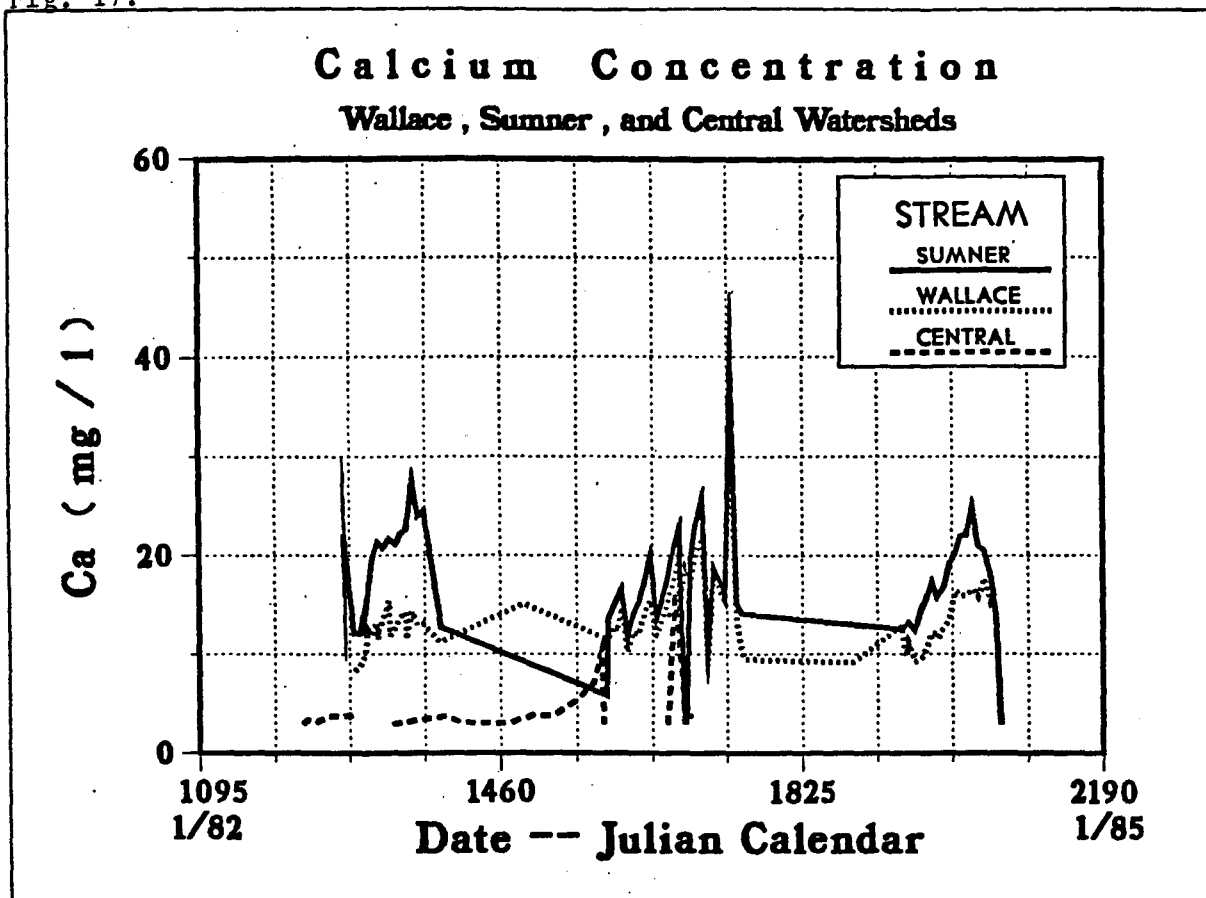


Fig. 18.

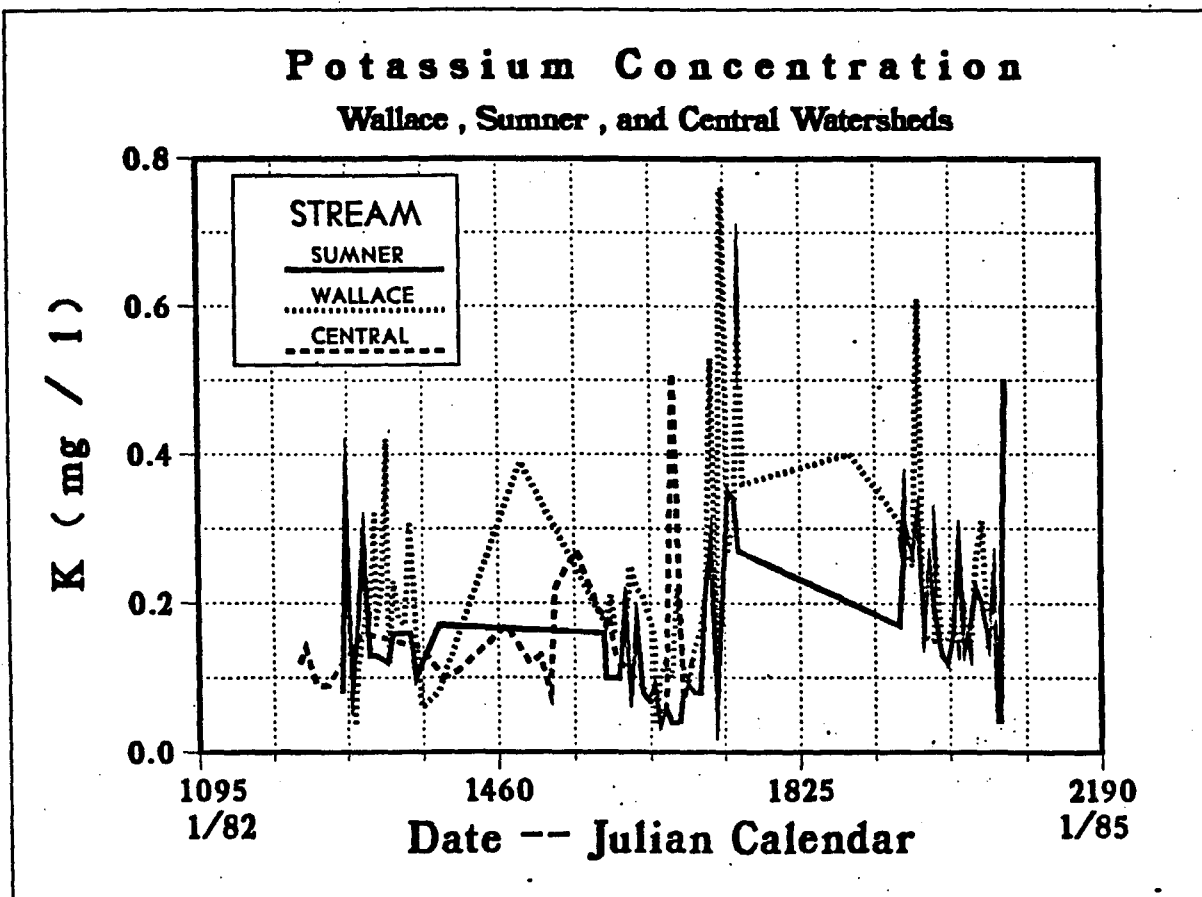


Fig. 19.

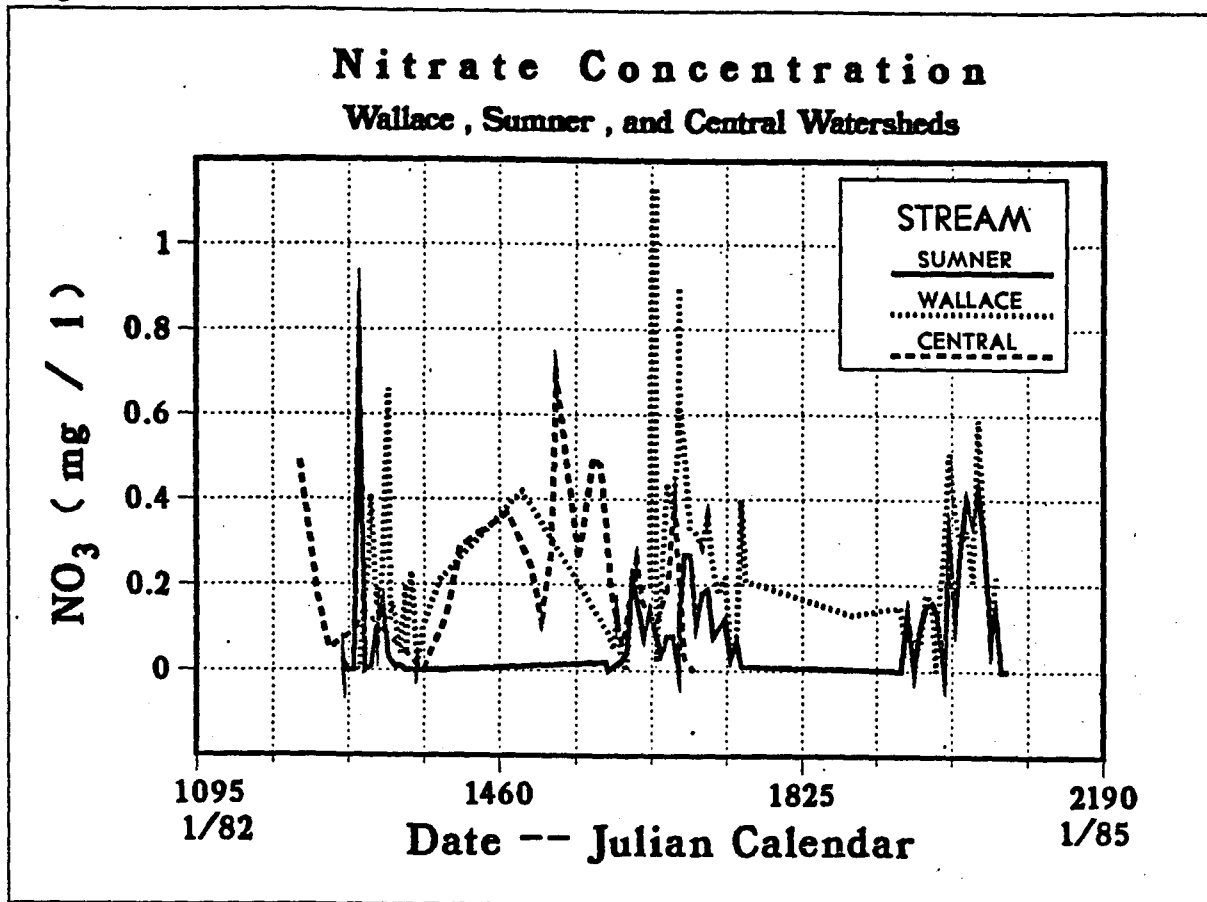


Fig. 20.

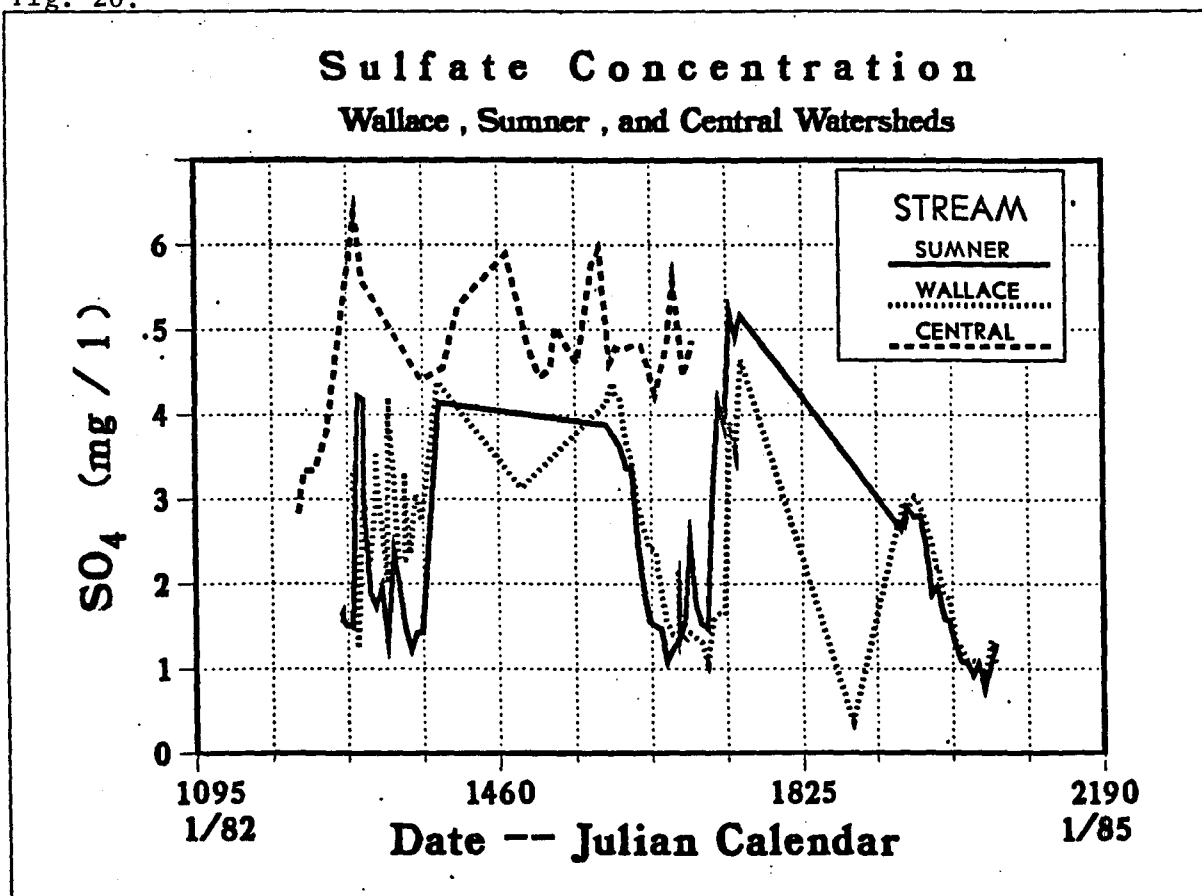


Fig. 21.

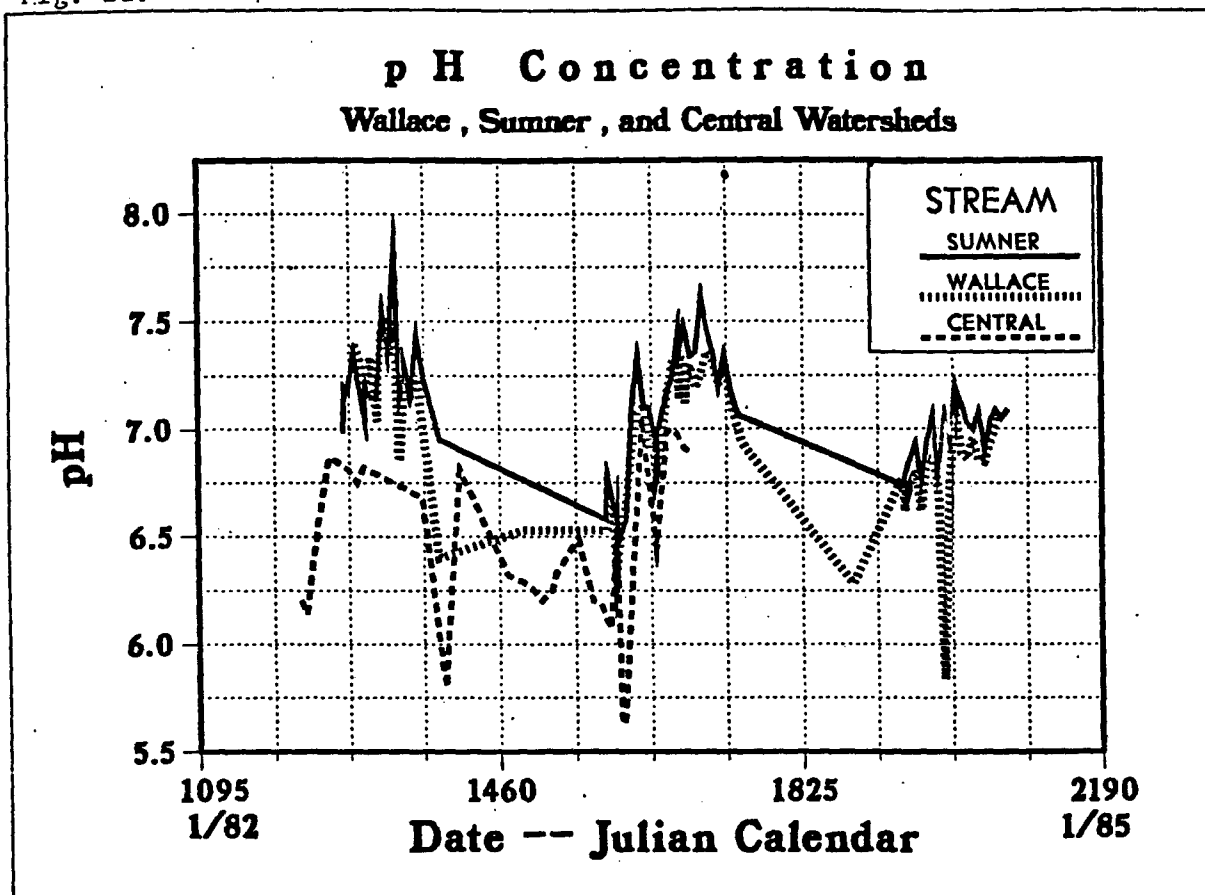


Fig. 22.

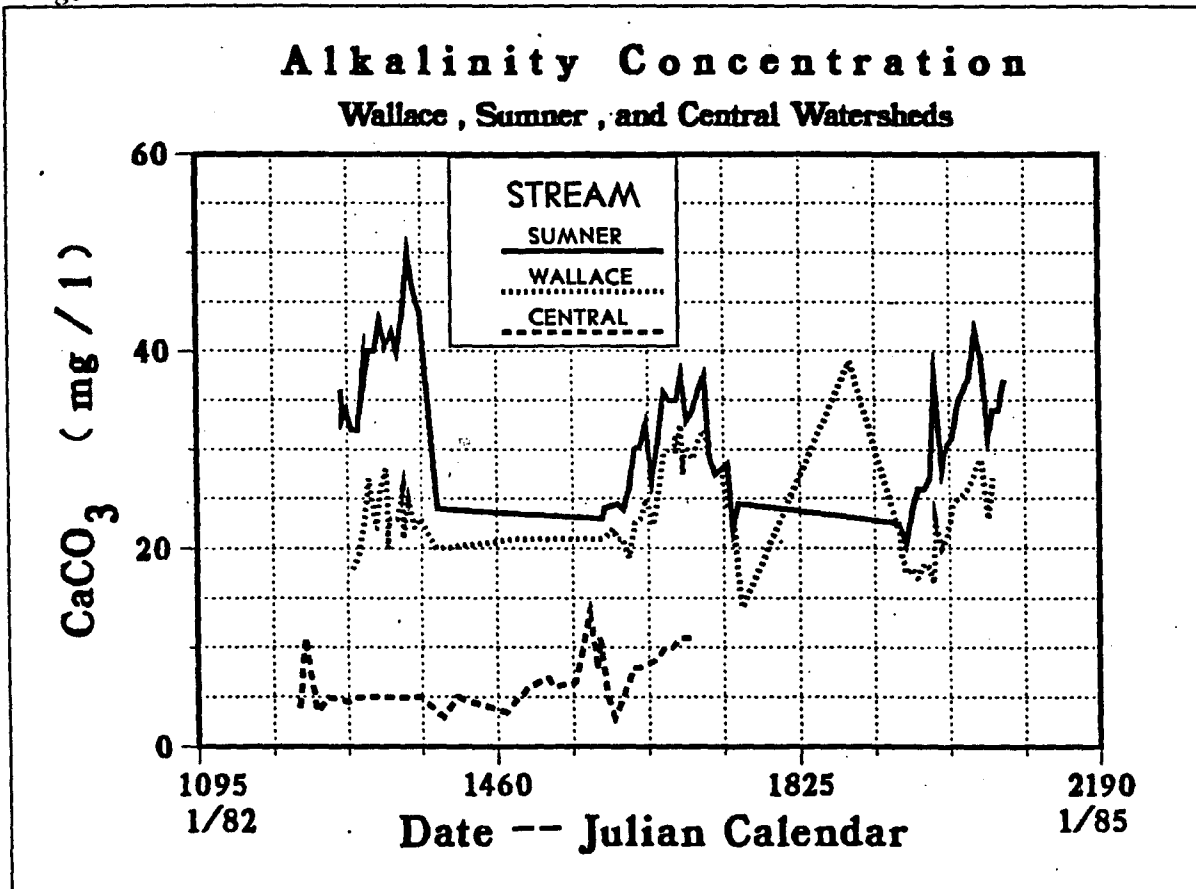


Fig. 21 shows the occurrence of spring decline in pH levels during periods of snowpack runoff. However, a similar trend is not common among all watersheds. Clearly the more sensitive Central Lake showed the most spectacular declines. Note also the occasional decline in pH associated with major precipitation events in the fall of the year. However, it must also be noted that all these systems are brown water drainages.

An additional note might be mentioned here regarding the relationship between ion concentration and stream discharge. The only long-term discharge record available in this region is the USGS Hydrologic Benchmark Station located at the mouth of Washington Creek on Isle Royale. A plot of precipitation input and stream output reveals considerable year to year variation (Fig. 1). For example, in 1983, a year with major events occurring during the latter portion of the water year (see Fig. 2) stream discharge was 82% of input. Conversely, in 1977, a year of almost equal total precipitation input, stream discharge was only 22% of input. This is in some contrast to watersheds such as at Hubbard Brook where year-to-year variations of input and output certainly do occur, but the absolute difference between input and output is quite similar (p. 18, Likens et. al. 1977).

There have been numerous attempts made to use the long-term chemistry record of these USGS stations to see how they might reflect past pollutant emission patterns. We have done a detailed analysis of the USGS's long-term chemistry record for Washington Creek and find that the relationship between input and discharge varies so much that it could mask other trends (Stottlemeyer 1984). For example we have found that a given ion species can vary considerably in its concentration relative to stream discharge. Unfortunately, for some species of interest this relationship is not at all consistent from year to year. Also regressions indicate that the slope of ion concentration versus discharge is generally steeper during years of low total stream discharge. In addition, the long-term decline in precipitation for a site such as Washington Creek probably has resulted in a long-term increase in the concentration of many ion species. However, the response among species varies considerably.

VEGETATION PLOT AND BIOMASS ANALYSES

Introduction

Fire has been an important factor in the history of Isle Royale. Prior to acquisition of the island by the National Park Service during the 1930's, mining was of economic importance and the burning of large tracts of forest to expose mineral deposits was not an unusual event in the mid and late 1800's. Since park establishment the only fire of some significance was the catastrophic fire of 1936 that burned approximately one-third of the island (Linn, Sumner and Sprugel, 1966). As a result of this fire history a great portion of the vegetation of Isle Royale is a mosaic of seral stands in varying successional stages.

Classical botanical research took place on the island in the early part of this century (Cooper 1911, 1912, 1913; Adams, 1909) but was primarily taxonomically oriented. More recently studies have been completed concerning the flora and vegetational ecology of the boreal forest regions of the island (Janke, 1977-1983) and the variation in herbivore pressure on vegetation types for much of Isle Royale (Janke, 1976; Krefting, 1974; Peterson, 1977). However, there are little if any data on productivity and biomass of either aquatic or terrestrial systems on the island.

The objectives of this study are twofold: characterize the vegetational composition and phytosociology of the three experimental watersheds; and quantify and compare the aboveground standing biomass and nutrient content of the tree, shrub/tall herb, and herbaceous vascular plant strata of the watersheds. These findings will be further utilized in the establishment of nutrient budgets for the two watersheds in the future.

Study Area

Isle Royale lies within the vegetational transition zone between the northern boreal forest found on the north shore of Lake Superior and the eastern deciduous forest which predominates up to the south shore of Lake Superior (Braun, 1950; Shelford, 1963; Larsen, 1980). Two major forest types characterize the island's vegetation: the boreal forest formation which is dominated by *Picea glauca* (Moench.) Voss and *Abies balsamea* (L.) Mill. and occurs primarily in proximity to Lake Superior; and the deciduous forest formation dominated by *Acer saccharum* Marsh and *Betula lutea* Michx. which is found in the inland-upland areas

where lake influence is diminished. Linn (1957) has extensively studied the transition zone between the two climax types.

The Sumner and Wallace lake/watershed ecosystems are 159.1 ha and 170.2 ha in area respectively. These watersheds are a mixture of birch, aspen and spruce-fir. A portion of the Wallace Lake watershed burned in the fire of 1936. There is no evidence of fire in the last 125 years for the remainder of the Wallace Lake or Sumner watersheds. Both have middle precambrian metamorphosed volcanic substrates which are thought to be slightly less sensitive than the underlying early precambrian granites which dominate the surface features of the Canadian Shield (NADP, 1982). The geology of the island has been documented by Huber (1975). Annual precipitation input to Isle Royale (76 cm) exceeds that of the north shore of Lake Superior (68 cm) but is much less than that which falls on the south shore (88 cm) at an equivalent elevation. Based on climactic data collected for several decades it appears that Isle Royale is more similar to the north shore of Lake Superior than the south shore, but the lake still dominates the climate of the region when one examines regional temperature and precipitation regimes.

Trout Lake is located in the Huron Mountains. The forests of this undisturbed watershed are part of the Hemlock-White Pine-Northern Hardwoods formation of the Deciduous forest (Braun, 1950). In fact, as Braun notes, this is one of the few remaining examples of virgin deciduous forest in the region. This particular forest formation extends across the north from Minnesota to the Atlantic coast and is characterized by the alternation of coniferous and deciduous communities or mixed forest communities. Climax forests of this formation are dominated by sugar maple, beech, basswood, yellow birch, hemlock and white pine. Braun (1950) further divides the Hemlock-White Pine-Northern Hardwoods formation into 4 sections. The divisions are a result of variations in species composition within the formation due to species reaching the limits of their geographic range. Trout Lake is included in the Superior Upland section as defined by Braun, which is characterized by the absence of beech which reaches its geographic range limit just to the southeast of the Huron Mountains (northern- and westernmost stand of this major hardwood component is but 30km to south). In our vegetation studies at Pictured Rocks National Lakeshore just 100 km. to the east beech is an important component in the climax; however, not a single beech tree was encountered in sampling at Trout Lake.

Methods

Vegetation sampling was undertaken in the Sumner Lake and Trout Lake watersheds with the establishment of two north-south transects in each watershed. The two transects divided each lake approximately in thirds. A stratified random sampling design was utilized to locate two tenth-hectare (50m x 20m) vegetation plots on each transect. Diameter at breast height (1.5m) was recorded for all tree species (dbh > 2.5cm) in the canopy and understory. Height of all trees was measured with a clinometer. Increment cores were obtained from all trees with a dbh greater than 7 cm in two 10m x 20m subplots in each 0.1ha plot. These tree cores were frozen to minimize decomposition and will be analyzed to determine tree age. Saplings (dbh < 2.5cm, height > 0.5m) were recorded as to species and height in a 2m x 5m subplot located in each of the four corners of the 0.1ha plot and the same was done for seedlings (tree species < 0.5m tall) in 1m x 1m subplots nested in the sapling plots. A 50m long transect was established in the center down the long axis of the plot along which five 1m² subplots were established at predetermined locations. Herbaceous vascular plant cover was estimated for each non-tree species < 0.5m in height in each of the five subplots. Coverage of taller herbs and shrubs all exceeding 0.5m in height was estimated in three 2m₂ x 2m subplots which were nested outside three of the five 1m² subplots. Current growth of shoots of herbs and shrubs was clipped and bagged by species for each plot. There was no attempt to identify grasses and sedges to genus and all species from the families Gramineae and Cyperaceae were lumped together in one category.

Dry weights were obtained to the nearest 0.01 grams for each species. The tissue samples were dried at 65 °C for 24 hours and ground in a Wiley Mill to pass a 60-mesh stainless steel sieve. The ground material was dried an additional 72 hours at 65°C, placed in plastic whirl-pac bags and stored at 2°C until a nutrient analysis can be completed for those species contributing significantly to the biomass of the watershed. To minimize contamination polyethylene gloves were worn for all sample collection and handling.

The aboveground standing biomass for trees in the two watersheds was estimated when possible using published equations for predicting biomass for the various species. These equations are listed in Appendix B. Data are being collected in the experimental watersheds to develop volume equations specific to Isle Royale.

Vegetation Chemical Analyses

Subsamples from all plant species were collected and are currently being analyzed. No results are yet available.

Samples of herbaceous tissue are assessed for Ca, Mg, Na, K, NH_4 , PO_4 , NO_3 , and SO_4 . Drying, grinding, and extracting procedures closely follow those outlined by Bormann and Likens (1970). Citrus leaves from the National Bureau of Standards are used as standards and for determining the efficiency of nutrient recovery when experimenting with different digestion and extraction methods. They are processed in an identical manner to the samples, and replicates are also ran. Samples are handled with plastic gloves and stored frozen in clean plastic bags. Glassware is washed in concentrated HNO_3 and rinsed with deionized water (conductivity $< 1.0 \mu\text{mhos}/\text{cm}^2$ at 20°). Polyethylene storage bottles are washed in dilute HCl and rinsed several times with deionized water. Plant tissue is ground in a Wiley Mill with a 60 mesh screen. Ground material is dried for 72 hours at 65°C and 0.5 gram subsamples weighed to the nearest 0.01 mg. The subsamples are placed in clean, dry crucibles and, starting with a cold muffle furnace, ashed for 2 hours at 500°C .

For cation analyses, about 1 ml deionized water and 1.0 ml reagent grade 6 N HCl are added to the crucible and brought to the boiling point over a hotplate. The contents are then diluted with deionized water to 100 ml in a clean volumetric flask and filtered through a 0.45μ membrane filter. The filtrate was diluted 100x and analyzed on a Dionex Model 10 Chromatograph.

Results

The Sumner Lake and Trout Lake watersheds differ fundamentally in terms of vascular flora. Total aboveground biomass for the herb, shrub and tree strata is estimated to be 115,563 kg/ha in the Sumner Lake watershed and 2,282,642 kg/ha in the Trout Lake watershed (Tables 1 & 2). Biomass data has not been calculated for four species of trees in the Trout Lake watershed and one tree species at Sumner Lake due to a lack in the literature of appropriate equations for predicting biomass for those species. Basal area and density estimates have been presented for comparison with other species. It is our feeling that probably only one of those species, Ostrya virginiana, makes a fairly large contribution to the biomass of the Trout Lake watershed and that the remaining species do not contribute significantly due to their low density. However, a more intensive literature search is planned in an attempt to turn up appropriate regression equations for predicting biomass for

Table 1. Cover percentages and biomass of aboveground current growth for the four small lake watersheds. Species listed in the table are those contributing at least 3% to the biomass of the herb or shrub/tall herb strata. Species present in the watersheds but contributing less than 3% to the aboveground biomass are listed in Appendix II.

WALLACE LAKE WATERSHED			NONAME LAKE WATERSHED		
Species	Cover %	Weight kg/ha + SE	Species	Cover %	Weight kg/ha + SE
HERBS			HERBS		
Aster macrophyllus	40.4	394.2 + 89.3	Lycopodium annotinum	0.9	61.8 + 40.5
Lycopodium clavatum	2.1	62.8 + 51.2	Aster macrophyllus	5.2	59.2 + 14.6
Grasses/Sedges	5.8	52.8 + 26.9	Grasses/Sedges	3.2	48.3 + 22.6
Rubus parviflorus	7.3	47.1 + 19.0	Viburnum edule	0.7	39.2 + 39.2
Lycopodium obscurum	2.0	46.7 + 35.3	Diervilla lonicera	2.2	38.5 + 17.7
Clintonia borealis	8.4	40.7 + 17.0	Cornus canadensis	2.9	25.6 + 15.5
Aralia nudicaulis	6.7	32.3 + 3.7	Amelanchier sp.	0.2	24.8 + 21.5
Lycopodium annotinum	0.8	31.0 + 18.7	Rosa acicularis	0.4	19.6 + 18.7
Linnaea borealis	1.4	29.5 + 21.1	Lycopodium clavatum	0.3	17.6 + 12.4
Other	---	133.9	Other	---	91.4
TOTAL		871.0	TOTAL		426.0
SHRUBS/TALL HERBS			SHRUBS/TALL HERBS		
Rubus parviflorus	12.3	298.3 + 117.0	Lonicera canadensis	0.4	54.7 + 54.7
Osmunda claytoniana	2.5	95.1 + 95.1	Viburnum edule	< 0.1	20.3 + 20.3
Rubus strigosus	1.4	60.6 + 60.6	Lonicera dioica	0.1	9.9 + 9.9
Viburnum edule	0.3	54.6 + 25.1	Rubus parviflorus	0.1	6.9 + 6.9
Pteridium aquilinum	0.5	39.5 + 30.5	Grasses/Sedges	< 0.1	5.2 + 5.2
Thalictrum dasycarpum	0.2	19.7 + 13.7	Other	---	5.0
Other	---	51.2	TOTAL		102.0
TOTAL		609.0			
SUMNER LAKE WATERSHED			TROUT LAKE WATERSHED		
HERBS			HERBS		
Aster macrophyllus	37.4	536.6 + 170.2	Grasses/Sedges	1.2	13.7 + 13.7
Rubus parviflorus	6.3	160.1 + 80.6	Dryopteris marginalis	0.2	3.5 + 2.4
Aralia nudicaulis	20.7	130.7 + 40.0	Aster macrophyllus	0.3	3.1 + 3.1
Equisetum palustre	1.7	43.4 + 43.4	Malanthemum canadense	0.3	1.4 + 0.6
Other	---	228.2	Streptopus roseus	0.5	1.3 + 0.3
TOTAL		1,099.0	Other	---	4.0
SHRUBS/TALL HERBS			SHRUBS/TALL HERBS		
Rubus parviflorus	13.1	164.4 + 16.4	Dryopteris marginalis	2.0	4.0 + 4.0
Lonicera canadensis	3.5	109.2 + 14.9	Other	---	---
Juniperus canadensis	2.1	81.3 + 81.3	TOTAL		4.0
Cornus stolonifera	0.8	33.3 + 33.3			
Other	---	42.8			
TOTAL		431.0			

Table 2. Basal area, densities and biomass of aboveground current growth of trees for the four watersheds. Standard errors are calculated after pooling the data from the four sample plots in each watershed.

Species	Basal Area cm ² /ha	Density stems/ha	Weight kg/ha + SE
WALLACE LAKE			
Betula papyrifera	58,046	222.5	31,114.93 + 27.
Populus tremuloides	49,935	70.0	18,219.04 + 80.
Picea glauca	43,098	262.5	16,596.30 + 31.
Abies balsamea	12,908	90.0	4,249.19 + 26.
Alnus rugosa	18,688	717.5	4,158.40 + 00.
Thuja occidentalis	16,136	90.0	3,794.90 + 22.
Picea mariana	9,285	20.0	3,555.12 + 87.
Salix spp.	1,015	17.5	238.98 + 8.
TOTAL			81,926.86
NONAME LAKE			
Pinus banksiana	78,551	435.0	31,594.14 + 40.
Picea mariana	17,616	320.0	4,347.43 + 9.
Betula papyrifera	3,620	100.0	1,063.00 + 12.
Abies balsamea	354	20.0	56.05 + 4.
TOTAL			37,060.62
SUMNER LAKE			
Betula papyrifera	79,050	130.0	46,386.96 + 84.
Populus tremuloides	120,175	147.5	45,886.90 + 53.
Picea glauca	28,843	127.5	10,993.10 + 51.
Thuja occidentalis	20,957	67.5	7,057.94 + 61.
Abies balsamea	9,355	17.5	3,708.11 + 153.
Fraxinus nigra	130	12.5	---
TOTAL			114,033.01
TROUT LAKE			
Acer saccharum	187,793	285.0	1,985,207.40 + 4,2
Betula alleghaniensis	20,005	50.0	158,296.40 + 2,0
Acer rubrum	6,435	10.0	64,641.95 + 9,5
Tsuga canadensis	143,125	282.5	47,006.53 + 93.
Quercus rubra	28,920	97.5	16,433.59 + 52.
Pinus strobus	31,154	77.5	9,860.98 + 60.
Betula papyrifera	1,143	7.5	626.04 + 69.
Abies balsamea	922	5.0	308.95 + 152.
Populus grandidentata	679	2.5	184.01 + 184.
Pinus resinosa	474	7.5	45.52 + 12.
Ostrya virginiana	14,005	275.0	---
Acer pensylvanicum	2,414	47.5	---
Tilia americana	11,142	12.5	---
Fraxinus americana	149	2.5	---
TOTAL			2,282.611.37

d
t
SE
+ 27
+ 80
+ 31
+ 26
+ 00
+ 22
+ 87
+ 8
+ 40
+ 9
+ 12
+ 4
+ 84
+ 53
+ 51
+ 61
+ 153
-
+ 4
+ 2
+ 9
+ 93
+ 52
+ 60
+ 69
+ 152
+ 184
+ 12
-
-
-
-

these species in the future. Biomass data for the Wallace Lake and Noname Lake watersheds, which was collected in 1983 and included in the 1983 Progress Report, is also displayed for purposes of comparison with Sumner Lake and Trout Lake biomass estimates. Figure 23 compares the distribution of biomass between the herb, shrub and tree strata in the four watersheds. Although there was a significant difference in total biomass among the four watersheds, the distribution of biomass among the vegetation strata was almost identical. In all four watersheds greater than 98% of the estimated total biomass was contained in the tree stratum. Only those species contributing at least 3% to the total biomass of the herb and shrub strata in the respective watersheds are listed in Table 1. Species in each watershed contributing less than 3% to the biomass of the herb and shrub strata are listed in Appendix B

Sample plots in the Sumner Lake watershed contained a total of 49 species of vascular plants: 43 herbs and shrubs and 6 trees. *Aster macrophyllus* was the dominant species in the herb stratum contributing over 48% of the biomass. The shrub stratum was dominated by *Rubus parviflorus* which contributed almost 33% to the biomass of that stratum.

The number of tree species, 14, encountered in sampling in the Trout Lake watershed exceeded that found in the other three watersheds. However, species diversity in the herb and shrub layers was very low as only 13 species were noted for a total of 27 species of vascular plants in that watershed. Vascular ground cover was sparse with grasses and sedges contributing the greatest percentage of biomass in the herb stratum. Only one of the four plots at Trout Lake contained vegetation in the shrub/tall herb stratum, and consequently that single species, *Dryopteris marginalis*, was found to be dominant there.

The results of the previous years' studies revealed a total of 59 species of vascular plants (51 herbs and shrubs and 8 trees) for the Wallace Lake watershed, and 37 herbs and shrubs and only 4 species of trees for a total species count of 41 at Noname Lake.

Discussion

In terms of species composition, the three Isle Royale watersheds seem to be fairly representative of boreal forests of the Great Lakes region. Maycock (1961) found *Rubus parviflorus* to be the only shrub which occurred in all four of the boreal forest stands he studied on the Keweenaw Peninsula to the south of Isle Royale. *Lonicera*

canadensis was the second most important shrub in his stands. As Table 1 indicates, *Rubus parviflorus* was the dominant species in the shrub/tall herb stratum of the Sumner Lake and Wallace Lake watersheds, and *Lonicera canadensis* made the greatest contribution to the biomass in that stratum at Noname Lake. He also reports *Aster macrophyllus*, *Maianthemum canadense*, *Mitella nuda*, *Carex pedunculata* and *Aralia nudicaulis* as the only herbs which occurred in all four of the stands he studied. With the exception of *Carex pedunculata*, these species occur with exceptional consistency in our sample plots also. However, *Maianthemum canadense* and *Mitella nuda*, being such small individuals, do not contribute much to the biomass. In fact, *Aster macrophyllus*, *Maianthemum canadense* and *Aralia nudicaulis* occur with 100% constancy in the four sample plots at Sumner and Wallace Lakes, and the first two species also occur in all of the Noname Lake plots.

Vegetation in the herb and shrub/tall herb strata in the Trout Lake watershed was fundamentally different from the three Isle Royale watersheds. Grasses/sedges were dominant in the herb stratum and *Dryopteris marginalis* was the only species encountered in sampling within the shrub/tall herb stratum. However, as Table 1 indicates, no species had very high average cover values. All species, with the exception of grasses/sedges (1.2%), had average percent cover values less than 1%. In their phytosociology studies in similar but younger northern hardwood forest systems at Hubbard Brook, Siccama, Bormann and Likens (1970) found *Dryopteris spinulosa* and *Maianthemum canadense* to be the two most important species based on percent cover and biomass. *Dryopteris marginalis* and *Maianthemum canadense* are listed in Table 1 as important species in the Trout Lake watershed. However, in terms of species diversity the Hubbard Brook researchers encountered 97 species of vascular plants in their northern hardwood forest as compared to only 27 species encountered in our studies at Trout Lake. This large difference is due mainly to a much lower species count in the subordinate vegetation strata at Trout Lake as 14 species of trees were listed for both watersheds.

The aboveground current growth of subordinate vascular plants (herbs and shrubs) totalled 1,530 kg/ha in the Sumner Lake watershed and only 31 kg/ha in the Trout Lake watershed. The current growth in the herb and shrub/tall herb layers together totalled 1479 kg/ha in the Wallace Lake watershed and 528 kg/ha in the Noname Lake watershed. Figure 23 shows that in all four watersheds these two strata combined contribute less than 2% to the total aboveground

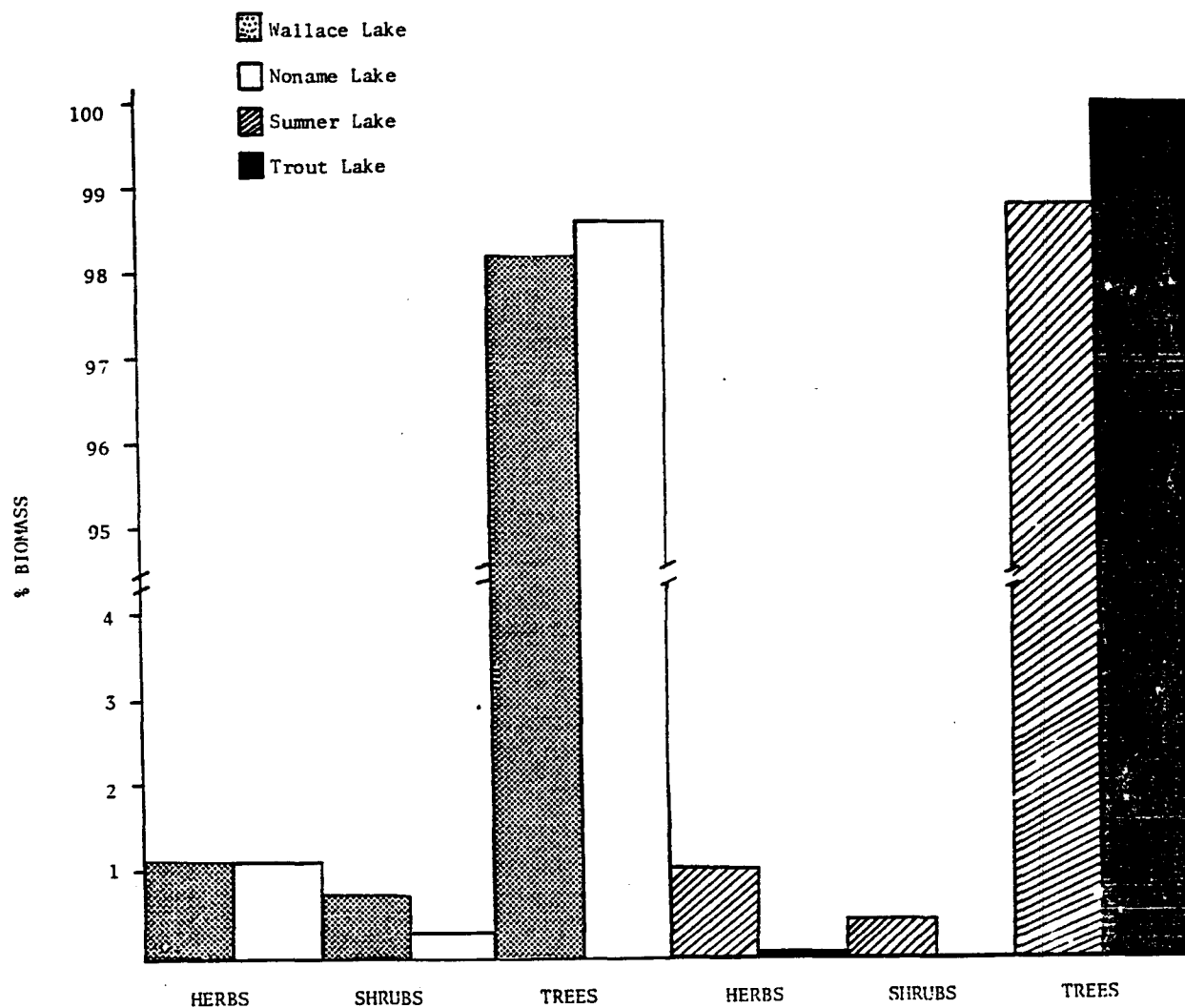


Figure 23. A comparison of biomass within the herb, shrub/tall herb and tree strata for the four watersheds; Wallace, Noname, Summer & Trout.

biomass in each of the watersheds. In comparison, biomass of the herb and shrub layers of the control northern hardwood forests at Hubbard Brook was estimated to be 162 kg/ha (Siccama, Bormann, and Likens, 1970). They found the fraction of biomass in shrubs and herbs to be less than 1% and these findings were comparable to those of high-elevation broad-leaf forests in the Great Smoky Mountains.

Although the herb and shrub strata at Hubbard Brook contain less in the way of biomass than do those strata in the three Isle Royale watersheds, Whittaker, Bormann, Likens, and Siccama (1974) report the aboveground weight for trees at Hubbard Brook to be 132,810 kg/ha. This is higher than our estimates of biomass in the tree strata of the three boreal forest ecosystems on Isle Royale, but considerably lower than the 2,282,600 kg/ha estimated for trees in the virgin Hemlock-White Pine-Northern Hardwoods forests at Trout Lake in the Huron Mountains. Therefore, the smaller amount of biomass on the forest floor at both Hubbard Brook and Trout Lake might be attributed to the denser forest canopy.

In terms of species composition and estimated standing biomass the Wallace Lake and Sumner Lake watersheds are very similar. This would be expected since the two watersheds are coterminous with very similar topography and soil conditions and subject to almost identical climatic conditions. The slightly higher estimate for biomass of trees in the Sumner Lake watershed might be due in part to the fact that a portion of the Wallace Lake watershed burned in 1936 and this area would be in an earlier successional stage at the present time.

The lower standing biomass in the Noname Lake watershed when compared to the other two on Isle Royale can be attributed to the much poorer growing conditions in that watershed. Soils are very shallow and rocky and the dominant tree species in the Noname Lake watershed is *Pinus banksiana* which typically has a slow growth rate. Previous studies in jack pine stands on Isle Royale (Rutkowski, unpub.) have shown that percent cover of bryophytes exceeds that of vascular plants in the herb and shrub layers combined. Possibly the bryophytes are outcompeting (alleopathy) the vascular plants under these poorer growing conditions which would explain the lower biomass estimates for herbs and shrubs in those stands.

The variability among sample plots is evident in the fairly large standard errors for mean biomass of individual species in the two watersheds (see Table 1). However, our standard

error values are comparable to those from similar studies and are only slightly higher than those calculated by Siccama et al. (1970) in their Hubbard Brook watershed. Unless the vegetation of the entire watershed was uniform one would expect a certain amount of variability due to placement of sample plots in different vegetation types. Our higher values can partially be attributed to the larger size of our watersheds, 159, 176 and 46 ha in the Sumner, Wallace and Noname Lake watersheds respectively, (area of the Trout Lake watershed is yet to be calculated) as compared to 13.2ha at Hubbard Brook. In addition to size differences there was also a significant difference in sampling intensity in our study when compared to Hubbard Brook. For example, our herbaceous biomass values were calculated from data collected on 20, 1m x 1m subplots in each watershed while the Hubbard Brook data were collected from 208 such plots. Also one must keep in mind that the Hubbard Brook site is basically an eighty-year old successional forest which has quite low species diversity in the understory. The Isle Royale sites are in more diverse mature boreal forested ecosystems with very diverse understory conditions. At Hubbard Brook the mean standard error for all herbaceous species was 43% while our values for Wallace and Noname were 50.6 and 66% respectively. Our variation for shrub species is considerably above their values since we often have a species only occurring on one of four plots in a watershed. This reflects the high spatial variability characteristic of this mature vegetation on a recently glaciated substrate.

Biomass as it relates to economic forest productivity is a familiar concept and has been an essential part of forest management for years. More recently, however, biological forest productivity has come of interest with the study of total ecosystems and concern for energy and nutrient budgets (Stanek and State, 1978).

There are several published regression equations for determining biomass of the various tree species. The equations are based on allometry, the concept that two dimensions or weights of organs grow in such a way that the ratio between their geometric growth rates remains constant over considerable periods of time (Peterson, Chan and Cragg, 1970). Stanek and State (1978) have compiled the equations available in the literature for estimating the biomass of individual plants (trees, shrubs, lesser vegetation) and their components (leaves, branches, bole, bark, wood, roots, etc.). Most authors arrived at these regression equations with the use of destructive sampling methods. These involved the actual removal of trees and intensive measure-

ments of various components and then sectioning or taking subsamples from the components to obtain oven-dry weights. However, to facilitate practical application the resulting equations use easily determinable characteristics (such as diameter at breast height or tree height) to determine biomass.

Many researchers stress the equations they have developed are not necessarily applicable to all sites (Moir and Francis, 1972; Doucet, Berglund and Farnsworth, 1976; Peterson, et al., 1970; Whittaker, et al., 1974). Site quality and stand age are important in forming the equations, therefore a single equation will not sufficiently describe the biomass of a certain species for all sites. There is also some discrepancy in the literature as to which measurement is the best predictor of biomass. Peterson et al. (1970) found the product of the square of the diameter at breast height and height (D^2H) to be the best predictor of aboveground biomass in the aspen stands they studied. In his study of biomass in jack pine stands, Hegyi (1972) used diameter at breast height alone. He found that the use of other independent variables (i.e. height or diameter² x height, etc.) did not appreciably improve the regression equations.

Destructive sampling insures accuracy in calculating standing biomass particularly when the sample size is quite large. However, this type of sampling is impossible in a protected area such as Isle Royale. Therefore, we've had to rely on published equations for determining biomass of the tree stratum in our watersheds. In choosing the appropriate equations several things were taken into consideration. First of all, we looked for research that had been carried out in similar forest types with similar site quality. There apparently have been no studies of this type in the Upper Great Lakes region and no single author had equations covering the nine species from our watersheds. Another factor taken into consideration is that the regression equations are only appropriate for a defined range of diameters. When they are applied to trees with diameters not falling within this range the predictions may be invalid. There is also a lot of variation in the particular tree components for which one can obtain biomass for the various species. We were consistent in utilizing equations which predicted biomass for the tree or whole plant above ground level. Therefore, our results do not include that portion of the biomass contributed by the roots. Previous studies have shown root biomass to be generally 18-21% of the aboveground biomass (Whittaker et al. 1974), but in some cases it can approach 50%.

After taking all these factors into consideration we chose the most appropriate equations. However, none of the published equations for black spruce (*Picea mariana* (Mill.) BSP.) were appropriate for use in our watersheds. In this case the equation for white spruce was substituted (Baskerville 1965). The equation for western red cedar (*Thuja plicata* Donn) was utilized for those white cedar trees with diameters exceeding 14.0 cm (Kurucz, 1961). Also, in the case of quaking aspen (*Populus tremuloides* Michx.) and white spruce several of our trees had diameters which exceeded the range for which the equations were appropriate. We feel that the published regression equations were sufficient in predicting standing biomass for the trees in our watersheds. This is supported by the fact that our highest standard error of the mean was 8% of the biomass for that species and that 8 out of the 12 predictions had standard errors under 1%. However, we plan to verify our choice of equations by collecting intensive measurements on recent windfalls from each watershed to test how well our form class data match that used by the authors of the equations we're utilizing.

ANION MOBILITY IN FOREST SOILS

In boreal ecosystems, the potential exists for inputs of H^+ , sulfate, and nitrate ions to affect forest productivity. This occurs as these ions enter the soil and chemically alter the soil solution. The net effect can be nutrient leaching from the rooting zone and mobilizing toxic concentrations of such elements as aluminum. Studies have been conducted to assess the effect of acids on forest soils with particular emphasis on nutrient cycling and cation leaching (Abrahamsen 1980, Alexander 1980, Cronan et al 1978, Norton et al 1977). In soils deficient in sulfur or nitrogen, increases in forest productivity may occur (Jonsson and Sundberg 1972, Cowling and Dochinger 1980).

The research currently underway on Isle Royale is particularly appropriate as there is little information on the effects of acid deposition and forest soils for the upper Great lakes region (Fish & Wildlife Service 1982, Westman 1980). Only within the last few years have some forest soils in the upper Great Lakes region been classified as sensitive based on surface soil characteristics (McFee 1981). Such soil parameters as cation exchange capacity, pH, % organic matter, cation/anion adsorption capacity and others have been used as criteria to identify those soils which may prove to be vulnerable to acid deposition.

A concern of soil scientists today is the fact of SO_4^{2-} deposition in forest ecosystems, and how such anions might affect nutrient cycling and budgets (Johnson and Cole 1977). Since chemical charge balance must be maintained in forest soils at all times, the occurrence of nutrient ion leaching can be determined by examining anion flux. Effects of pollutant-derived H_2SO_4 and HNO_3 on cation leaching depend in part on the ability of plant-soil systems to serve as sinks for SO_4^{2-} and NO_3^- . Because productivity in most forests is N limited, NO_3^- depositions are, in general, immobilized and biologically recycled. The fate of SO_4^{2-} is more variable. With the possible exception of the Pacific Northwest and portions of the Great Plains, sulfur is not generally a limiting nutrient. Generally the biological requirements for S are considerably smaller than for N and biogeochemical processes of soil adsorption and precipitation influence the hydrologic flux of SO_4^{2-} through soil profiles (Richter, et al, 1983).

In the upper Midwest, sulfate/nitrate ratios in atmospheric deposition (Fig. 10) suggest that sulfate is the anion which

most likely could result in cation nutrient leaching. Studies conducted by Mollitor and Raynal (1982), Johnson and Cole (1977,1980), Gebhardt and Coleman (1974), Chao et al (1964), and others, suggest that sulfate adsorption in soils is enhanced by increasing concentrations of aluminum and iron which favor adsorption kinetics, and low organic matter content in the mineral horizons which, when present in increasing amounts, blocks adsorption sites. Artificial acidification experiments (Overrein & Seip 1980) have shown that acid rain at pH 4 or above is inefficient at displacing nutrient cations from podzolic soils characteristic of this region. As soils approach moderate pH levels of 5.0-5.5, base cations are more effectively replaced by H^+ inputs.

The majority of forest soils summarized to date on Isle Royale range between pH 4.6 under spruce and 4.9 (0.01M $CaCl_2$ w/v ratio 1:2) under northern hardwoods. It appears that² less acid, poorly developed podzolic forest soils with low cation exchange capacity, developed on coarse siliceous material, are relatively susceptible to acidification and nutrient leaching via anion mobility due to inputs of atmospheric sulfate and nitrate (Krug and Frink 1983). Precipitation and stream chemistry data collected in watershed ecosystems on Isle Royale and the Keweenaw Peninsula show little, if any, incorporation of SO_4 in the ecosystem, and even NO_3 discharge from boreal ecosystems generally exceeds that³ observed in northern hardwood systems.

In general, the effects of anthropogenic inputs of acid sulfate and nitrate must be evaluated on the basis of internal ecosystem nutrient cycling. Due to the requirement for charge balance sulfate and nitrate ions must be mobile in the soil to facilitate cation leaching. Net nutrient losses will only occur if leaching losses are greater than nutrient replacement from deposition and mineral weathering.

In sum then, soil sensitivity is commensurate with moderate pH values, low concentrations of Al and Fe, low organic matter content, and inputs of N and S in amounts exceeding the requirements for vigorous plant growth.

Hypotheses

1. Ecosystem input/output ratios for NO_3 and SO_4 are lower in boreal forested ecosystems than northern hardwood ecosystems on Isle Royale.
2. High inputs and outputs of SO_4 , coupled with ecosystem adsorption of the H^+ ion in precipitation makes

cation leaching by SO_4 a real possibility in boreal forested soils.

3. In ecosystems where coniferous species are more dominant, such as boreal systems, the preferential utilization of high-energy NH_4 opens the possibility of some seasonal leaching losses due to NO_3 mobility.

4. The high precipitation inputs of NH_4 , NO_3 , Ca, Mg, and K due to fertilizer use accompanied with dust from disturbed lands in the upper Midwest and Great Plains, further decreases the need in the boreal ecosystem for NO_3 increasing the potential for nutrient leaching and/or ionic reequilibrium due to this anion.

Methods

Site Selection

Soil lysimeter plots were established in 1983 within the Wallace Lake and Washington Creek watersheds being studied on Isle Royale, and in the Calumet watershed located on the Keweenaw Peninsula. Initial site evaluations for plot selection were accomplished in June 1983. The primary criteria used were forest type and percent organic matter in the soil. Soil cores were taken at each prospective plot. Subsamples were then dried at 65°C for 24 hours or until no further weight loss was recorded. Initial subsample weights were approximately 50 grams. After oven drying, the samples were then ashed in a muffle furnace at 550°C for 8 hours, cooled in a desiccator and weighed again for loss on ignition.

Within the Wallace Lake watershed, one plot is located in a pure spruce (*Picea alba*) stand and the other is located in a white birch-aspen stand. In the spruce plot, percent organic matter (including organic horizons) is approximately 16-18% OM and the soil pH is 4.6. The birch-aspen plot is approximately 12-14% soil organic matter content with a pH of 4.9. Percent organic matter was determined on volume-weighted composite samples of the profile including the B horizon. For comparison purposes a lysimeter plot in a northern hardwood forest dominated by sugar maple was established within the Washington Creek watershed in the southwest portion of Isle Royale. On the Keweenaw Peninsula a site was established in the Central Lake watershed in July 1983. This is a sensitive watershed system forested with boreal and northern hardwood vegetation, and it was thought desirable to monitor such a site to complement the Isle Royale sites. However in September 1983, after obtaining one month of data it was learned that a logging operation

was to be initiated later that fall. The magnitude of the disturbance was sufficient to warrant abandonment of the soil plot. The present lysimeter site on the Keweenaw is located in the Calumet watershed, a small first order watershed dominated by successional northern hardwoods. It complements the Isle Royale sites since it receives more winter snowfall and is readily accessible year-round.

The Isle Royale and Calumet sites were selected in watersheds where an input/output nutrient database exists. Again, the primary criteria used in site selection was forest type and percent soil organic matter. The rationale for site selection is based upon the hypothesized differences believed to exist in the nutrient dynamics of boreal and northern hardwood forest types owing to slight to moderate differences in acidity between organic and nonorganic forest soils.

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Plots were located using a simple random grid design (Black 1965, Cochran 1953). Within each plot the following samples are collected: throughfall, litter leachate, and soil solution. Throughfall is sampled using ten, 20 cm dia. plastic rain collectors consisting of a funnel, filter (to eliminate insects and particulate contamination), and holding bucket. The rain collectors are placed beneath the stand in a design resembling the letter "H". Three snow buckets (50 liter plastic waste containers) per site are used for precipitation collection during the months of November through April. The Isle Royale sites are sampled at least twice during this period and every two to four weeks throughout the remainder of the year. The Calumet site is sampled similarly but on a more frequent basis during the winter months. For litter layer leachate, zero-tension lysimeters were constructed of 15x25x5 cm deep trays connected to a tube and 500 ml collection bottle. " NYTEX" netting is secured over each collector to minimize debris and clogging. Three such collectors are located in each plot. The zero-tension lysimeters were installed by cutting a rectangular hole slightly larger than the collector and a trench and pit dug to receive the tubing and collection bottle. Soil solution is collected in triplicate in each of four mineral horizons which are roughly equivalent to the A1, E/B, Bsl/Bs2, and BC horizons. Sampling soil solution within the mineral layers is accomplished using porous-cup tension lysimeters manufactured by Soil Moisture Co.. The lysimeters are about 5cm dia. and in 25, 45, and 70cm lengths (three samplers per depth within each site). The lysimeters were installed using a standard soil auger with a diameter slightly larger than the samplers to minimize disturbance of the soil column. Lysimeters of this type

have been widely used in the study of soil water and ion transfer through forest soils (Cole 1968, Cole et al 1961, Haberland and Wilde 1961, Walliham 1960). The lysimeters were placed approximately one meter apart both within and between depths.

Initially sampling was performed biweekly; however, due to the relatively dry conditions for the months of July through mid-September and the inaccessibility of Isle Royale during the months of November through May, sampling was conducted more or less on an event basis providing sufficient soil solution was present. Throughfall was collected seven to ten days following precipitation events regardless of whether or not soil solution was collected. During spring run-off, weekly sampling was performed at the Calumet site and biweekly on Isle Royale. The amount of throughfall was measured for each bucket and a 125ml subsample retained for determination of pH and conductivity. Upon determination of pH and conductivity, a volume-weighted composite sample from each plot was filtered through a 0.45 μ filter for subsequent chemical analysis.

The tension lysimeters are sampled using a hand pump connected to a liquid trap. Tension is applied for 12 to 24 hours prior to sample collection. Volumes vary appreciably but 125ml is collected if available. pH and conductivity are determined within 12 hours after collection. A subsample was then filtered and stored in a 60ml dark plastic bottle under refrigeration until analysis of ionic species could be performed on an ion chromatograph. Aluminum determination was performed on an AA following acidification with HCl and addition of KCl to enhance detection (Standard Methods 15th ed. 1980). Silica was determined colorimetrically with absorption measured at 420nm (Standard Methods 15th ed. 1980). The data presented in the following section include the period from July 1983 through August 1984 for Isle Royale and February through August 1984 for the Calumet site.

Soil Descriptions and Chemistry

Basic soil characteristics were examined and described for the four lysimeter plots and 12 vegetation plots located in the Wallace, Sumner, and Trout Lake watersheds. The inclusion of basic soils properties contribute to the understanding of the dynamics of the watersheds and the potential susceptibility to detrimental effects of atmospheric deposition.

Soils of the upper Great Lakes region are primarily of glacial origin. Most of the soils described herein have also been influenced by more recent (3500-8000yr. BP) lake level fluctuations created by glacial retreats. While there are no summary reports describing soils of the western Lake Superior region, the soil samples collected in the study are believed to be common representatives for the area (S.Shetron, Prof. of For.Soils, MTU, personal communication, 1984). More detailed soil descriptions are currently being prepared by the Soil Conservation Service. Soil pedon classifications included, in this report (Appendix C), were written according to "National Cooperative Soil Survey Standards" (Soil Survey Staff 1975, 1981).

The Trout Lake plots are located in a mature northern hardwood forest dominated by sugar maple, hemlock and yellow birch with red pine and red oak occurring frequently through- out (see previous section). The soils are primarily Haplorthods, sandy to loamy, mixed, frigid on upland sites. One plot is on a ridge and is an eolian deposit over granite bedrock. The remaining three plots are glacio-fluvial in origin. The Sumner Lake watershed plots include three Haplorthod and one Boroasprist soil. They range from sandy to silty, mixed, frigid to euic. Their physiographic positions range from ridge crest to low area in rolling uplands. The soils here are glacio-fluvial with one eolian plot represented. Five soil plots are located within the Wallace Lake watershed. Four are located in the vegetation plots which were established around the lake and two are located in the lysimeter plots which were established in late spring of 1983. One soil pedon corresponds to both a lysimeter and vegetation plot (birch-aspen). Three of the soils are Alfic Lithic Haplorthods. The remaining two include an Alfic Fragiorthod and an Alfic Haplaquod. All are sandy to coarse loamy, mixed, frigid. These are upland plots in areas dominated by tag alder, birch, aspen, fir, spruce or open field vegetation. All the soils are glacio-fluvial, Post-Duluth lake stage deposits. The soils located in the lysimeter plots in the Calumet and Washington Creek watersheds have not been fully described, however, individual soil characteristics are presented in Appendix C and in the discussion of lysimeter plot data.

Soils analyses include determination of bulk density, %OM, pH, exchangeable cations, cation exchange capacity, and sulfate adsorption capacity (as the sum of extractable Fe and Al). Soil textural analysis and total N are presently being determined but the results are not yet available.

Bulk density was determined in the field by the Core Method (Blake, 1965). A thin-walled cylindrical metal corer was driven into the soil and extracted. A known volume of soil is obtained from a series of metal sleeves located in the corer and these soil cores are then oven-dried to constant weight at 105°C. The bulk density is the oven-dry weight divided by the sample volume.

Percent organic matter was determined by loss on ignition at 550°C for 8 hours. Each soil sample was oven-dried to constant weight then ashed, cooled and weighed. Percent organic matter is the weight lost divided by the oven-dried weight expressed as a percentage.

Soil pH was determined in a solution of 0.01M CaCl_2 with w/v ratio of 1:2 for mineral horizons and 1:5 for organic horizons (Peech, 1965). A Fisher Scientific Accumet model 810 pH meter with a Beckman combination electrode was used to measure the solution.

Exchangeable base cations were obtained by extracting 10 gms of air-dried soil, ground to pass a 2mm sieve, in 100ml of 1N NH_4Cl . The extract was allowed to stand overnight, then filtered and washed with an additional 100ml of extractant and adjusted to a final volume of 200ml. Determinations for Ca, Mg, Na, and K in the extracts were conducted using a Perkin-Elmer flame atomic adsorption spectrophotometer.

Cation exchange capacity for these soils was estimated by summing the exchangeable base cations and exchangeable aluminum (Soil Conservation Service, 1975). The extraction for aluminum was conducted using 0.02 M acidified ammonium oxalate [$(\text{NH}_4)_2\text{C}_2\text{O}_4 \cdot \text{H}_2\text{O}$] and is described below.

Sulfate adsorption capacity was determined by extracting Al and Fe with 0.02 M ammonium oxalate acidified to a pH of 2.0 as adapted from McKeague (1966). A 125mg soil sample and 10ml aliquot of ammonium oxalate were combined in a 20ml centrifuge tube and shaken in a darkened chamber for four hours. The samples were then centrifuged and Fe and Al determinations made by atomic adsorption spectroscopy. The values reported are the sum of extractable Fe and Al expressed as μeq of SO_4 .

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Results and Discussion

The chemical characteristics for the four lysimeter plots are presented in Figs. 24-29. Complete field profiles for all soils are described in Appendix C. A brief summary of some of the soil characteristics of the lysimeter plots is presented below followed by a summary of some of the lysimeter data. The collection of these data is still ongoing, and there has been little interpretation of the results to date.

Soils

The highest organic matter content soil is the spruce plot soil in the Wallace Lake watershed. Here the mean percent for the entire profile including the two organic horizons is 16-18%. By far the greatest contributors are the organic horizons which average 63% organic content. The content decreases drastically in the mineral horizons averaging 2.7%. A slight increase from 2.3% to 3.4% occurs in the transition from the Bsl to E/Bt and 2Bt horizons. The birch/aspen plot, situated about 500m from the spruce plot, has a mean organic matter content of approximately 12-13%. Here the major contributors are the Oi, Oa, and A horizons. A greater proportion of fine roots than are found in the spruce plot appears responsible for the increase observed in the A through 3E horizons. The Windigo maple plot has the highest unweighted percent organic matter when compared to the Wallace Lake plots. Again, this is primarily due to the presence of fine roots in the soil profile and probably increased microbiological activity and mechanical mixing of organics into the soil by earthworms.

No data are presently available for percent organic matter by horizon in the Calumet plot; however a measurement of 12-14% organic matter was made on a composite sample of the entire profile.

Soil pH was low in the spruce profile decreasing from 4.02 in the Oi horizon to 3.77 in the E. The pH increased with depth through the 2Bt where it was 5.12. The pH change with depth was relatively small in the Wallace birch/aspen plot in comparison to the spruce plot. The pH increased from 4.87 in the A horizon to 5.09 in the 3E horizon and decreased slightly to 4.98 in the 2Bt horizon. The Windigo soils were somewhat lower in pH than the Wallace birch/aspen soils. The pH of the Oi horizon was 4.60 and decreased to 4.43 in the A/E followed by an increase with depth into the Bs2 where soil pH was 4.87.

Cation exchange capacities for the soils studied are presented in Table 3. In the spruce plot CEC increases

Table 3 Soil Characteristics for Isle Royale Lysimeter Plots

Exchangeable Bases										
Horizon	Depth cm	%OM	pH	Ca	Mg	K	Na	(Al)	Fe	CEC
				----- (in meq / 100 gms of soil) -----						
Wallace Lk.- Spruce plot										
Oi	7-2	84	4.02	-	-	-	-	-	-	-
Oe	2-0	42	3.67	-	-	-	-	-	-	-
E	0-5	2.3	3.77	.13	.04	.001	.014	1.78	.65	2.62
Bhs	5-18	12.3	4.35	.18	.06	.007	.060	3.08	4.60	3.39
Bs1	18-27	2.3	4.30	.17	.05	.006	.050	9.88	5.00	10.10
E/Bt	27-39	3.4	4.89	.43	.33	.008	.080	4.50	5.80	5.35
2Bt	39-60	3.2	5.12	1.16	.77	.009	.120	4.26	2.31	6.32
Wallace Lk.- Birch/Aspen plot										
Oi	7-5	68	-	-	-	-	-	-	-	-
Oa	5-0	34	-	-	-	-	-	-	-	-
A	0-5	8.0	4.87	1.25	.21	.019	.071	3.96	1.81	5.5
Bhs	5-21	9.6	4.96	.42	.05	.004	.106	3.55	1.61	5.8
2Bs1	21-24	3.6	4.94	.35	.07	.005	.058	9.60	.91	10.1
2Bs2	24-49	"	"	"	"	"	"	"	"	"
3E	49-65	5.0	5.09	.29	.05	.003	.080	-	-	-
3E/Bt	65-85	2.7	4.91	.32	.05	.003	.094	20.90	.46	21.3
3Bt	85-89	2.6	4.98	"	"	"	"	14.40	"	14.9
Windigo - Maple plot										
Oi	1-0	71	4.60	6.67	1.19	.33	.46	-	-	-
A/E	0-10	15	4.43	1.25	.15	.022	.072	9.70	7.50	11.1
Bhs	10-22	12	4.61	.40	.05	.006	.050	18.50	4.17	22.6
Bs1	22-40	9.0	4.72	.49	.06	.004	.060	23.40	1.81	24.0
Bs2	40-55	3.4	4.87	.13	.03	.003	.064	14.40	2.03	14.6

Fig. 24.

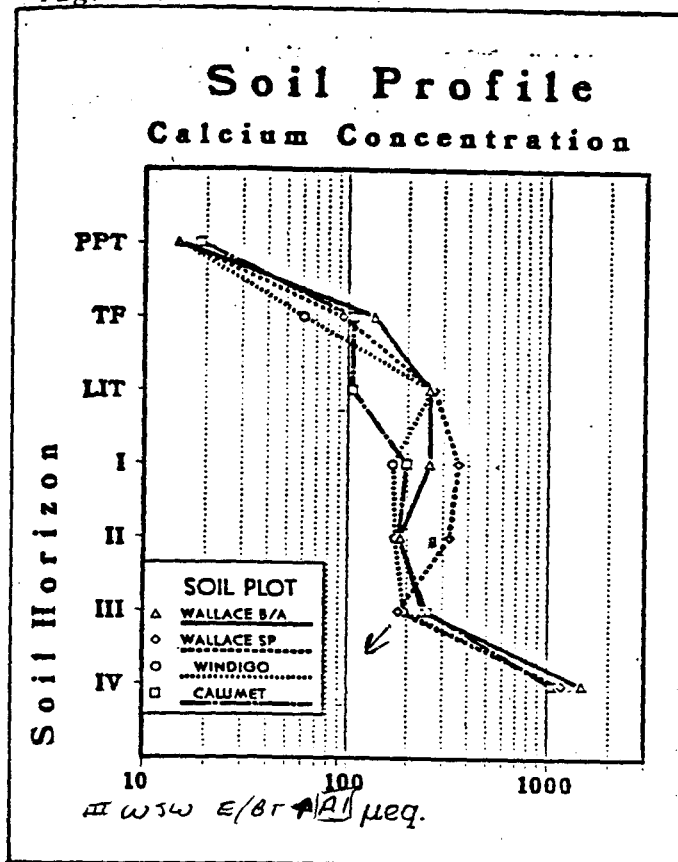


Fig. 25.

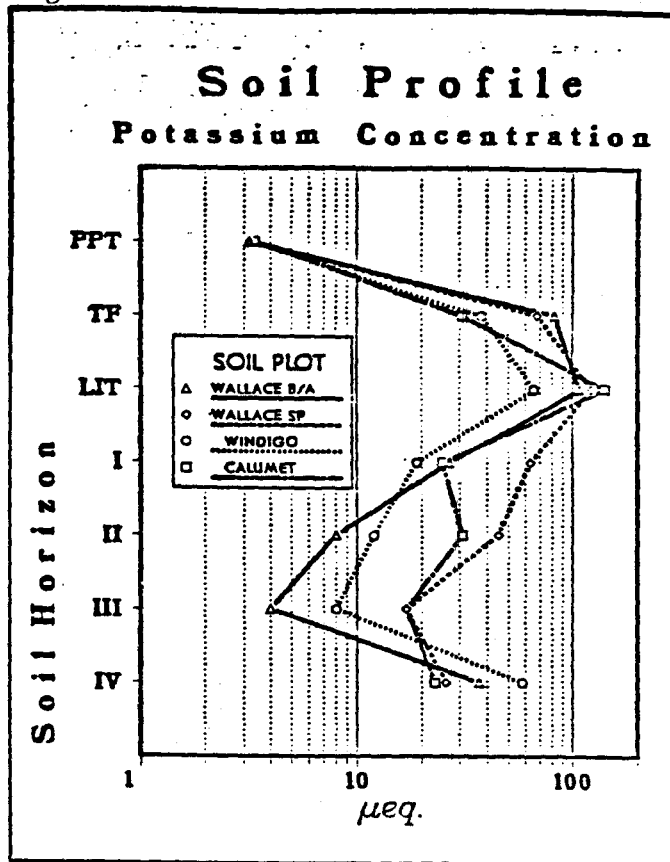


Fig. 26.

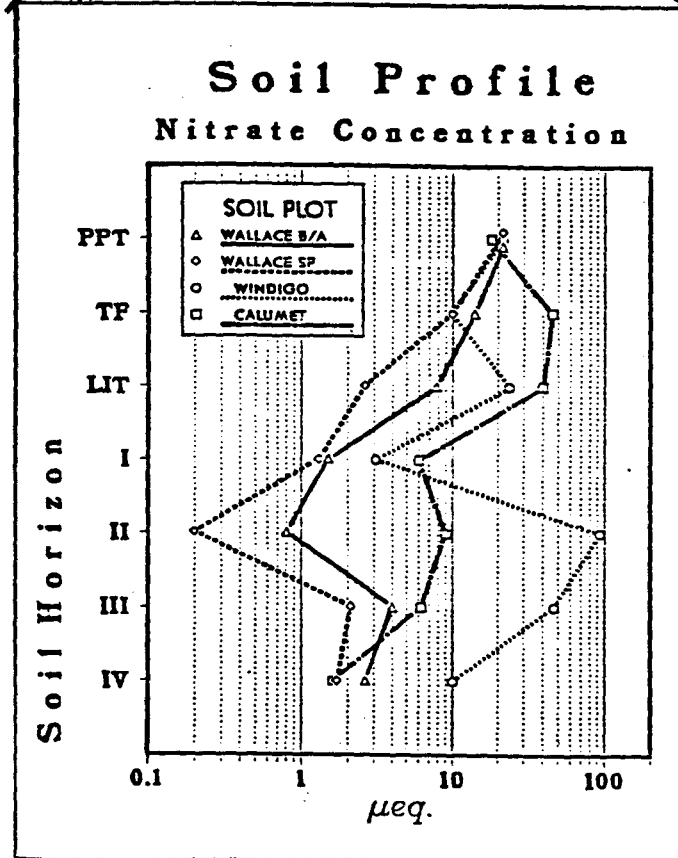


Fig. 27.

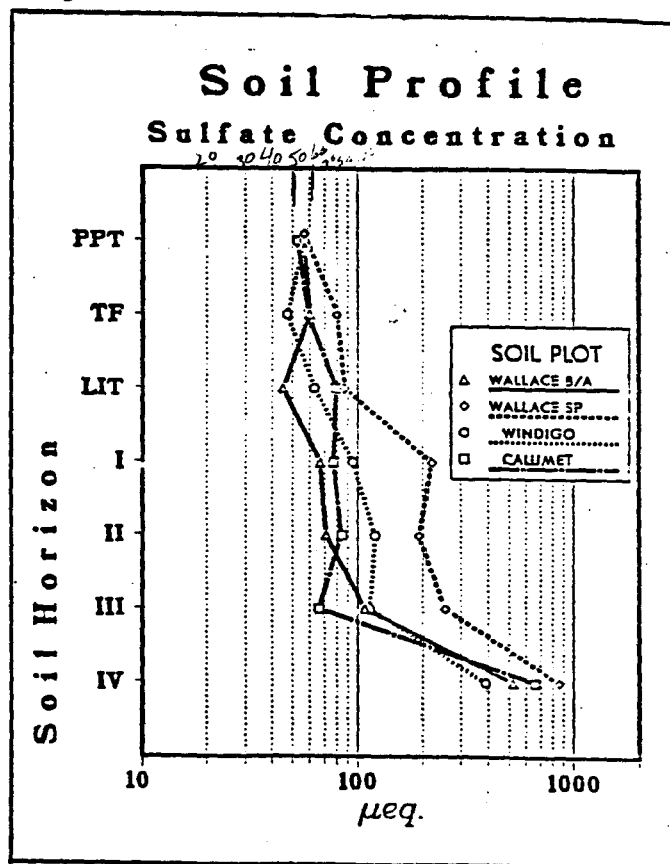


Fig. 28.

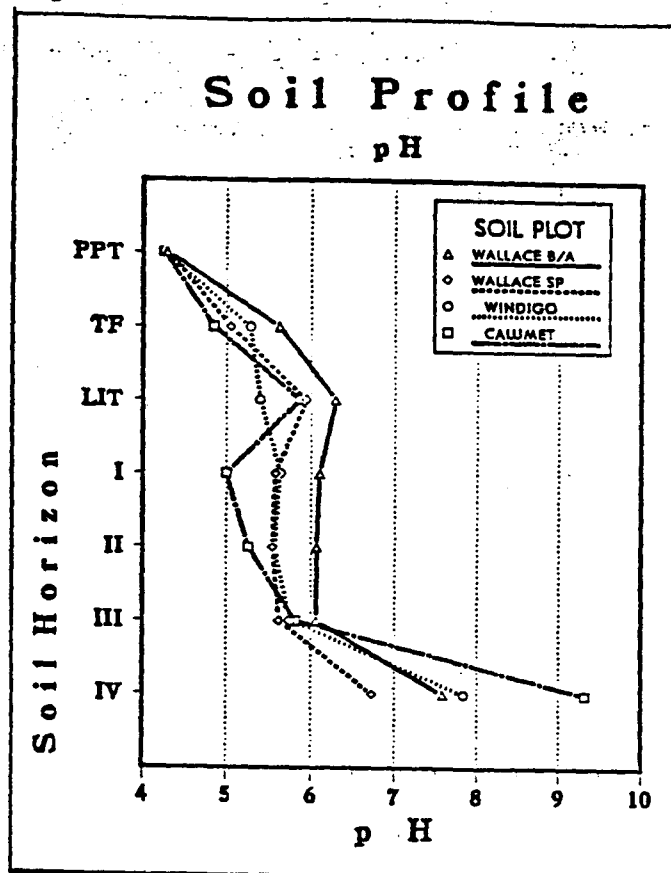
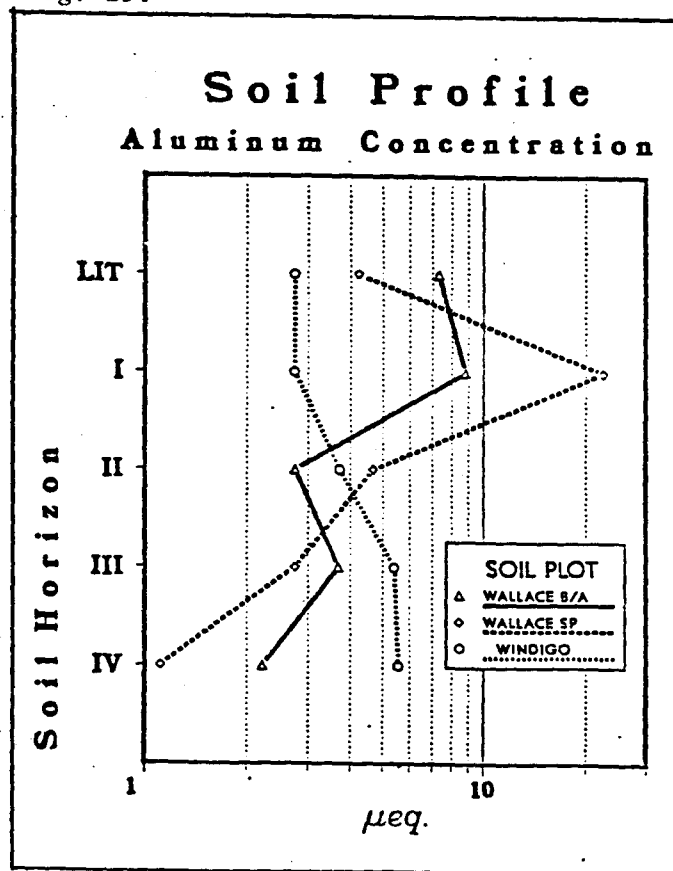


Fig. 29.



from 2.62 in the E horizon to 10.1 in the Bsl, primarily due to the aluminum content which was $9.88\mu\text{eq}/100\text{g}$. of soil. The values decrease to 5.35 in the E/Bt and 6.32 in the 2Bt horizons. In both of these lower two horizons aluminum accounts for 84% and 67% of the constituents comprising CEC. Calcium increases significantly in the 2Bt horizon to $1.16\mu\text{eq}/100\text{g}$ of soil which represents an 18% contribution. In the birch plot CEC increases from 5.51 in the A horizon to a maximum of 21.37 in the 3E/Bt, aluminum comprising 98% of the total. The maple plot shows an increase down through the profile from 11.10 in the A/E to a maximum of 24.00 in the Bsl. Here too aluminum is the primary constituent comprising 82%, 98% and 99% of the CEC in the Bhs, Bsl and Bs2 horizons.

Throughfall and Lysimeter Chemistry

Figs. 24 - 29 are preliminary plots of soil throughfall and lysimeter data collected up through August 1984. Ca (Fig. 24) and K (Fig. 25) show the usual dramatic increases in concentration with passage of incident precipitation through the canopy. In general concentrations are highest in hardwood canopies, but since these are year-round data this is not as pronounced as found in some other studies. The concentrations of Ca and K are again enhanced as the throughfall penetrates the litter layer. Data for litter leachate are not weighted by volume. Ca concentrations in the mineral soil profiles (data not corrected for concentration due to evapo-transpiration) show little change with depth until the C horizon. Here Ca concentrations increase rapidly which is subsequently reflected in stream water chemistry.

Potassium concentrations decrease dramatically in the A and B horizons and somewhat in the C. This is expected at least for the upper two mineral horizons since K is a very mobile and quickly recycled critical nutrient. It too shows some increase in concentration at the lowest sampling depths, but this is unexplained at present.

NO_3 concentrations (Fig. 26) generally decreased in throughfall samples except for one station. This is unexplained since this anion generally remains about the same in concentration or increases slightly in throughfall. The reductions could be due to delay in collecting the throughfall following an event. This will be checked. The concentration greatly decreases as the soil solution moves from the litter layer through the B horizon. It then shows an increase in concentration for most stations followed by another decline. The decreases in the litter, A, and B

horizons probably are real since this is a zone of considerable evapotranspiration which would normally concentrate the anion. The increase between the B and C horizons is less clear, but has been observed by other investigators (Richter et al. 1983). The data collected on SO_4 (Fig. 27) need closer examination. Concentrations in throughfall increase only slightly or not at all which is not usually the case. Earlier data collected on Isle Royale show marked increases in concentration in throughfall relative to incident precipitation (Stottlemeyer 1982), and increases approaching 40-50% have been common in other investigations. However, complicating throughfall analyses is the fact that concentrations are not only a function of amount of throughfall, but are also significantly influenced by a series of other factors such as amount and frequency of precipitation events, wind, canopy character, and attached flora/fauna in the canopy. SO_4 do markedly increase with depth in the soil horizons with relatively uniform increases in the A, B, and B/C horizons. Concentrations in the C horizon increase rapidly in a manner and level very similar to Ca (Fig. 24).

The reduction of H^+ ion by the forest canopy and litter layers is readily seen in Fig. 28. pH levels generally decrease slightly in the A and B horizons with subsequent pronounced increases within the C horizon.

Discussion

The increases in cation concentrations at the deeper soil depths most probably are due to the fact the sampling depth was often near bedrock, and/or often associated with clay layers. The result is a presence of lateral water flow often quite high in dissolved minerals. Ca and K inputs were up this year relative to previous years (see input/output watershed budgets) due mostly to the fact total precipitation inputs were much above a twenty-year average.

NO_3 and SO_4 inputs this year were much below those observed in 1982-83 despite the increase in total precipitation input. This could, in part, account for the slight increases particularly for SO_4 found in the throughfall. Generally investigations show this anion significantly increasing in throughfall both in concentration and loading. In comparing the input/output budgets of the first section of this report one can quickly see that the bulk collectors located in the open do not account for most of the SO_4 leaving the ecosystem. Sulfate containing rock and till are not common here, but there certainly is some contribution due to decomposition as

suggested in Fig. 27. Unfortunately, we have not had a chance to analyze our full data sets to begin to separate contributions from dry fallout to the litter layer from decomposition. Increases in the A and B mineral soil layer SO_4 concentrations probably are due to evapotranspiration. Regardless, the input/output budgets suggest that over the longer term these watersheds have deficits in the S budget, that is, there is much higher output than input. Much of the difference is probably due to dry fallout especially when it is noted that these are mature forested ecosystems some with about 50% coniferous canopy.

The neutralization of H^+ by the forest canopy is thought to be the result of cation exchange (Fig. 24, 25, and 28). Generally, the decrease in strong acidity is most pronounced in hardwood canopies (Richter et. al. 1983, Stottlemeyer 1982). However, this is not so evident in this past year's data set (Fig. 28). Neutralization here appears to be as pronounced in the spruce canopy. But this was a year of higher precipitation inputs especially during the fall of 1983 after leaf drop (Fig. 2), and since our data set incorporates year-round throughfall the conifers might have had more influence than during a year of more even precipitation distribution.

Regarding the question of anion mobility in boreal forest soils and the potential for cation leaching, we have not yet had the opportunity to compare the results shown in Table 3 with those observed in Figs. 24 - 29. It can not be assumed that all the SO_4 observed in soil leachates represents contributions from acid rain. There are numerous sources of decomposition products which can contribute to the SO_4 observed. We are in the process of converting all the data shown to flux values with which we hope to be able to provide some estimate of the SO_4 that is contributed to stream flow from acid rain, and some estimate of the cation losses which might be associated with this SO_4 movement through boreal and northern hardwood ecosystems.

LAKE PHYSICAL PARAMETERS AND PRIMARY PRODUCTIVITY

Introduction

One of the core studies to be conducted on all sites is a running estimate of lake physical and biological characteristics including some study of invertebrate communities. The protocol to be used among sites as to the periodicity of sampling has been agreed to among the four NPS units (Sequoia-Kings Canyon, Olympic, Rocky Mountain, and Isle Royale) cooperating in this study. This year survey studies were conducted on Isle Royale twice during May and early June to look at variability during spring runoff, in late July, and in October or early November. The last sample run has not been tabulated yet. Three lakes were sampled during 1984: Trout, Wallace, and Sumner. Two of these lakes were sampled during 1983, and the results presented in last year's annual report. This year Trout Lake, in the Huron Mountains, was added since its watershed has been substituted for Central Lake. These three lakes will continue to be so studied next year except that we plan only one sampling date instead of two in early spring. Winter study of Trout Lake is also possible, but winter biological work on the Isle Royale lakes, beyond determining physical factors, is not logistically feasible. The only possible modification to the sampling protocol next year might be the inclusion of Lake Theresa in the survey to see if it might add to the information base. This lake, which is highly colored, appears to have no perennial surface inflow or outflow. Its chemistry is quite different from Wallace and Sumner, but in many respects it is not representative of aquatic ecosystems on the island. Its proximity to Wallace in particular does make additional study quite feasible.

Methods

Two stations are sampled on each lake. These are located along the long axis of the lake at one-third intervals. Four depths were sampled at each station (0.5, 1, 2, and 2.5 or 3 meters).

Temperature and light attenuation were measured with a lowered thermometer and photocell. A one-liter van Dorn bottle was used to collect water and plankton samples. Specific conductance (Beckman Conductimeter), alkalinity, and pH (Corning Portable), are determined within 12 hours of sample collection. A 60-ml subsample is filtered (0.45 μ filter) and later analyzed for major ion species on an automated Dionex Model 10 Ion Chromatograph. An additional

500-ml is preserved with Lugol's solution and retained for plankton analysis.

Primary production is measured by the in situ ^{14}C Carbon method as outlined by Wetzel and Likens (1979). Samples are placed in 130-ml glass Dissolved Oxygen bottles and inoculated with 1-ml of $5\ \mu\text{Ci NaH}^{14}\text{CO}_3$ from premeasured ampoules using a variable volume repeatable syringe. Two light and one dark bottle are suspended horizontally beneath two separated floats and incubated for 4 hours between 1100 and 1500 hours. After incubation, aliquots from each bottle are filtered through 47 mm Nucleopore ($0.45\ \mu$) filters at less than 380 mm Hg. Filters are folded into Whatman Qualitative filters and sealed in Whirl-paks for travel. Samples are then desiccated for six hours, fumed with HCl for 10 minutes, and desiccated for an additional 4 hours. Activity is determined with a Packard Liquid Scintillation Spectrometer at Michigan Technological University. Carbon assimilation is determined according to Wetzel and Likens (1979).

Chlorophyll a is determined spectrophotometrically as outlined in Standard Methods (1980) and modified for DMSO extraction per Burninson (1979). For this 305-ml subsamples from each depth are filtered through 47mm Gelman Acetate filters ($0.45\ \mu$) at less than 380 mm Hg vacuum. Filters are folded into Whatman Qualitative filters and stored frozen (<30 days) in Whirl-pacs until analysis. The acetate filters are dissolved in 4-ml of reagent grade dimethyl sulfoxide (DMSO) and heated in a 65°C hot water bath for 10 minutes. Samples are then diluted to 10-ml with 90% acetone, agitated on a Vortex Mixer, and centrifuged for 10 minutes. The supernatant is measured and read on a Beckman Spectrophotometer at 750, 665, and 663 nm. To this 30 μl of 4N HCl are added and the samples re-read to correct for over-estimation due to phaeophyton. Chlorophyll a and Phaeophyton a are calculated by Lorenzen's (1967) spectrophotometric equations.

Results

The results presented in Figs. 30 - 34 are for the first three "sets" of 1984. The last "set", ran in late October on Isle Royale and early November for Trout Lake, have yet to be graphed. For simplicity we keep the data presented about equal for each site. Trout Lake is quite deep at one of its two stations (18m), but the data shown below relate only to the upper 5m. Each lake is sampled at two stations. Variation between stations is quite limited except at Trout

Fig. 30.

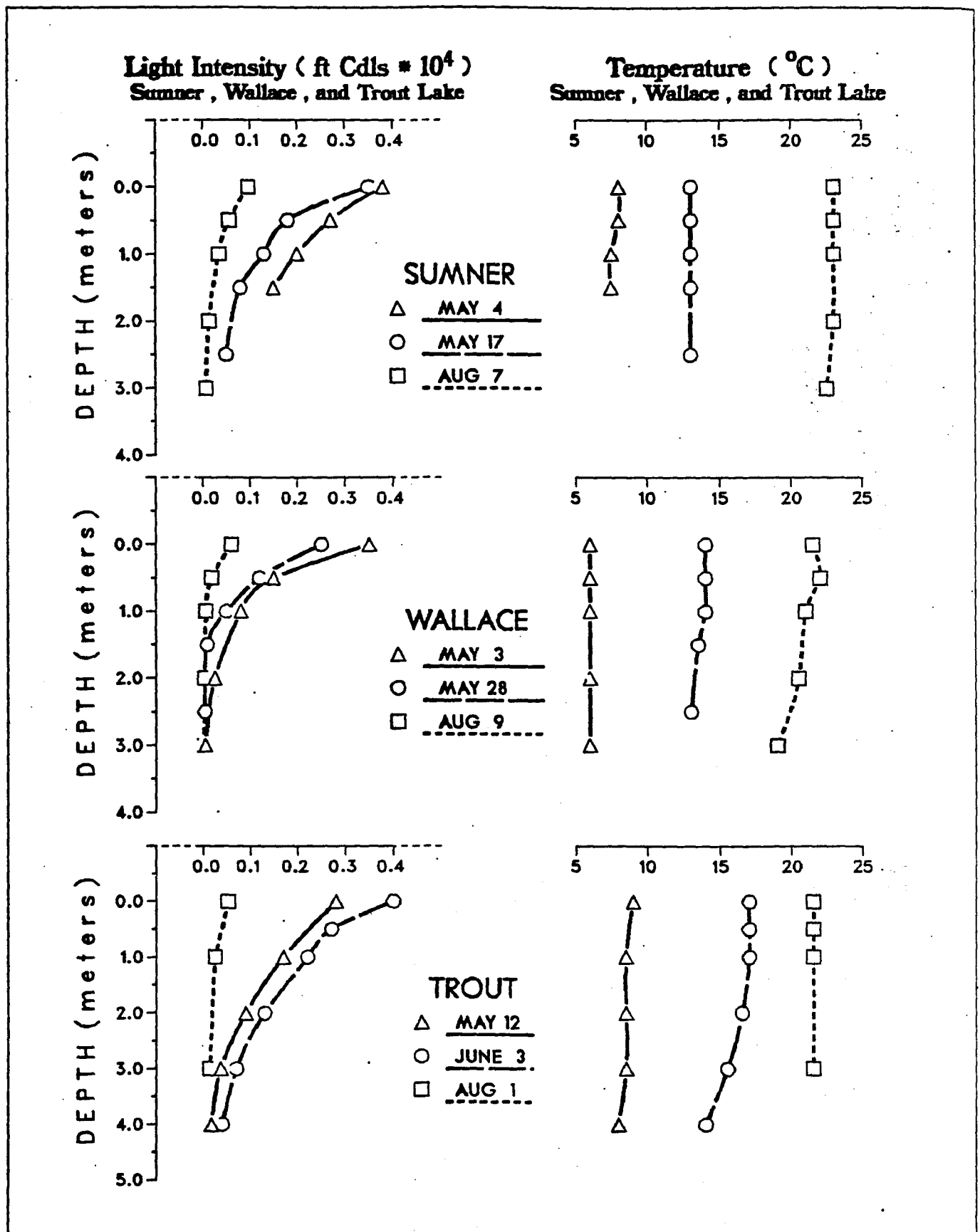


Fig. 31.

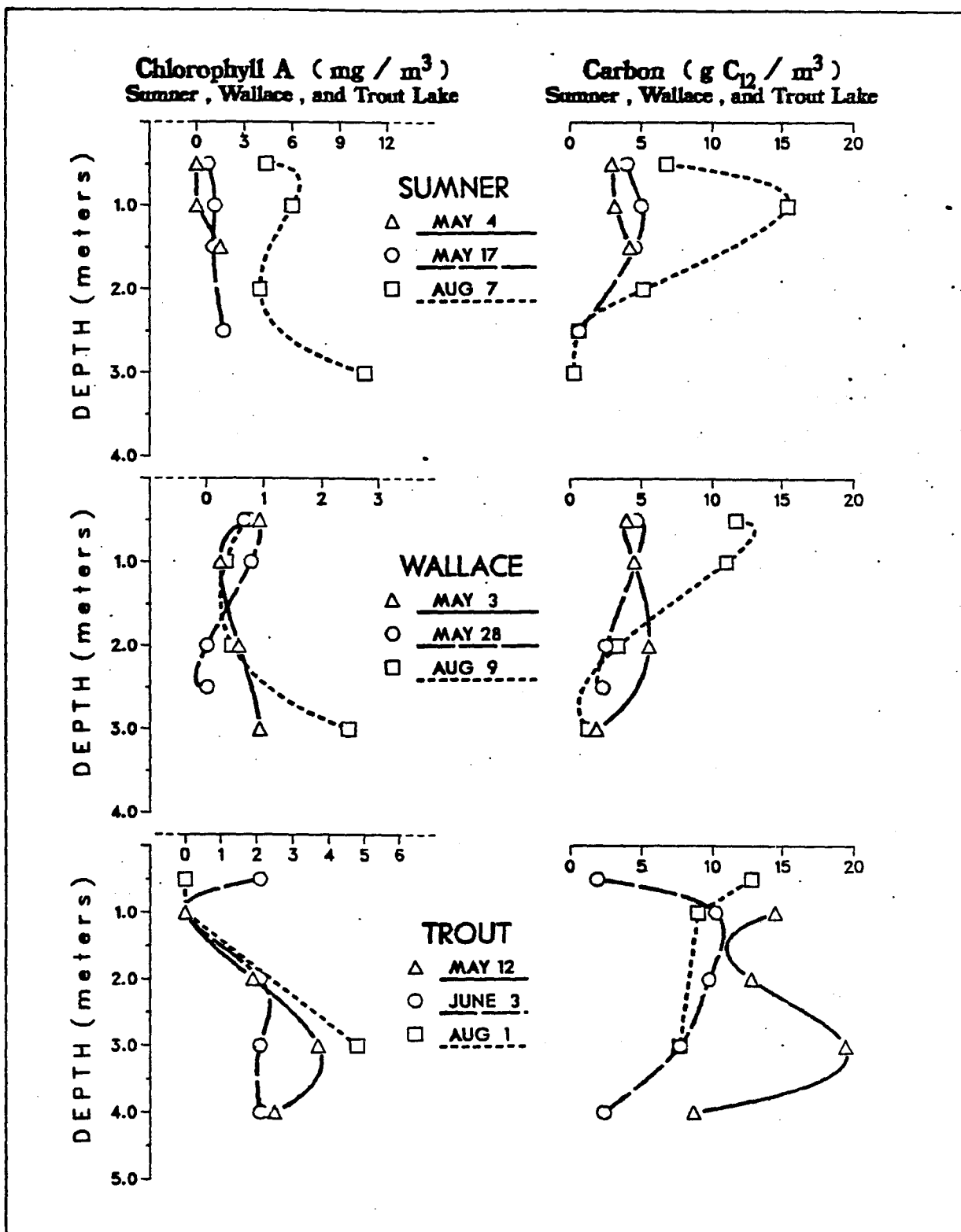


Fig. 32.

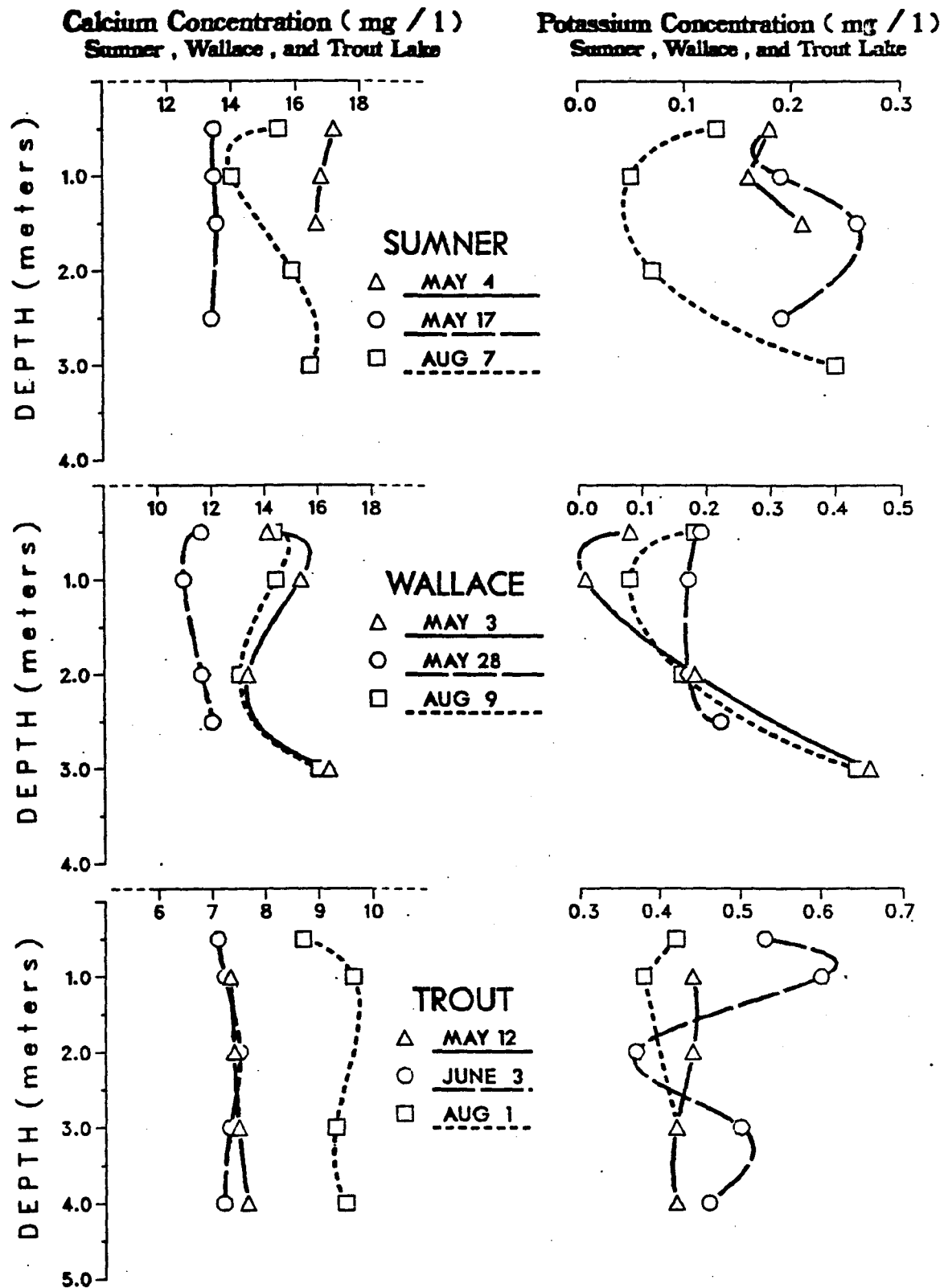


Fig. 33.

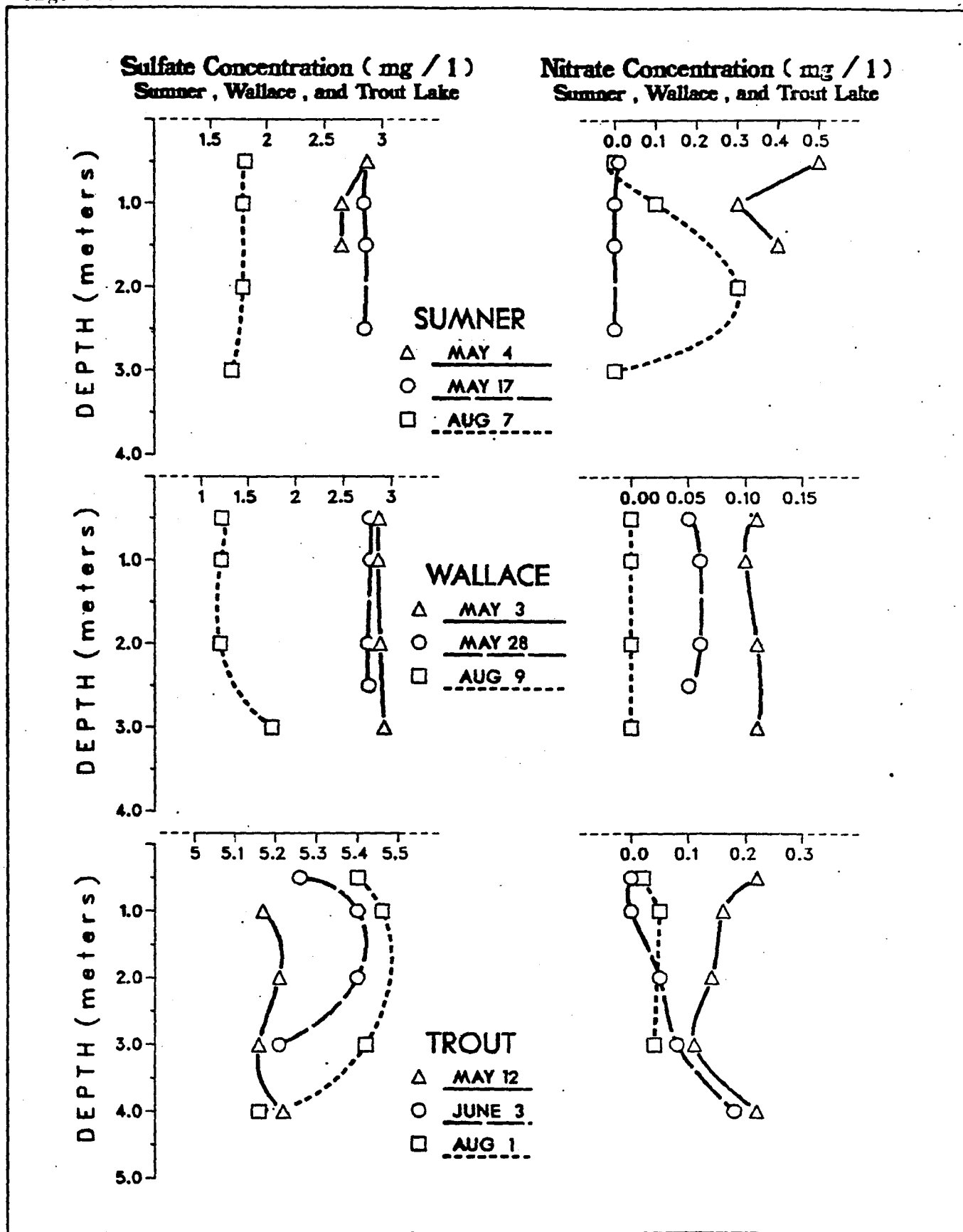
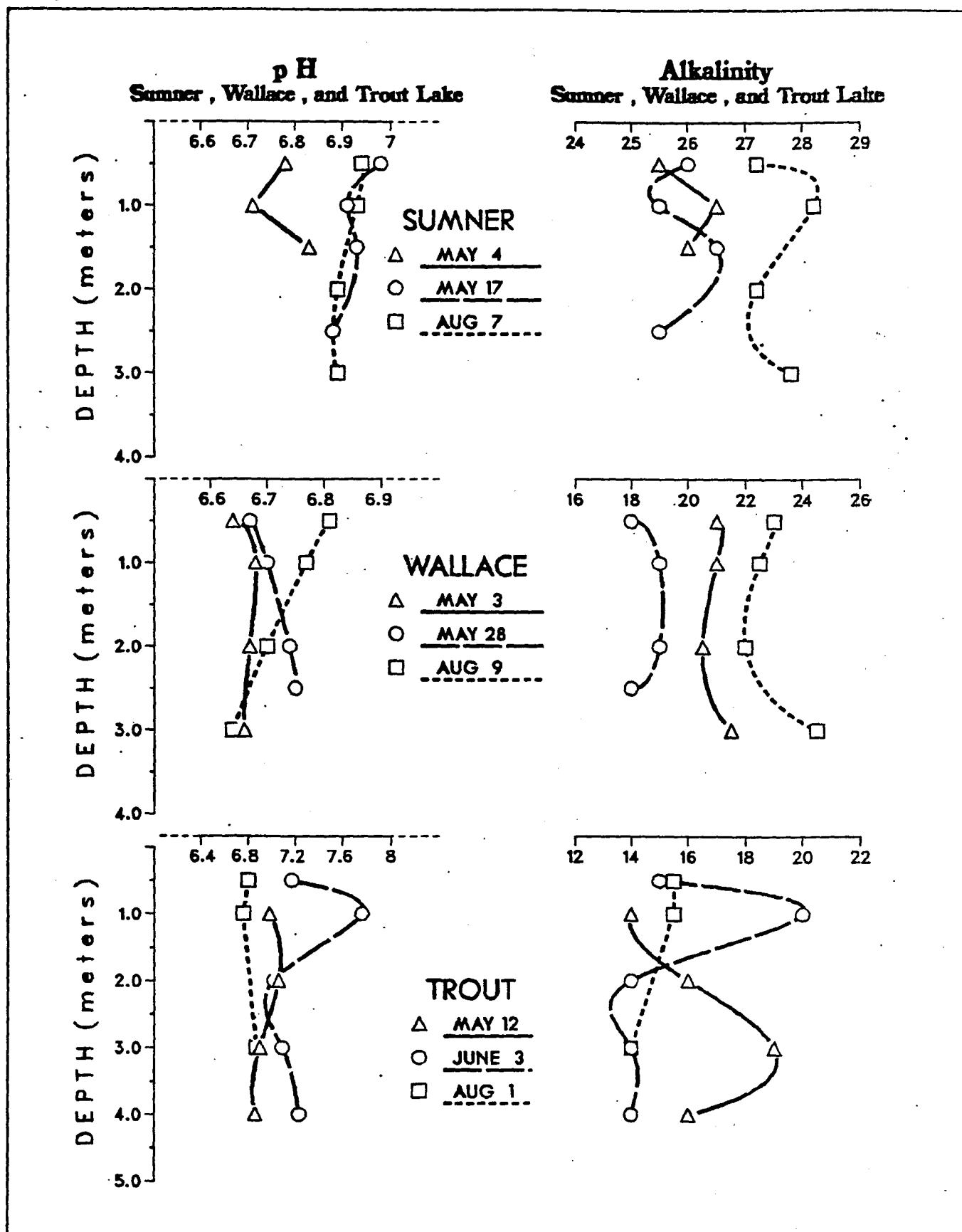


Fig. 34.



Lake. Therefore, the figures below show data for only one of the two stations for each sampling date.

Fig. 30 clearly points out that thermal stratification is non-existent on these sampling dates. Thermal stratification was found at the one station on Trout Lake in August, but that was the only observation. Wallace and Sumner have high surface to depth ratios which is the rule for lakes in this region. Therefore complete mixing is common. The light penetration curves show the mixing of organic material which is particularly heavy in Wallace. The August sampling dates were overcast with fog which accounts for the very low light readings. The lakes do warm up quickly after spring runoff especially Trout which as a southeastern aspect backed by hills.

Chlorophyll a and carbon₁₂ assimilation are shown in Fig. 31. Chlorophyll a values are much below the average generally found in northern Wisconsin lakes, but are 10 to 20 fold the levels found in the nutrient poor Experimental Lakes Area of western Ontario. It should be noted that our C₁₂ values are for the four-hour incubation period, and have not been corrected for daily radiation input. This correction has been made, but is not included in this preliminary printout. Naturally, for the earliest date the radiation input from 1000 to 1400 hours is a significant portion of the daily total, while the summer values would be increased proportionately more by the radiation correction. The correlation between chlorophyll a and C₁₂ production can be explained by the fact the lakes are well mixed which would distribute the active chlorophyll, but the production rate would be limited by light penetration into the lake.

Trout Lake has much lower levels of dissolved solids (Figs. 32 and 33) with one-half the concentration of Ca and HCO₃ found in Sumner. However, it has the highest levels of K and spring NO₃ values were 2x that observed in Wallace. In May Sumner had the highest NO₃ recorded in any lake.

Plankton Analyses

Plankton have been enumerated and qualitatively analyzed for the three lakes on one sampling date. As expected, Sumner and Wallace are much more similar to each other than to Trout Lake in terms of planktonic diversity, total numbers of organisms observed, species composition and productivity as indicated by a qualitative evaluation of such characteristics.

Methods

Unconcentrated plankton samples collected in early May of 1984 were preserved with Lugol's solution until they could be examined. Sample bottles were shaken thoroughly and a 100 ml aliquot of each was filtered through a 5.0 μ nucleopore filter by hand vacuum pump. Low pressures were used to keep cell damage to a minimum. Filters were then placed directly onto slides and viewed with a compound light microscope. The plankton were enumerated by viewing 13 random fields at 400X. Nearly all plankton looked at were smaller than net-plankton (ie. less than 64 μ in longest dimension). Those which had a largest dimension less than 5.0 μ (primarily bacteria) were not observed at all, as they passed through the filters. To derive numbers of organisms per ml of sample water, counted numbers are multiplied by a conversion factor derived from the diameter of the filter, amount of water filtered, and diameter of the field of view on the microscope at 400X.

Total #'s of organisms observed on 13 random fields.
(To get avg. #/ml original sample, multiply by 8.39)

lake	depth	station	
West		East	
T	0.5m	134 (58) 1*	164 (103)
S		74 (60)	73 (49)
W		98 (78)	72 (60)
T	1.0m	126 (81) 1*	126 (73)
S		136 (93)	134 (94)
W		108 (86)	122 (92)
T	1.5m	ns	ns
S		116 (75)	153 (93) 1*
W		ns	ns
T	2.0m	70 (44)	128 (77)

W		102	(77)		106	(79)
T	3.0m	117	(44)	3*	88	(49)
W		120	(90)		115	(81)
T	4.0m	129	(45)		91	(53)

* = larger zooplankton

() = diatom subset

Note: Trout Lake samples collected 6/3/84

Wallace Lake " " 5/3/84

Sumner Lake " " 5/4/84

Species diversity:

Bacillariophyceae		
Fragilaria sp.		T, W, S
Tabellaria sp.		T, W, S
Synedra sp.		T, W, S
Centronella sp.		T, W, S
Melosira sp. (B-8)		T, W, S
Achnanthes sp.		T, W, S
Navicula sp.		T S
Tetracyclus sp. (A-11)		T
Denticula sp.		T
Cyclotella sp.		T
Tetrahedron or Staurostrum sp.		T
Asterionella sp.	T	
Cocconeis sp.?		W
Peridineeae		
Ceratium sp.		T
Peridinium or Glenodinium sp.		T
Cyanophyta		
Nostoc or Anabaena sp.		T
Merismopedia sp.?		W, S
Oscillatoria sp. (E-12)		T
unID'ed unicellulars (A-14), (E-7)	T	
Chlorophyta		
Oedogonium sp. (G-5), (D-12)		T, W, S
Cryptophyceae		
Polytoma sp.? (A-5)		W, S
Rhodomonas sp.? (B-12)		T
(possibly biflagellate algal gametes)		

Chrysophyta		
Dinobryon sp.(stipitatum or sertularia)	T	
Bacteriophyta		
(C-14),(G-6),(G-8)	T,W,S	
Other Protozoa		
Diffugia sp. (Rhizopodia)	T	
(E-9)		S
Larger Zooplankton		
Bosmina sp. (a cladoceran)	T	
Polyarthra sp. (a rotifer)		S
ostracods	T	
calanoid copepods	T	
nauplius larvae	T	
UnID'ed		
(several; check drawings)		

Discussion

Trout Lake shows greater comparability to lakes in the ELA of NW Ontario than either Wallace or Sumner lakes, particularly as regards species composition and planktonic diversity. Although samples from Trout Lake were collected nearly a month later than those for the Isle Royale lakes, this time lag appears insufficient to explain such primary differences in the species compositions of Trout vs Wallace/Sumner lakes.

Schindler and Holmgren ('71) found that the algal class Chrysophyceae dominated the plankton communities of most of their lakes. This was the largest algal group in ELA, with the genera *Dinobryon*, *Mallomonas* and *Ochromonas* being most important. *Dinobryon*spp. were the only of these found in Trout, however they were the single most abundant organisms (in terms of actual #'s) when these samples were taken in early June. None of the Chrysophyta were found in either of the Isle Royale lakes. This is interesting in that *Dinobryon*spp. are often used as indicator organisms, and are found especially in oligotrophic, less productive and sensitive lake types. These have been worked on in the Alps, etc. High levels of phosphorus are toxic to *Dinobryon*spp.

In total numbers, the Bacillariophyceae (the diatoms) were the most important as a whole group in all three lakes. They comprised a higher proportion of the total plankton in Sumner and Wallace lakes than in Trout. Five species were found only in Trout, (including *Asterionella* sp. and *Cyclotella* sp. which are often indicative of lakes with silica to $< 0.5\text{mg/l.}$), whereas no species were exclusive to the Isle Royale lakes only. High numbers of diatoms in all samples may be the result of times of sampling, where spring maximums are the result of "diatom blooms" associated with specific environmental changes at that time of the year (see Fig. 31, Trout Lake for May 12).

The Cyanophyta and Chlorophyta comprised relatively insignificant parts of the planktonic communities, as was also the case for the great majority of ELA lakes looked at by Schindler. Although more types of these groups were found in Trout Lake, actual numbers were greater in the Isle Royale lakes. Blue-green and green algal productivity is likely to increase further into the summer in all three lakes, as was the case at Clear Lake where primary productivity was studied by Schindler and Nighswander

(1970). Among the Pyrrophyta, the only Peridineae (dinoflagellates) observed occurred in Trout Lake, where they were very low in total numbers. Yet these had substantial populations in Schindler's "Class C" lakes of the ELA (ie., shallow, weakly stratified lakes where diatoms are usually pretty important). The same genera of Peridineae found in ELA lakes by Schindler et al were also those found in Trout Lake; namely *Ceratium* sp. and *Peridinium* and/or *Glenodinium* spp. Another group of Pyrrophyta, the Cryptophyceae (cryptomonads) were of much less importance in T, W, & S lakes than in the ELA lakes. Possibly one species of cryptomonad was found in Trout which was also found in the ELA surveys, that being *Rhodomonas* sp. The only other possible cryptophyte was found in the Isle Royale lakes, but not in Trout.

Notice that the phytoflagellates found, *Dinobryon* sp., *Ceratium* sp., *Cryptomonas* sp., *Peridinium*/*Glenodinium* sp., etc., all tend to be plankton species which can survive through the winter. They can tolerate low temperatures, very low light intensities, and winter stratification. This could give them a jump on things in the earlier parts of spring. This is when the samples from Wallace and Sumner lakes were taken.

The Euglenophyta, which Schindler and Holmgren say "was the least important one in the ELA," also were not observed in the three lakes discussed here although this does not mean that they are not present, possibly in very small numbers or at a different time of the year. Concerning other protozoa, the only type found was *Diffugia* sp. (a rhizopod) which was in Trout Lake. Another unidentified form may also have been present, but was only seen in the samples from Sumner Lake.

The bacteria were not really examined, as they generally passed through the nucleopore filters (5.0 μ) through which the straight water samples were filtered. Yet some bacteria were observed, especially unidentified bacilli and chains of streptobacilli. Any bacterial types that were noted occurred in all three of the lakes from which samples were collected. As with Schindler et al, these were not considered in the enumerations.

The fact that very few of the larger zooplankton were observed is not surprising. No cladocerans, copepods, ostracods, nor zooplankton in general were found in the early May samples from Wallace or Sumner lakes. One exception being *Polyarthra* sp. (a common rotifer) which

was only seen once in the Sumner samples. Time of sampling can account for those zooplanton observed among the Trout Lake plankton: *Bosmina* sp. (a cladoceran), calanoid copepods, ostracods, and unidentified nauplius larvae. Though observed, these were quite rare (ie., only two or three per 100ml of raw water. The fact that no larger zooplankton were really in evidence in the Isle Royale lakes has no bearing on the relative productivities of the lakes as compared to Trout Lake. Note that water temperatures at Trout in early June were three to five degrees higher than those at the other two lakes in early May when samples were collected.

Although species composition may be similar in some respects in Wallace, Sumner, and much more so in Trout Lake to those observed and described by Schindler et. al. for Canadian Shield lakes (particularly the ELA lakes), this similarity is only weakly defined and inconclusive in light of the small number of samples enumerated thus far.

SNOWPACK NUTRIENT DYNAMICS IN LAKE SUPERIOR ECOSYSTEMS

Introduction

Since 1979 we have been closely monitoring winter precipitation inputs, snowpack accumulations with changing elevation, and streamflow quality and quantity during spring snow melt for three gaged watershed ecosystems. Initial data are extensive, but during the last three winters we have intensively monitored one watershed to look at the above characteristics and also changes in the nutrient content at different depths within the snowpack. Our conclusion for the period we have been sampling is that the existence throughout winter of thawed soils beneath the snowpack is a significant factor in reducing the solute (natural and contaminant) load of the snowpack before most of its moisture is released with spring melting. A summary of our methods and results for one season are given below. A more detailed text has been prepared, revised, and is again out for review prior to publication.

Methods

In the fall of 1979 three transects with northwest aspects and adjacent Lake Superior were located on Isle Royale National Park, Michigan's Keweenaw Peninsula, and at Pictured Rocks National Lakeshore along Lake Superior's south shore. Each transect has four stations with the first at or near the mean elevation of Lake Superior (183m) and subsequent stations located at approximately 225, 260, and 295m respectively. Each station was equipped with a bulk precipitation collector (0.36m diameter) and a snowpack measurement course marked. Most of the results presented below relate to the intensive sampling done on the Keweenaw site. These stations are located in a small (176ha) forested watershed drained by a gaged first-order stream which has been monitored for four years. Sampling is done weekly except during periods of rapidly changing stream discharge when a Manning auto-sampler is used to collect samples every six hours. Sampling is done on Tuesdays to coincide with precipitation collection at the nearby (16km) NADP site (MI 222570). During winter five snowpack measurements are taken at each station using a Mt. Rose sampler. Samples retained for chemical analyses are collected using a 10cm diameter PVC tube. At the uppermost station subsamples are taken from the snowpack at every 7.5cm change in depth, and a snowcutter used to measure density at each depth. Soil temperature was recorded using a thermometer equipped with a stainless steel sensor.

Samples are immediately brought into the laboratory at Michigan Technological University, and snow samples are melted at room temperature in carefully rinsed containers. All containers are covered during sample melting. Ph, specific conductance, and alkalinity (stream samples) are determined as soon as samples achieve room temperature. Filtered (0.45μ) subsamples are refrigerated (2°C) and chemical analyses for Ca, Mg, Na, K, NH_4 , Cl, NO_2 , NO_3 , PO_4 , and SO_4 conducted within one week using ion chromatography.

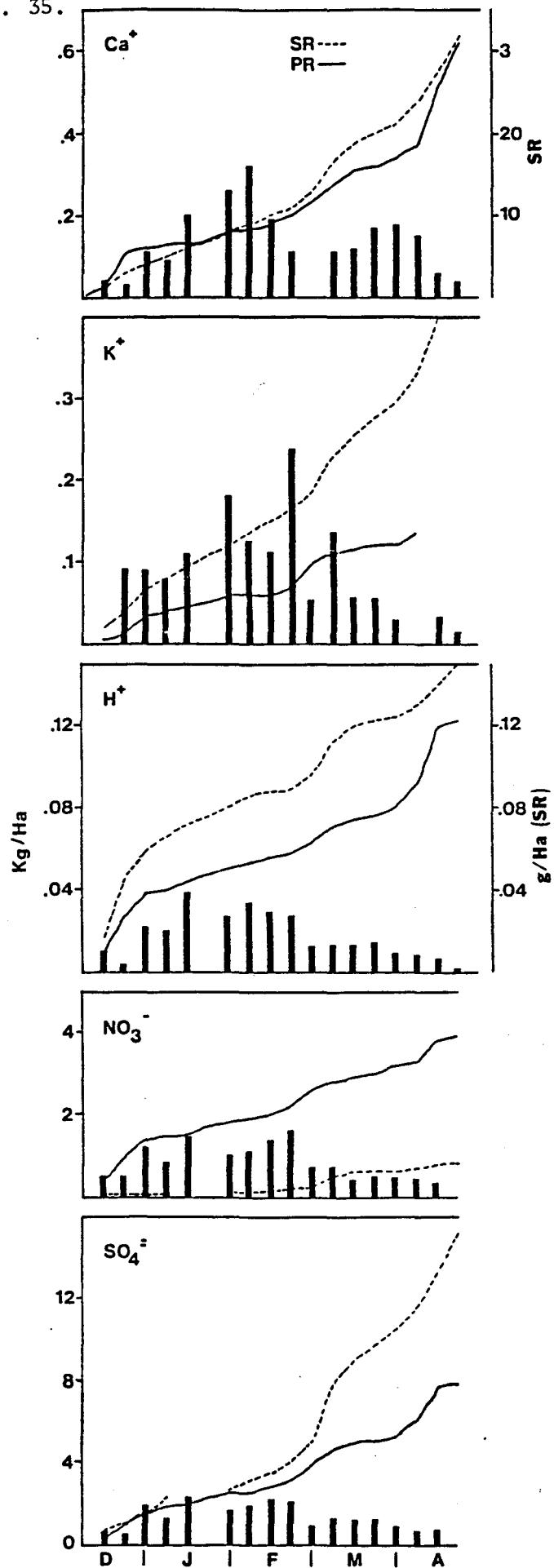
Results

Only summary ecosystem budget data will be presented below. Details regarding snowpack nutrient dynamics will be published shortly.

Fig. 35 shows the weekly mean (four stations) snowpack nutrient content, mean cumulative ionic input from precipitation (four stations), and cumulative watershed outputs for selected ionic species. Before mentioning specific comparisons it should again be noted that the snowpack this winter (1982-83) was not particularly large and was subject to earlier than usual thaws. With the possible exception of potassium, the snowpack was not a significant accumulator of precipitation inputs beyond the first week of February. In all instances by the second half of February the snowpack had lost a significant portion of its solute load along with nearly one-half its maximum water content.

The input/output ratio for calcium during this study period was approximately 0.02. This is about one-fifth the longterm value for the equivalent season observed for areas such as Hubbard Brook (Likens et al., 1977). Since this watershed has a metamorphosed volcanic substrate the rather high amounts of calcium being discharged must be coming from the glacial till deposits. Effervescence with the addition of acid to soil samples in the region is not unusual (S. Shetron, Michigan Tech University, personal communication, 1980). No ready explanation exists for why the calcium load in the snowpack exceeded the cumulative precipitation inputs for a few weeks in January and early February. High levels of dry deposition certainly is a possibility as is sample contamination. Most of these high calcium values in the snowpack were observed during the initial thaws in January and early February. During January and February the snowpack gained in calcium content. With the two-week thaw period in late February the snowpack lost about 45% of its

Fig. 35.



moisture content and 65% (0.22kg/ha) of its calcium content. During this same period precipitation only added 2g/ha while losses in stream flow amounted to 1.6kg/ha. The snowpack never regained a significant portion of calcium lost despite continued precipitation inputs as snow. The snowpack remaining on the ground in early April contained less than one-half the calcium which had entered the ecosystem as precipitation during the study period. Quite by chance the low average moisture content of the snowpack during the winter of 1982-83 is very close to that observed in a snowpack study at Hubbard Brook in 1972-73. The mean calcium content in the two snowpacks is nearly identical and the precipitation inputs are also quite similar.

For potassium the amount found within the snowpack often exceeded the cumulative input from precipitation. This occurred throughout the sampling period, and on many occasions the snowpack load exceeded the precipitation inputs by a factor of two or more. This has also been found in other studies. The reason for this is not clear but it is hypothesized that this could represent leaching of organic matter in the snowpack. This is possible for the present study since three of the open areas used for snowpack sampling had some taller grasses incorporated in the snowpack for the winter. And all sites are bordered by species such as birch which have a lot of cone scales and even seeds which are blown around and deposited in the snowpack during the winter. The ratio of precipitation input to stream discharge was 0.32, a value much higher than observed for calcium and slightly higher than the 12-year seasonal record for Hubbard Brook. However, both input and output levels during this study were below long-term records at Hubbard Brook. As with calcium the potassium content of the snowpack and the cumulative precipitation inputs are very similar to those levels observed at Hubbard Brook. By late March the snowpack contained about 0.05kg/ha potassium or about one half the accumulated precipitation value of 0.12kg/ha, a ratio very similar to that observed for calcium. In general the discharge of potassium in streamflow seemed little influenced by the dynamics of the snowpack. The only possible exceptions to this might be the increase in discharge during the thaw of middle March and losses of the remaining snowpack in middle April. However, in both instances these were periods during or immediately following increased precipitation inputs.

The nitrate content of the snowpack very closely followed precipitation inputs until the first mild thaw in late January. In February the snowpack gained in nitrate during a period of steady precipitation inputs and concurrent gain

in moisture content of the snowpack. With the late February thaw the snowpack nitrate content dropped from its maximum value of 1.6kg/ha to 0.7kg/ha and never again gained any significant amount. In contrast to the long-term input/output ratio of 0.65 observed for nitrate at Hubbard Brook, the input/output ratio was 4.3 during this study. The ecosystem is retaining about 75-80% of the nitrate which fell. This is significant for this is a season of relatively little biological activity. This indicates that quite a bit of biological activity might be going on especially in such areas where the soil remains thawed throughout most of the winter. A pronounced increase in the rate of nitrate discharge from the ecosystem was noted during the period of rapid snowpack thaw in late February. However, the actual nitrate discharge during the two week period was only 0.32kg/ha while during the same period the snowpack lost 0.90kg/ha and precipitation added 0.63kg/ha. Again, fully 80% of the nitrate input and release was retained somewhere in the ecosystem. During April, a period of increased biological activity, the ecosystem was even more efficient in nitrate retention. During the first four weeks of the month the snowpack lost 0.5kg/ha and precipitation added 0.78kg/ha but stream discharge amounted to only 0.20kg/ha, indicating a retention of about 85%. This ability to retain nitrate inputs even during periods of rapid snowpack melt has particular ramifications in a region where it appears that anthropogenic atmospheric inputs of nitrate are on the increase.

Sulfate content of the snowpack also closely followed precipitation inputs until the first thaw in late January. During the first three weeks of February sulfate accumulated in the snowpack following a pattern nearly identical to nitrate. During the late February thaw the snowpack sulfate content dropped from 2.25kg/ha to 0.94kg/ha and for the duration of the winter and spring the snowpack content never increased significantly from this level. During this same two week period precipitation added 1.09kg/ha and stream discharge amounted to 1.55kg/ha for a net retention of sulfate within the ecosystem of about 0.85kg/ha. However, as can be seen in Fig. 35 this was just the beginning of a period of rapid increase in stream discharge of sulfate, a pattern which was apparently only slightly influenced by subsequent losses of sulfate from the snowpack and that added by precipitation. On the first of March the mean snowpack sulfate content was 0.94kg/ha. From this date until termination of the study at the end of April precipitation added 3.91kg/ha sulfate, but stream discharge for this period amounted to 10.65kg/ha an amount over two-fold input and that melting from the snowpack. This

discharge was at a rather uniform rate. For the entire 18-week study sulfate discharge was exactly two-fold inputs from precipitation. During late March and early April, a period during which the snowpack lost approximately 65% of its maximum moisture content it is quite evident that the snowpack content of sulfate had very little influence on ecosystem discharge. There was very good correlation with precipitation inputs although the latter were again only about one-half the discharge rates.

Sulfate inputs during the 18-week study amounted to 7.85kg/ha compared to 3.89kg/ha for nitrate. At the time of maximum snowpack in middle January the ratio of sulfate to nitrate in the snowpack was 1.66. Following the February thaw the ratio changed to 1.40, and for the duration of the study the mean ratio was 1.95 while that for precipitation was 2.8. This could indicate slightly better retention of sulfate relative to nitrate in the snowpack.

This difference in the behavior of nitrate and sulfate has ecological ramifications. While there is some evidence that nitrate is increasing relative to sulfate in atmospheric deposition (Verry, 1983) it is quite evident our data indicate that the sulfate anion is the species to be concerned with in considering possible ecosystem cation leaching due to acid precipitation (Johnson et al., 1983). However, caution must be exercised for there is considerable year-to-year variation in snowpack accumulation patterns adjacent the Great Lakes, and evidence of considerable year to year variation in ecosystem response to spring snowpack runoff. This is especially true for those areas where the ground remains frozen until the time of snowpack ripening and melting.

The hydrogen ion content (calculated from pH) of the snowpack followed a weekly pattern very similar to that of nitrate and particularly sulfate. During December and January the snowpack content remained somewhat below that in the cumulative precipitation more so than observed for any other ion species. There is some evidence that hydrogen ion migration in the snowpack is more influenced by the thawed soil surface particularly during early winter. There was some net loss from the snowpack during the brief January thaw, but until the late February thaw the content of the snowpack was quite steady. With the February thaw the hydrogen ion content of the snowpack fell from 29.8g/ha to 12.7g/ha, a decline of almost 60%, and the snowpack content remained at about this level until it began the final decline with snowpack loss in April. During this period of maximum snowpack ionic loss in late February precipitation

inputs were rather uniform and amounted to 7.5g/ha, but stream discharge only amounted to 0.01g/ha. Over 99% of the hydrogen ion input and loss from the snowpack during this period was retained in the ecosystem. The highest stream discharge (140l/sec) occurred in early March, but the pH only dipped to 6.86 at its lowest point. During this period of rapid stream discharge there was considerable diurnal fluctuation in the rate so automatic samplers were in use sampling every six hours on the average. Immediately following this period of maximum rate of snowpack loss of hydrogen ion and water content stream hydrogen ion concentrations gave some evidence of being influenced by precipitation patterns, but the stream concentrations were so low that this could be an anomaly.

Long term seasonal data (November - May) for Hubbard Brook show an input/output ratio for hydrogen ion of about 5 while our study site showed a ratio of 870 for this one sampling period. Only about 0.01% of the hydrogen ion entering the system leaves it. Other cation species, most probably calcium and magnesium, must be involved in maintaining the chemical equilibrium of the discharge.

UPPER PENINSULA SURVEY OF LAKE AND STREAM SENSITIVITY

Introduction

Figs. 36 - 39 display the locations of a group of lakes and streams which were sampled primarily during the years 1979-80. The objective of this survey was to get some idea as to the main factors controlling stream chemistry particularly during low flow, and to get some relative assessment of lake sensitivity and chemistry in Michigan's Upper Peninsula and on Isle Royale. The information would be used to select a series of watersheds possibly with lakes in them that were representative of the region. Once selected more intense input/output monitoring would commence followed by some process studies.

Virtually all the stream data shown in the following figures were obtained in September of 1980 following an eight-week period without any measureable precipitation in the region. This was then found to be the driest summer on record. It could be safely assumed that the stream water represented baseflow conditions, and that it was not at all influenced by precipitation. The lake data also were collected primarily in 1980; however, a fair number were sampled in 1982 especially on Isle Royale and a few have been sampled since. The points on the scatter plots depicting lake chemistry generally represent the mean of a number of samples with n varying from 1 to about 10. All samples were collected in the summer season, and most were collected in late summer or early fall the period of time thought to perhaps best represent equilibrium conditions in this region.

Methods

Most samples were grab samples obtained while doing other sampling in the particular area, or as a result of a specific survey of a special region. All samples were collected beneath the surface with lake samples generally collected at 0.5m depth, and stream samples taken without determining flow. A full set of field data were collected for each sample, and the chemistry ran using procedures reported in the first section of this report. The data are presently on computer files maintained at MTU both on micros and the university mainframe.

Results - Streams

The stream samples will be discussed first, and their sampling locations are shown in Figs. 36 and 37. There is relatively little comparative literature on stream water

Fig. 36. Map of Michigan's Upper Peninsula showing relative location of streams mostly sampled at summer low flow in September, 1980.



Fig. 37. Map of Isle Royale National Park showing relative location of streams mostly sampled in the summers of 1980, 1981, and 1982.

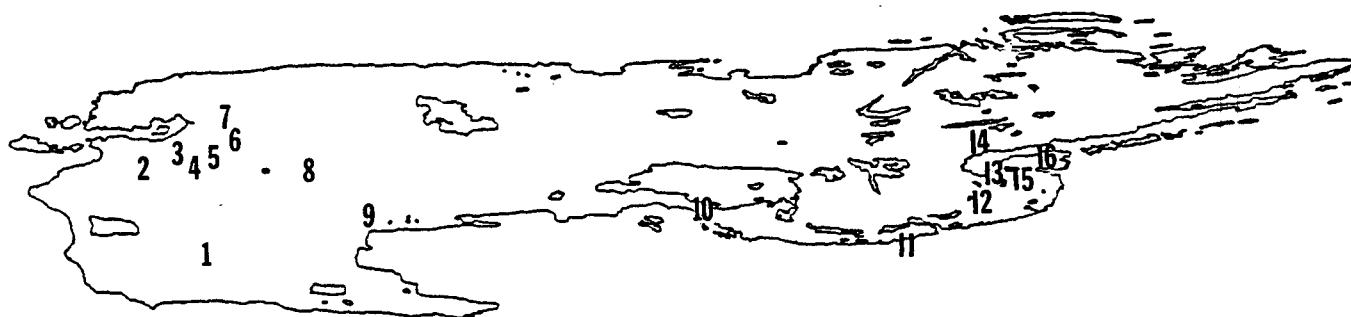
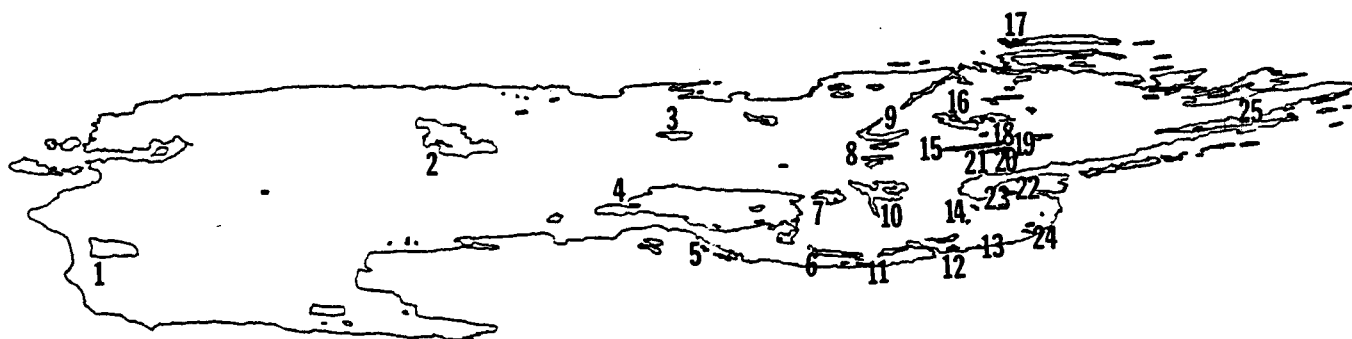


Fig. 38. Map of Michigan's Upper Peninsula showing relative location of lakes mostly sampled in late summer from 1981 - 1983.



Fig. 39. Map of Isle Royale National Park showing relative location of lakes mostly sampled in late summer from 1980 - 1981.



quality in this region since streams are generally thought to be minerotrophic and very well buffered. This is generally the case, but not always (Tom Burton, Michigan State University, personal communication).

Fig. 40 shows the relationship between SO_4 and alkalinity expressed as HCO_3 . In no instance is SO_4 found at levels above HCO_3 . This is also the case found during a year of monitoring streams leading from Minnesota into Lake Superior along the northshore (Wagner and Lemire 1976). In general our survey showed SO_4 increasing slightly to the west. The outlier is from a sample collected at Munising Falls in Pictured Rocks National Lakeshore, and it appears to be contaminated. Our values are generally higher than those found by Kelso (1982) in lakes north of Sault Ste. Marie, Ontario. PH (Fig. 41) when compared to HCO_3 shows a familiar trend, but at a given pH the corresponding HCO_3 is about 3x higher than that found for a similar pH value on the Canadian Shield. Again HCO_3 levels generally increase with the westernmost stations.

HCO_3 and SO_4 clearly are the dominant anions in the region, and Ca and Mg are the dominant cations (Fig. 42). The respective sums considerably exceed those found in surface waters of the Canadian Shield to the east (Kelso et. al. 1982), and on the average exceed those found in Lake Superior tributaries to the west (Wagner and Lemire 1977). However, these samples in all cases represent the maximum concentrations since they were collected at a record low flow. Fig. 43 shows that as the concentrations of Ca and Mg decrease below 1000μ eq another anion, in this case SO_4 , becomes relatively more important.

Fig. 44 shows that in all cases Ca concentrations exceed those of Mg, and that there is apparently little trend with increased alkalinity. However, contrary to many investigations the ratio of Ca/Mg often approaches unity. This is due to the high levels of Mg found locally particularly in areas of large glacial deposits. Such an area is found on the southwest end of Isle Royale.

Figs. 45 - 53 show the relationships between specific cation concentration and specific conductance. Fig. 50 shows the relationship between the sum of all cations in relation to specific conductance. Ca concentrations seem to increase to the west, but there are notable exceptions such as levels found in the Huron Mountains where exposed granitic substrates prevail. But even here the levels exceed those found to the east on similar Canadian Shield bedrock devoid of alkaline glacial till. The monovalents K and Na show rather

Fig. 40. Relation of alkalinity (μeq) to SO_4 .

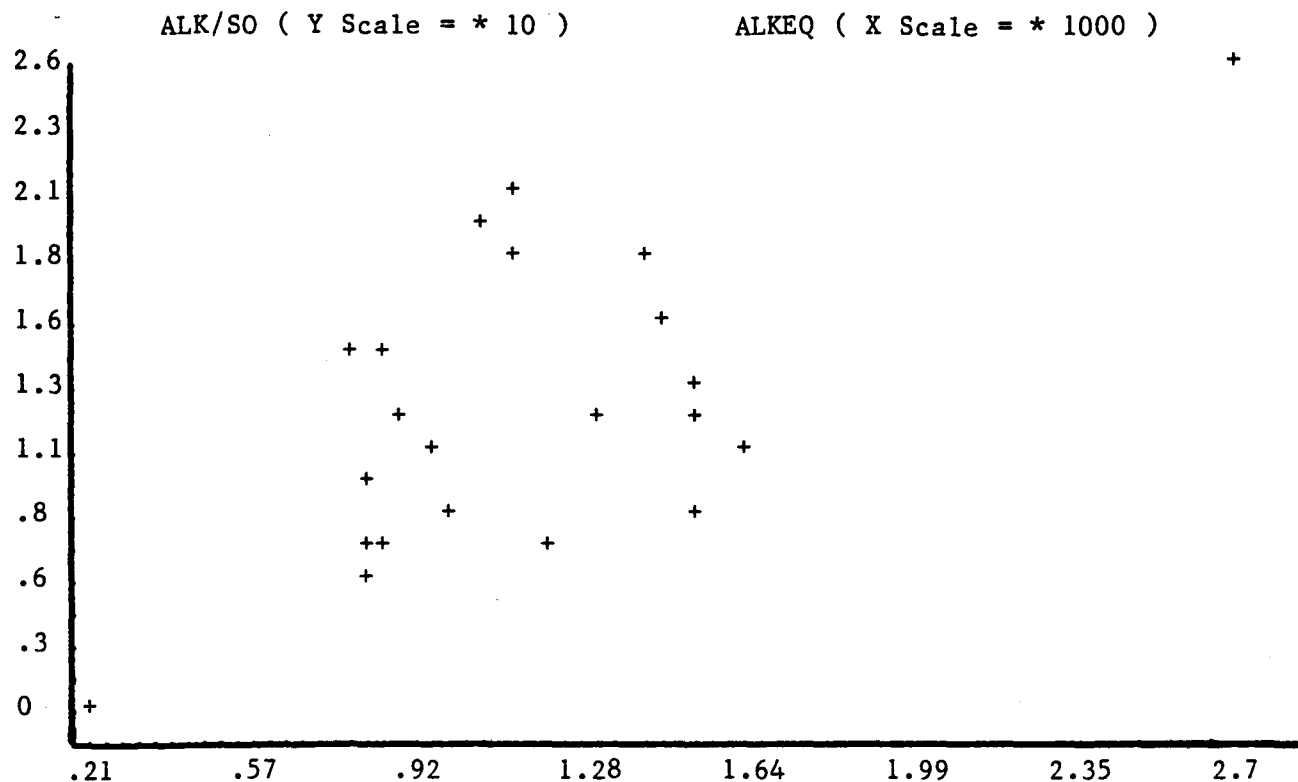


Fig. 41. Relationship between pH and alkalinity (μeq).

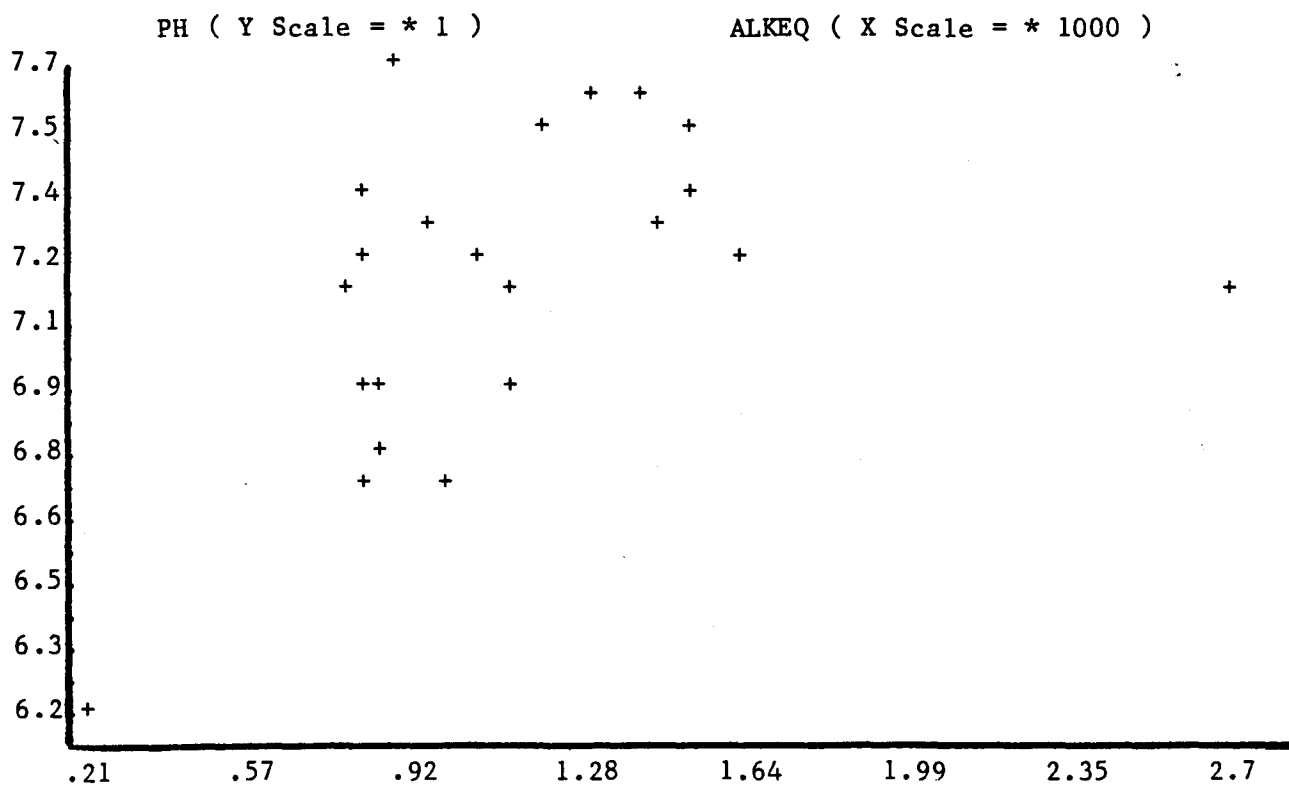


Fig. 42. Relationship of dominant anions and cations.

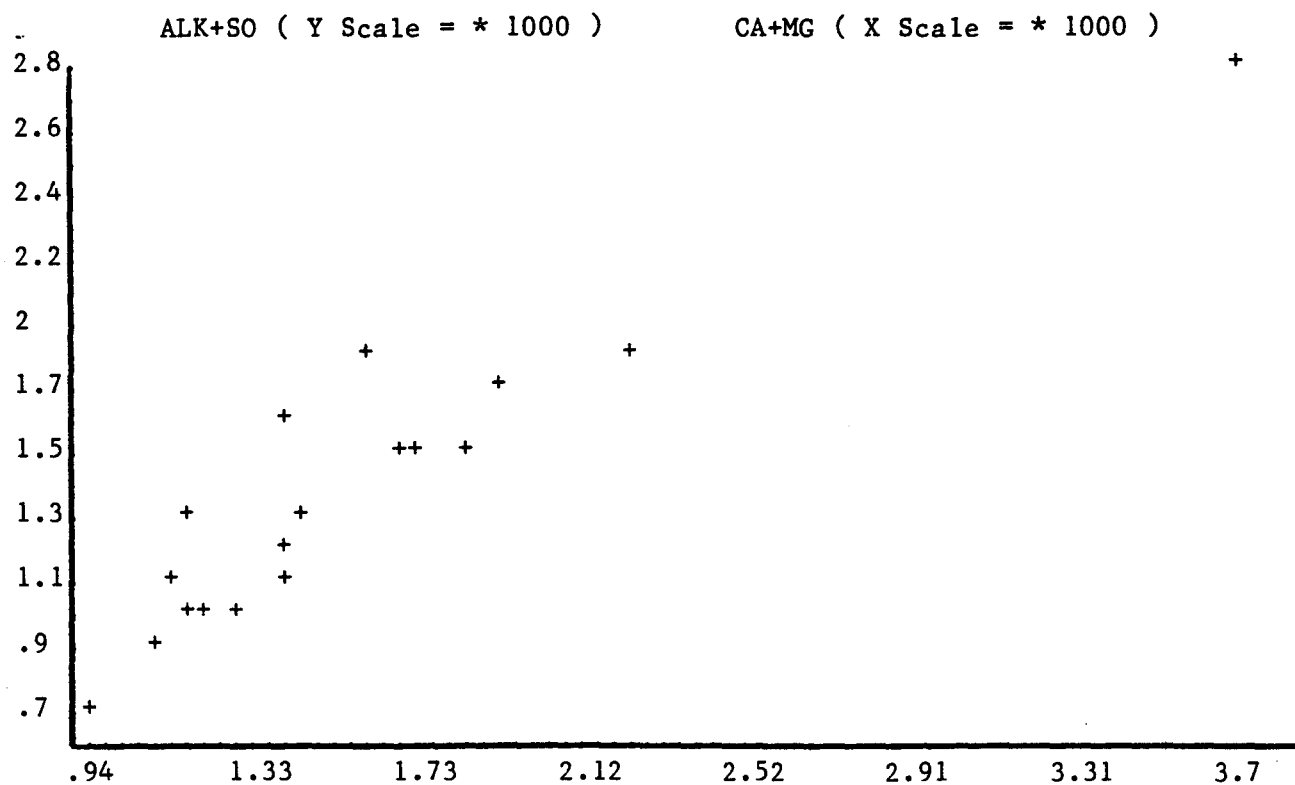


Fig. 43. Relationship of HCO_3 (μeq) to Ca plus Mg.

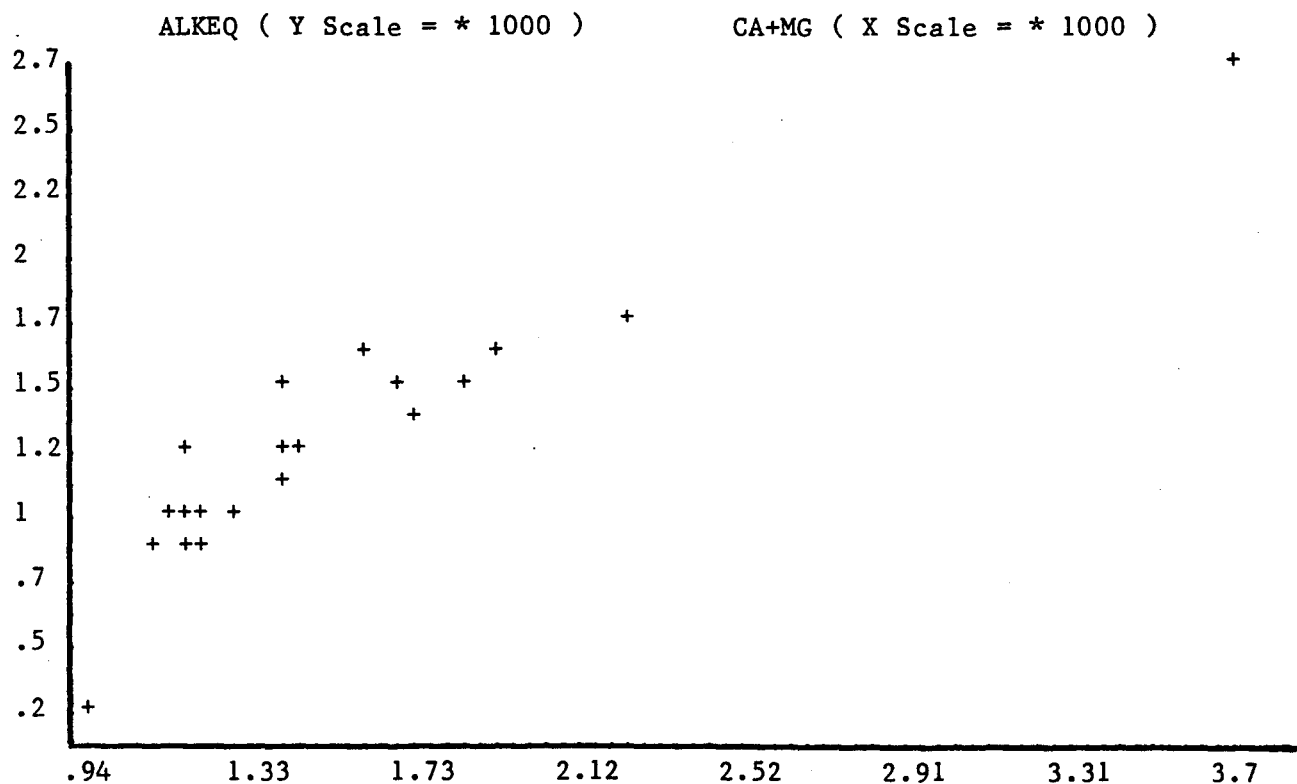


Fig. 44. Relationship of Ca to Mg (μeq).

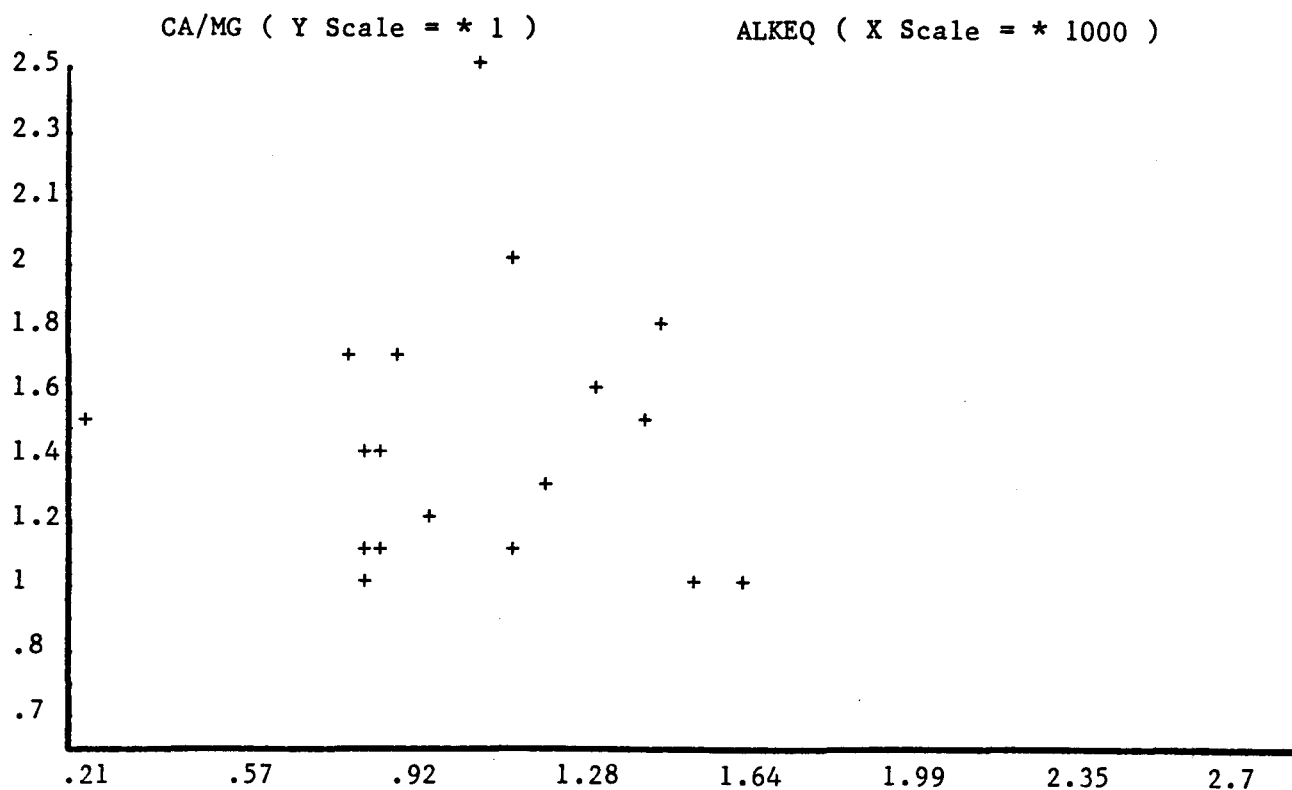


Fig. 45. Relationship of Ca (μeq) to specific conductance.

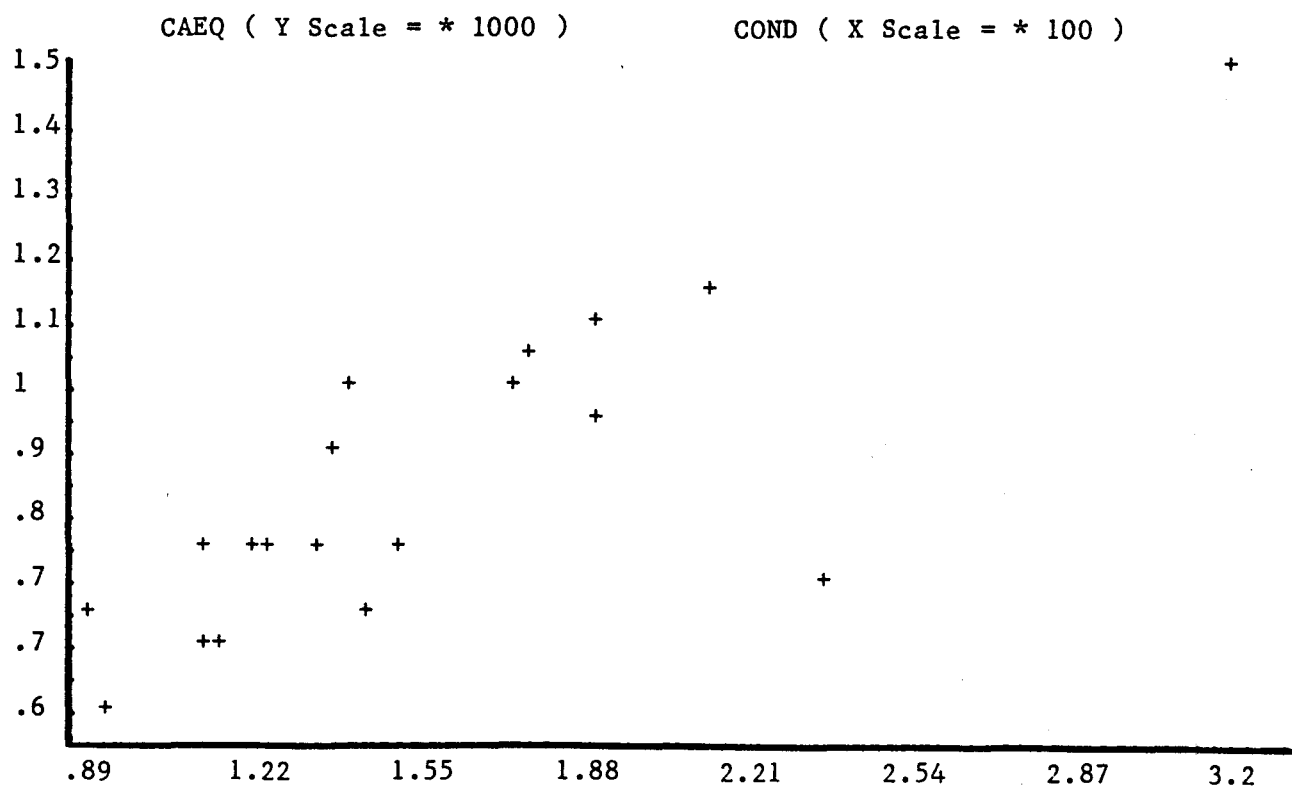


Fig. 46. Relationship of Mg (μeq) to specific conductance.
MGEQ (Y Scale = * 1000) COND (X Scale = * 100)

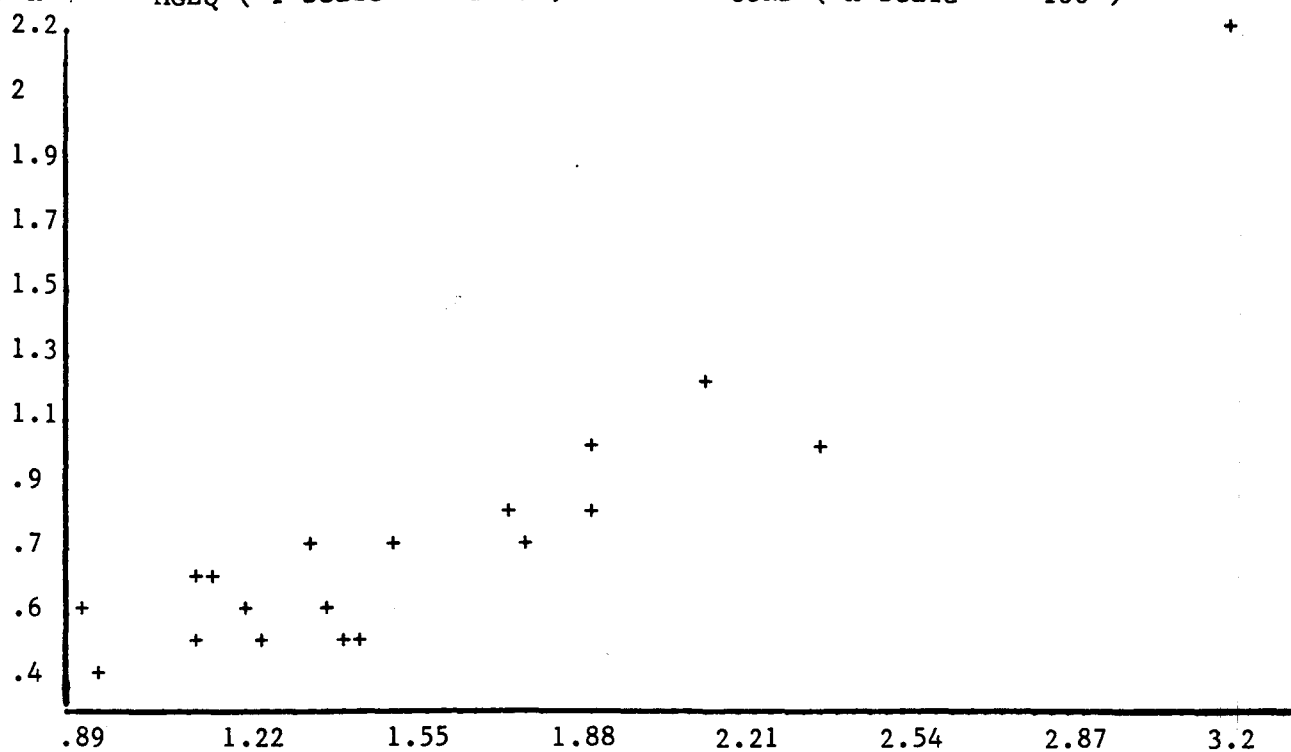


Fig. 47. Relationship of Na (μeq) to specific conductance.

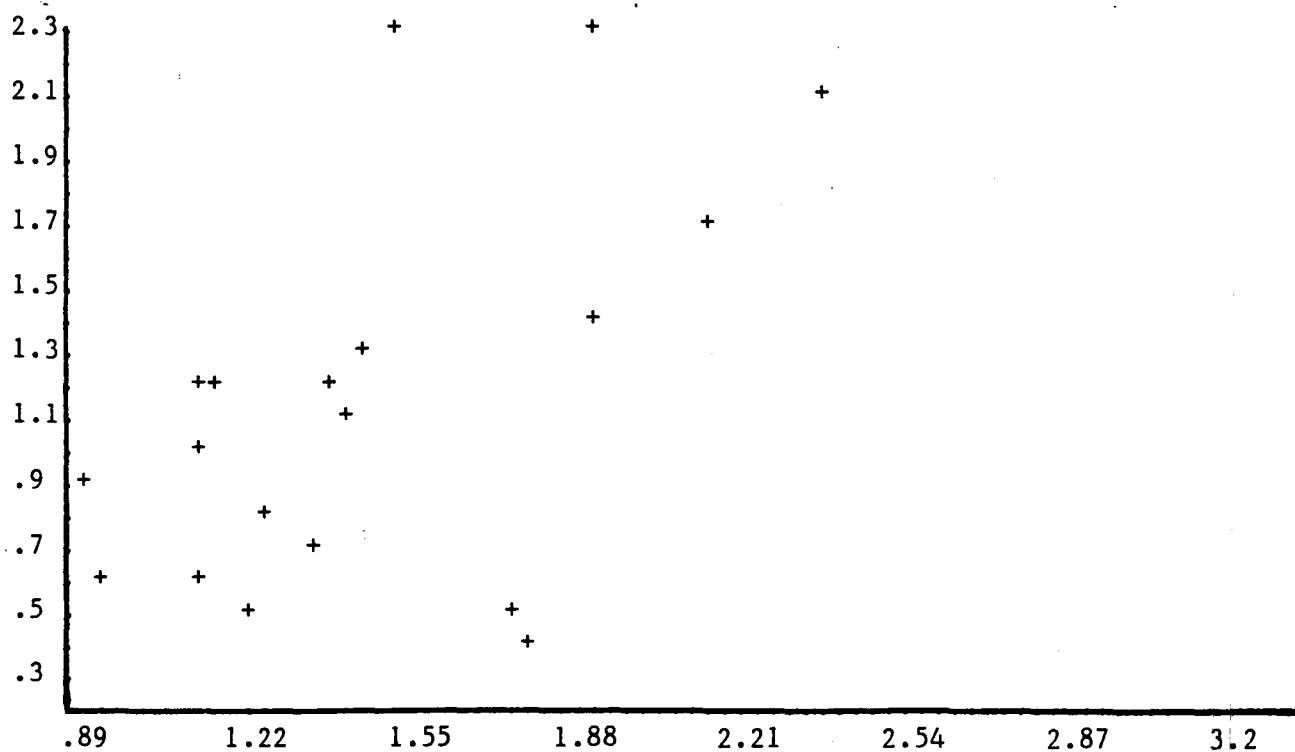


Fig. 48. Relationship of K (μeq) to specific conductance.

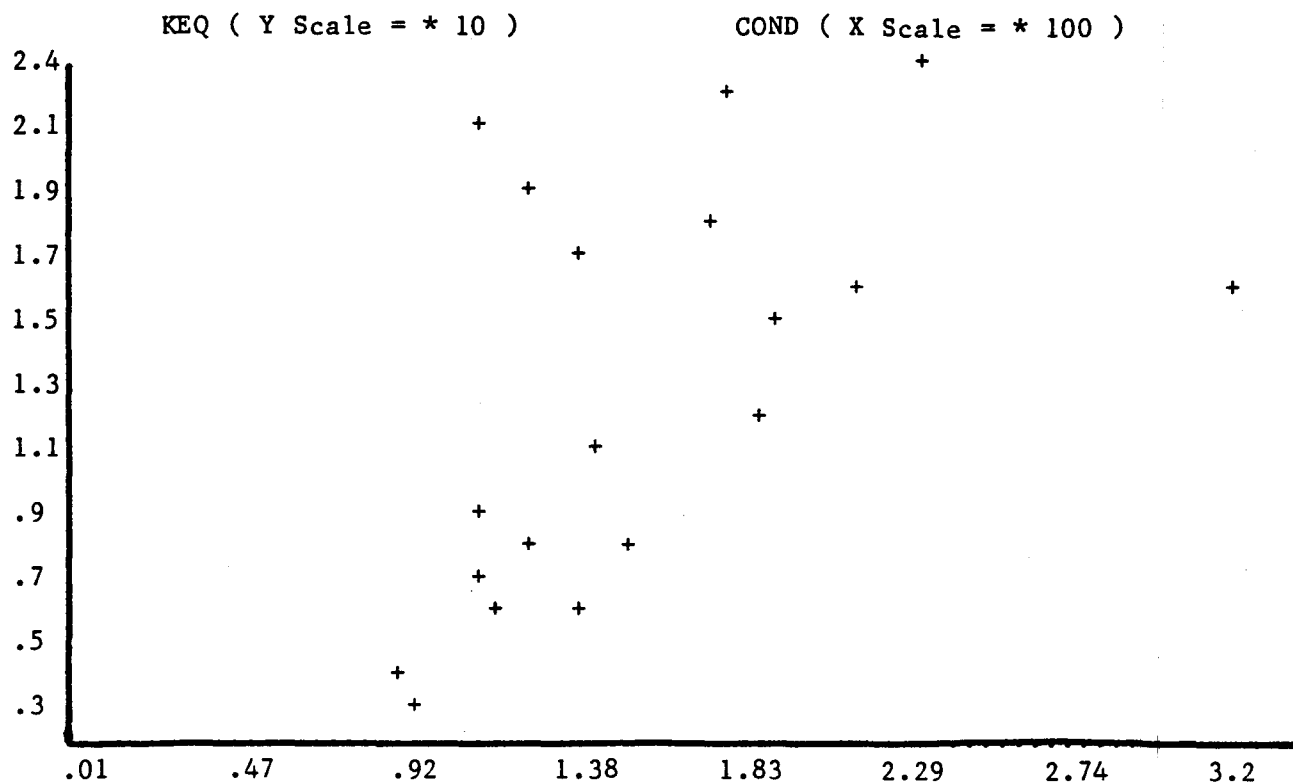


Fig. 49. Relationship of HCO_3 (μeq) to specific conductance.

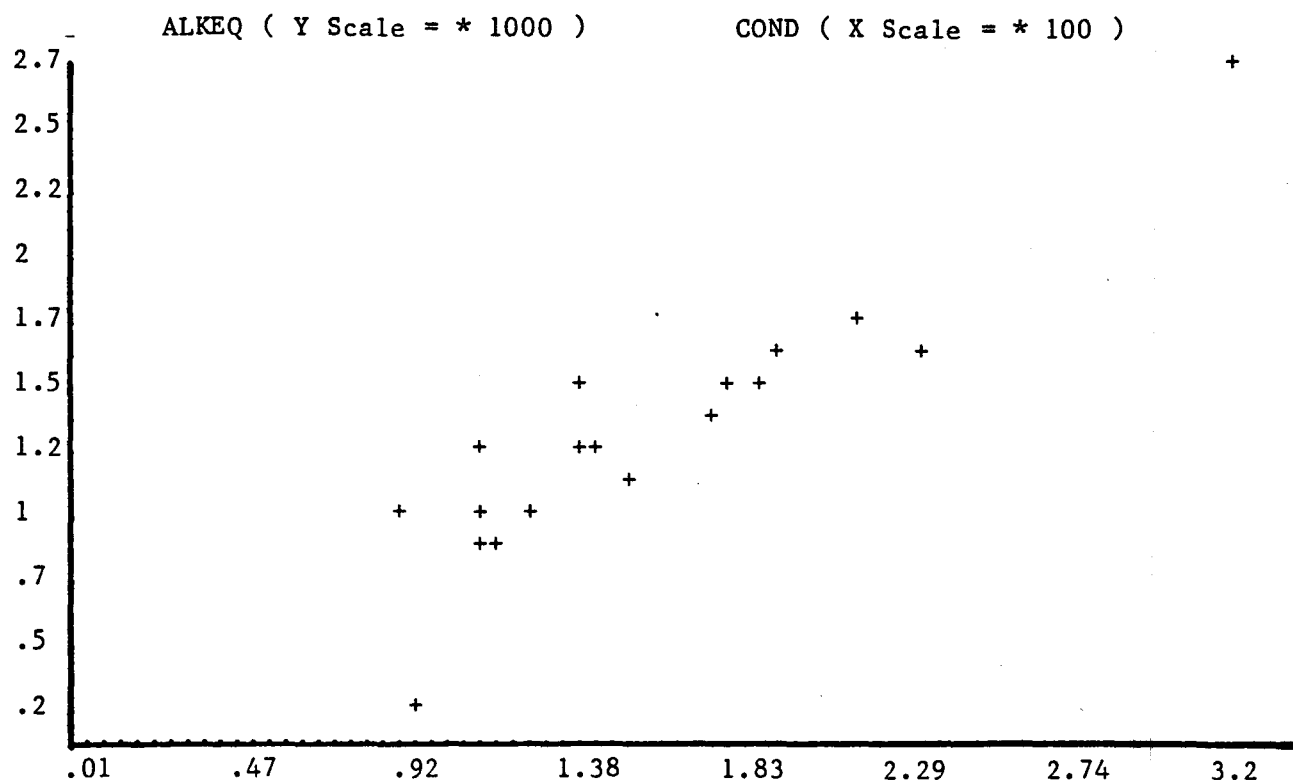


Fig. 50. Relationship of sum of cations (μeq) to specific conductance.

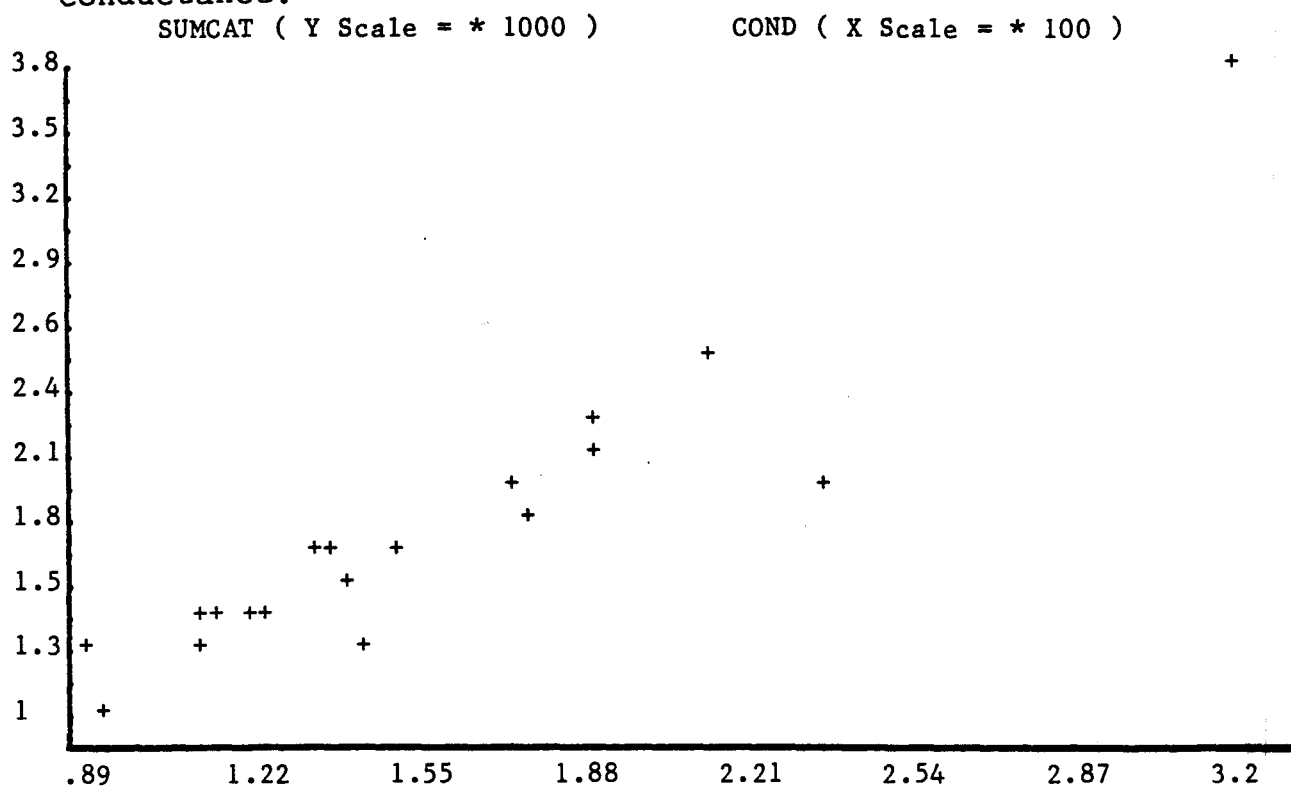


Fig. 51. Relationship of Cl (μeq) to specific conductance.

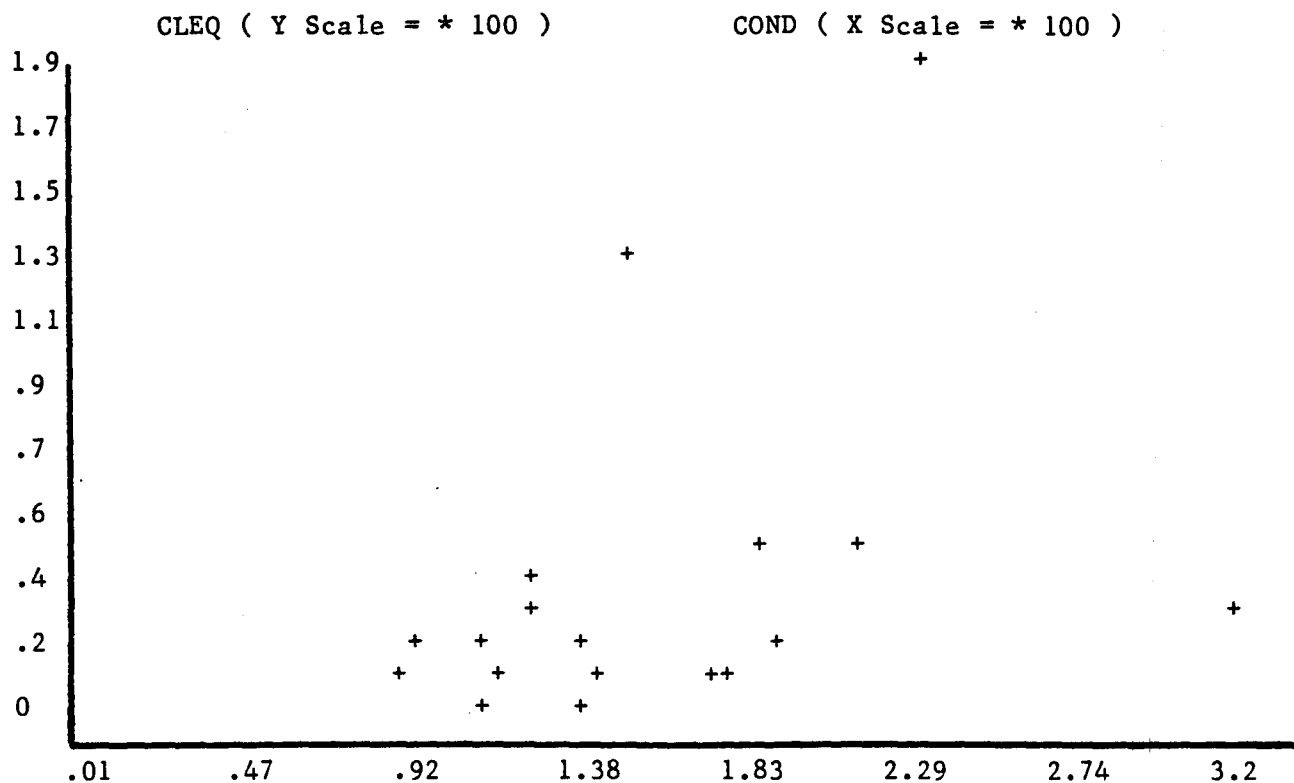


Fig. 52. Relationship of SO_4 (μeq) to specific conductance.

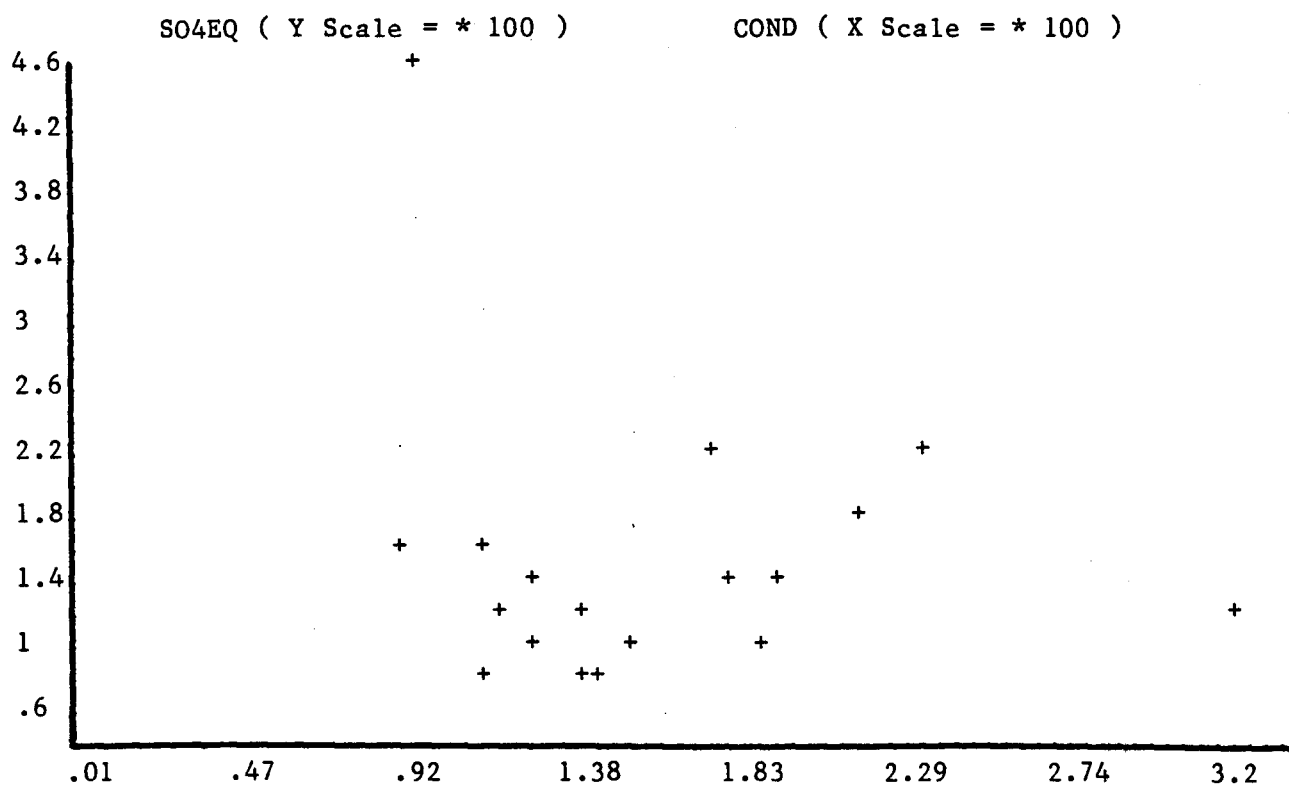
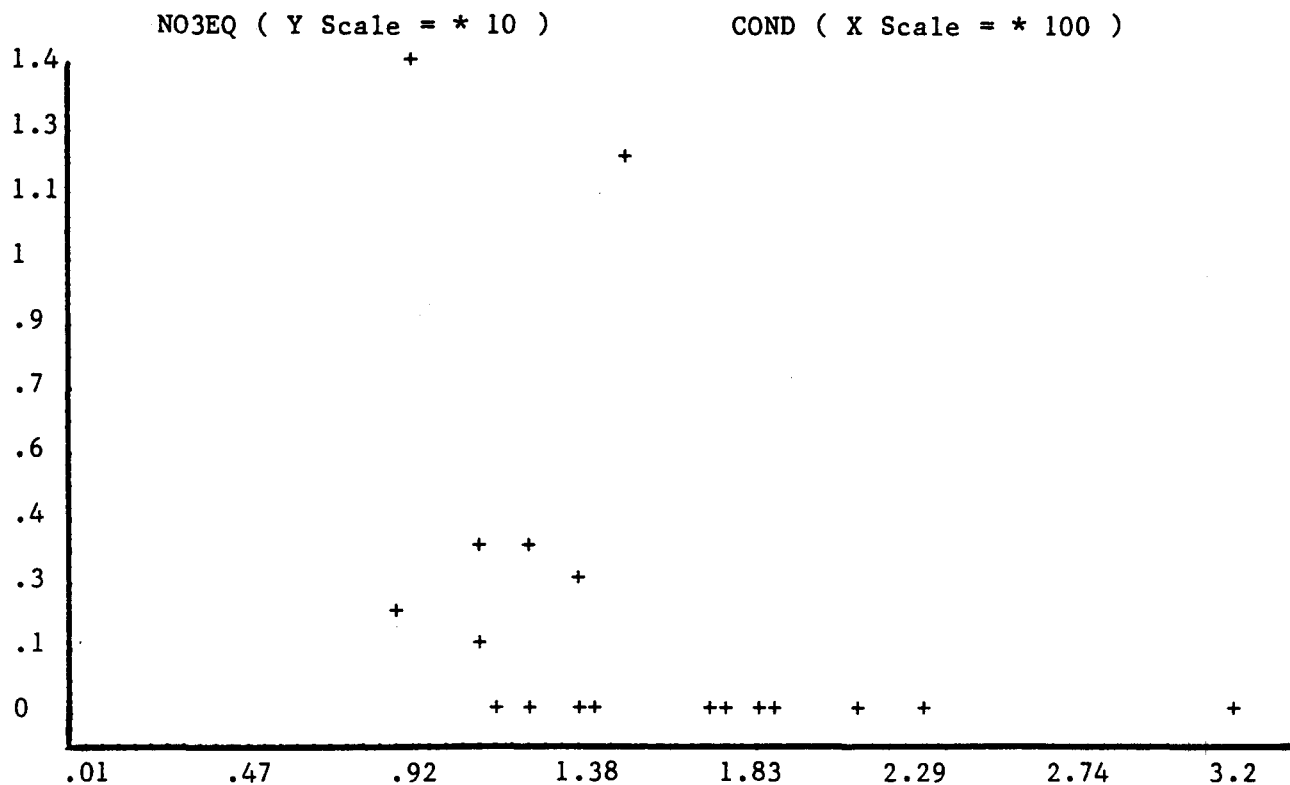


Fig. 53. Relationship of NO_3 (μeq) to specific conductance.



noisy trends. Contrary to the results found by Gorham et al (1983) in lakes of Minnesota, Wisconsin, and South Dakota we do not see an east to west increasing trend. Perhaps significantly the highest levels of K were recorded in the Pictured Rocks area, the same place the lowest Na values were recorded. K is the least abundant of the cations as expected since this is a very mobile ion rapidly recycled in forested ecosystems.

Cl (Fig. 51) shows little correlation with conductance which has also been the finding of other investigators. Its highest value is recorded for the undisturbed second-order Washington Creek watershed on Isle Royale. Input/output values calculated as part of the earlier discussion on budgets show Cl levels quite indicative of deposition dominated by continental air masses. SO_4 levels (Fig. 52) are generally lower than averages found in streams and lakes of Minnesota. However, again this probably reflects the absence of precipitation effects on this sample set.

NO_3 (Fig. 53) shows no correlation to specific conductance. Its concentration, particularly in summer, generally is at or below the level of detection (0.01mg/l) which masks any possible trends.

Discussion

This survey was taken also to gain a database for correlating stream chemistry to bedrock, soils, basin morphology, and vegetation. All watersheds sampled except two are basically free of any direct disturbance due to man. To date this work has not been completed, and cannot be interpreted here. The above results do, however, give some indication of the stream chemistry in the region when free of precipitation influences.

Results - Lakes

Figs. 38 and 39 show the location of lakes sampled primarily in 1980-82. Fig. 54 relates the concentrations of HCO_3 to SO_4 over the range of lakes sampled. At concentrations of HCO_3 below 100 μ eq bicarbonate is no longer the dominant anion, but is replaced by SO_4 . Here too is where pH begins a rapid decline (Fig. 55). Similar findings have been determined by other investigators working on shield lakes (Kelso et. al. 1982). Fig. 56 shows that, as observed in streams at low flow, two anions and two cations dominate lake water chemistry and provide most of the ionic balance. Indeed, the balance between the two groups appears quite uniform throughout the range of sampling. Lake

Fig. 54. Relationship of alkalinity (μeq) to SO_4 .

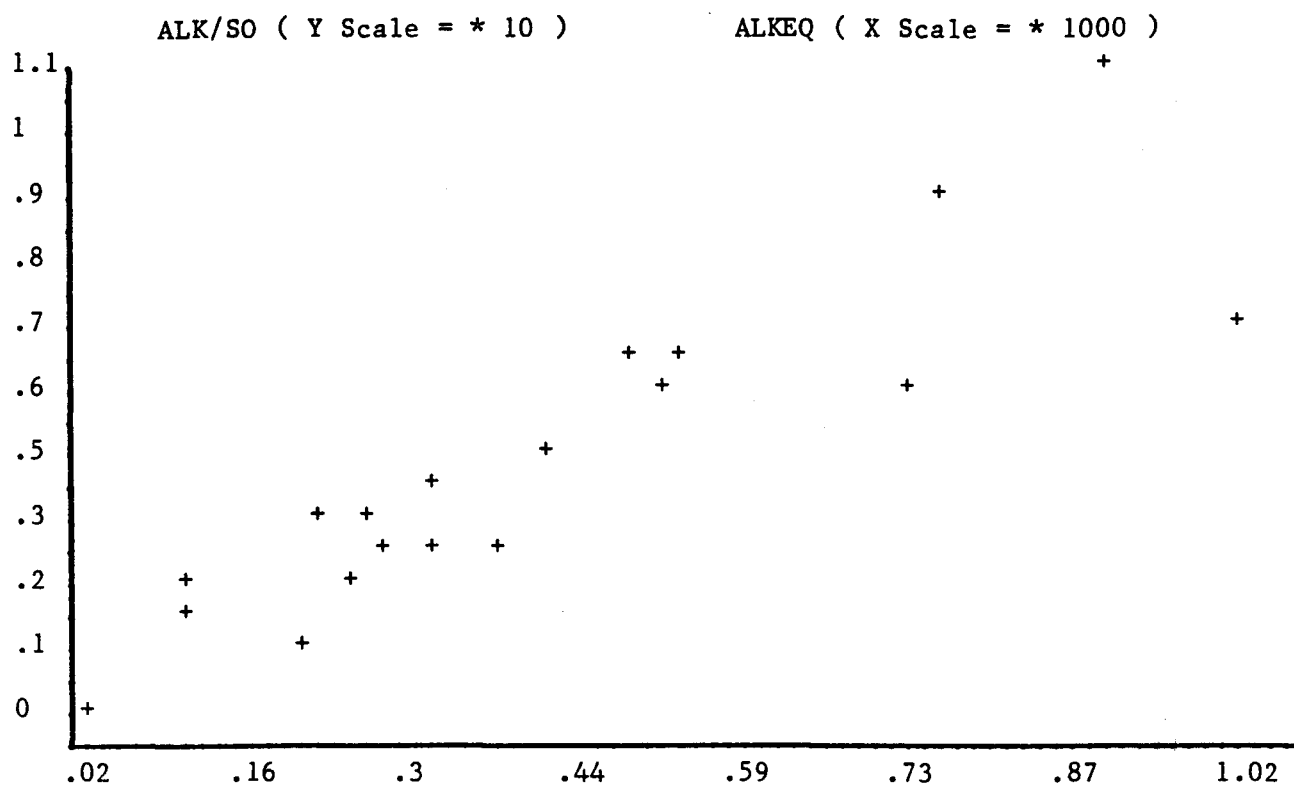


Fig. 55. Relationship between pH and HCO_3 (μeq).

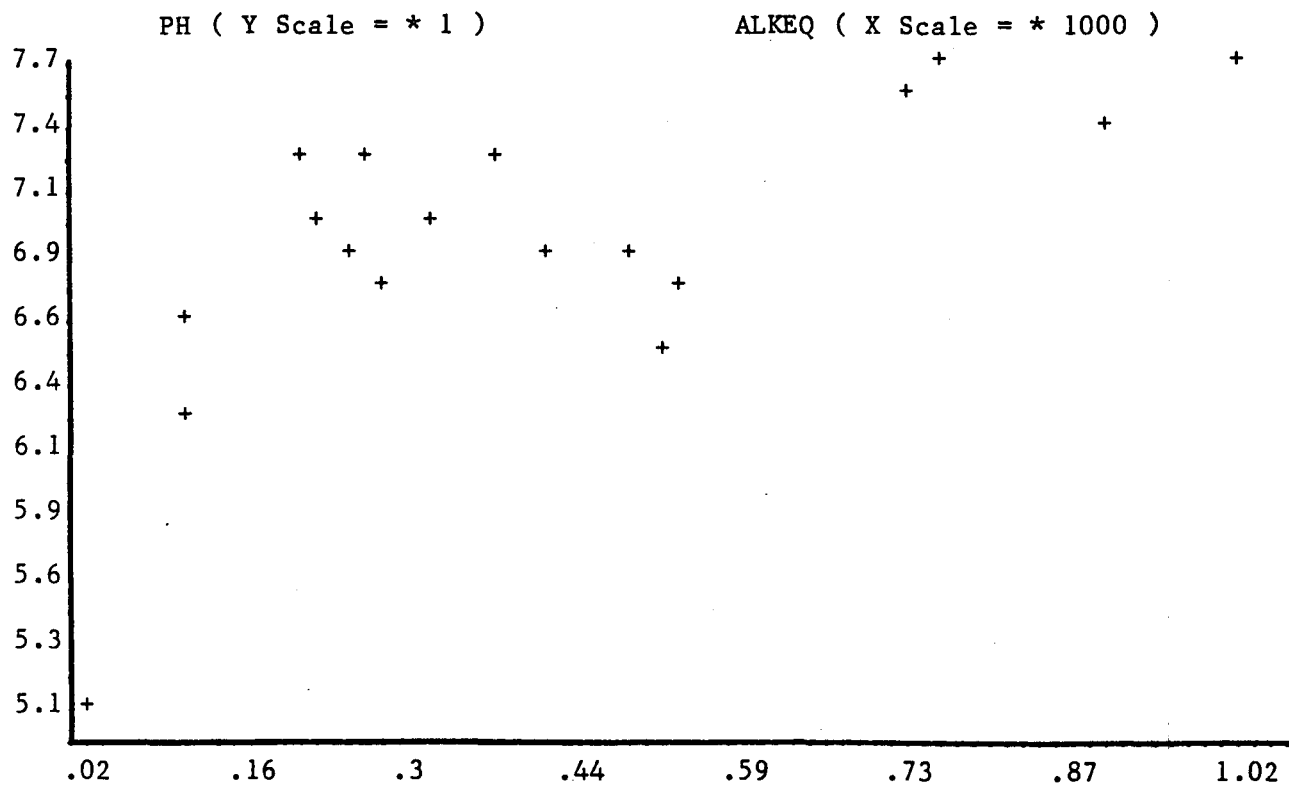


Fig. 56. Relationship of dominant anions and cations.

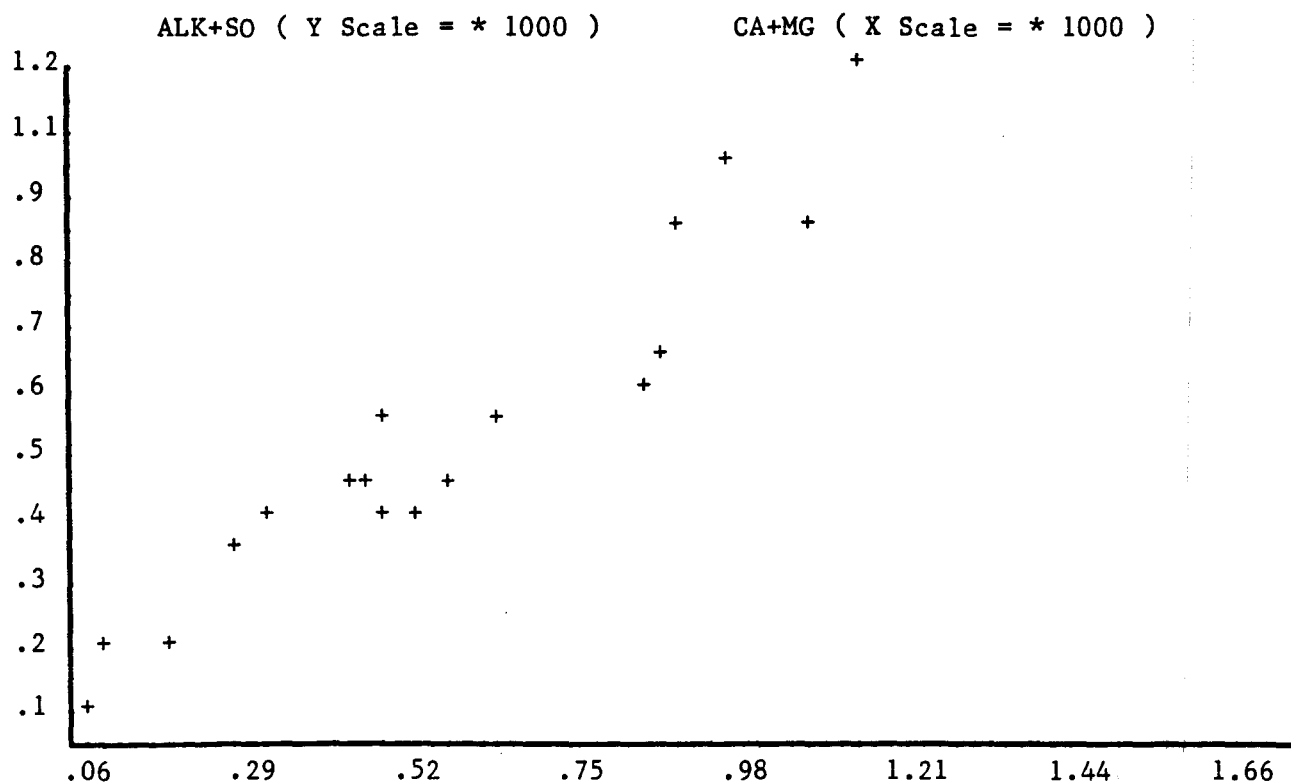
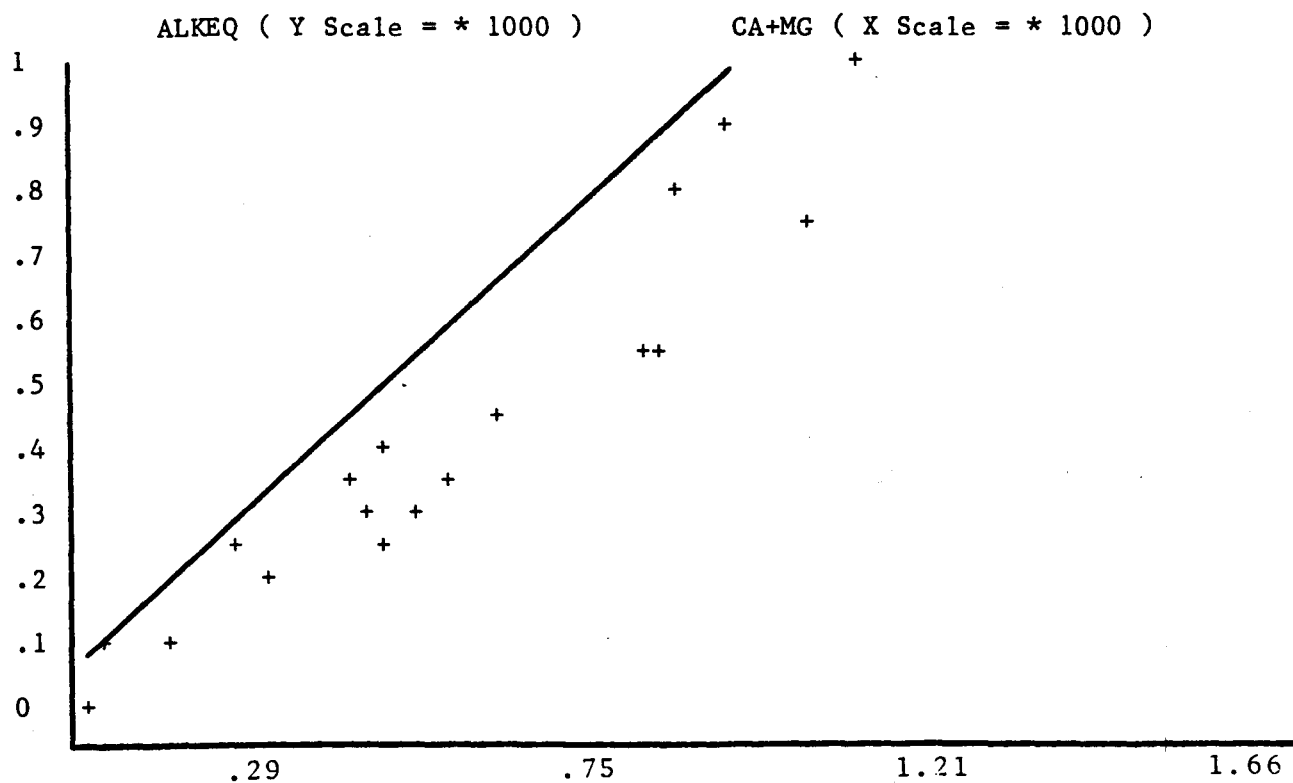


Fig. 57. Relationship of HCO_3 (μeq) to Ca plus Mg.



concentrations recorded here are as low as any found on shield lakes; however, our means are much above other similar surveys.

In Fig. 57 the relationship between HCO_3 and the sum of Ca and Mg is plotted. If one agrees with the Henriksen model that bicarbonate should balance the major cations in a 1:1 relationship in the absence of acidic inputs then such should be the case in the undisturbed areas studied here. However, such is obviously not the case. Most of the lakes have a bicarbonate deficiency. It is speculated that it is made up for by organic acids.

Fig. 58 shows, as in the streams, that Ca exceeds Mg concentrations in the lakes sampled. On average Ca exceeds Mg levels about 2x, but relative Ca concentrations decrease when HCO_3 concentrations exceed 200μ eq. This is opposite to the findings of some investigators working in poorly buffered lakes. Mg appears to be of increasing importance in high alkalinity lakes perhaps due to the local presence of dolomitic till. At HCO_3 levels below 100μ eq SO_4 becomes the dominant anion species.

Figs. 59 - 67 show the relationships between specific cation concentrations and conductance. For Ca (Fig. 59) the ratio is nearly identical to levels found in surveys of Minnesota (Gorham et. al. 1983). There is no obvious trend east to west which is perhaps due to the limited east-west sampling. The lowest values were found in seepage ponds and lakes in the vicinity of the Kingston Plains just south of Pictured Rocks, and the highest values were found at one station on the Keweenaw Peninsula and at several locations in the southwest portions of Isle Royale. The latter sites are all located in an area of extensive and deep (maximum 60m) glacial till and recessional moraine deposits (Huber 1974). For the remaining cations the concentrations are generally lower than those found to the west of here. The relationship between K and specific conductance (Fig. 62) is not very well defined in this sample set. The sum of cations (Fig. 64) gives a ratio to specific conductance which is about 40% higher than values common to the west. The reason for this different relationship is not clear, but probably has something to do with precipitation inputs (Stottlemeyer 1984).

Fig. 63 relates the concentration of HCO_3 to specific conductance. Here again at a given conductance the HCO_3 concentrations are much above those observed in Wisconsin and Minnesota. Cl (Fig. 65) is too noisy to note any trend, as is SO_4 and NO_3 at least for this relatively limited

Fig. 58. Ratio of Ca to Mg (μeq).

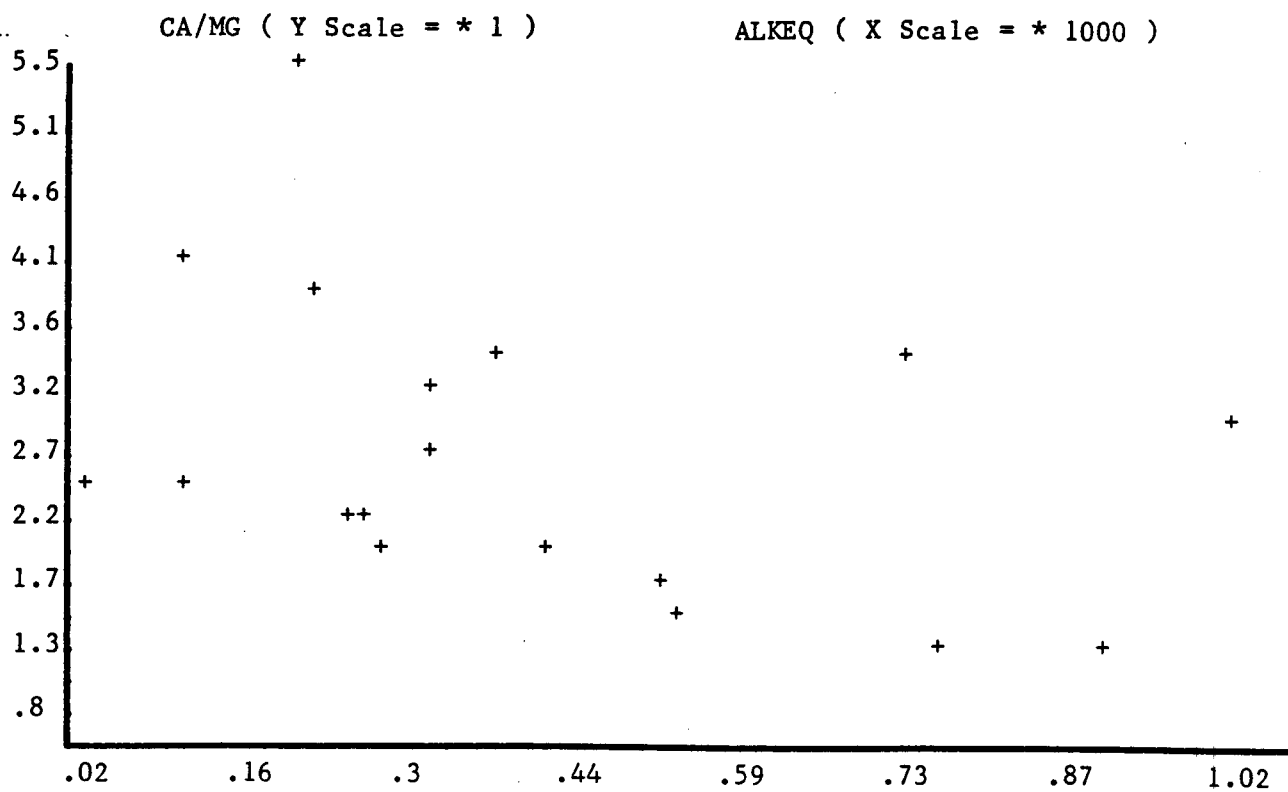


Fig. 59. Relationship of Ca (μeq) to specific conductance.

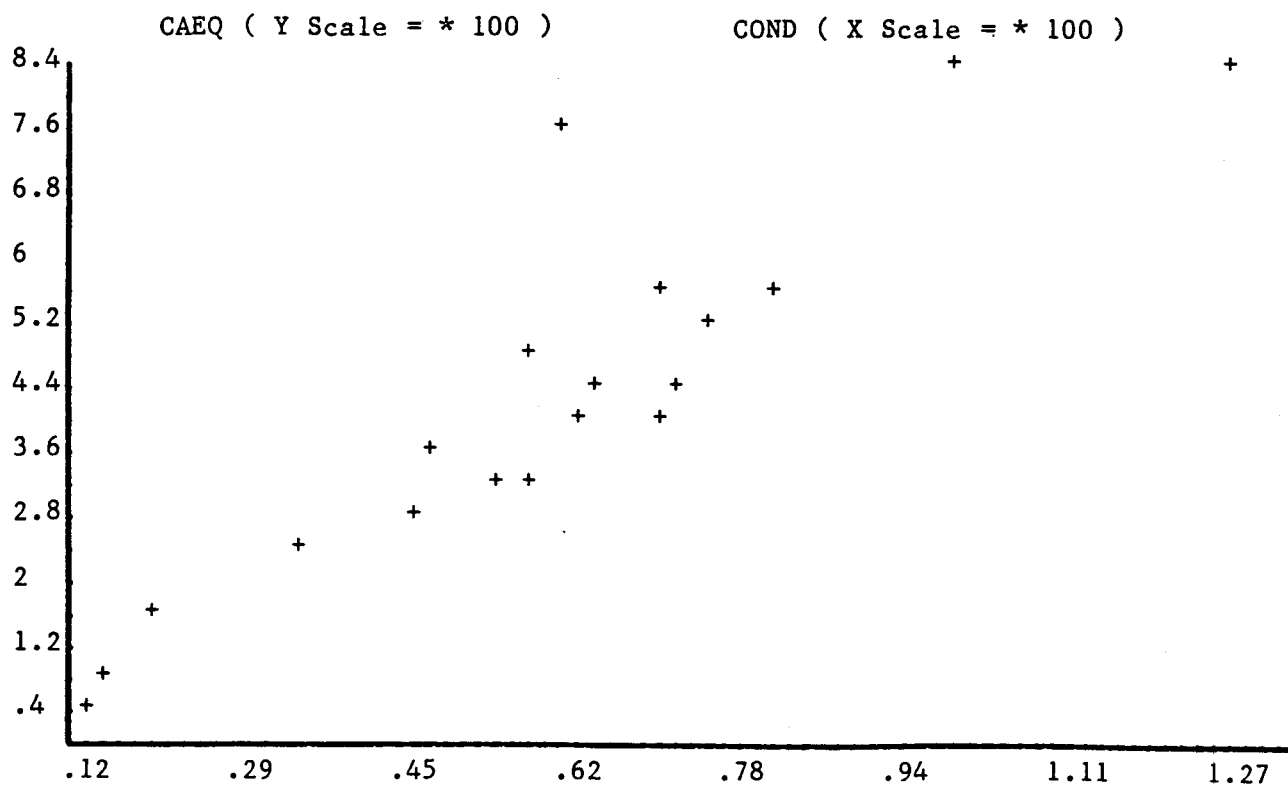


Fig. 60. Relation of Mg (μeq) to specific conductance.

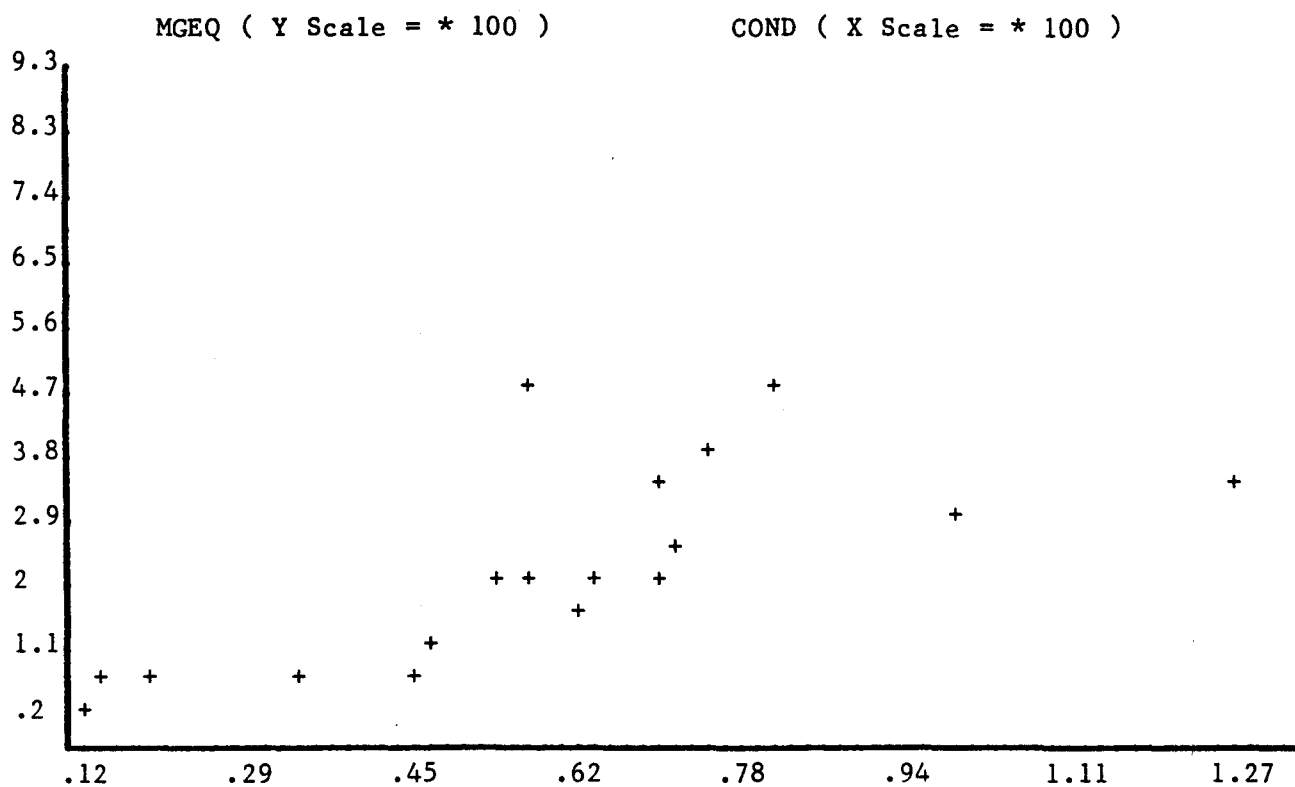


Fig. 61. Relationship of Na (μeq) to specific conductance.

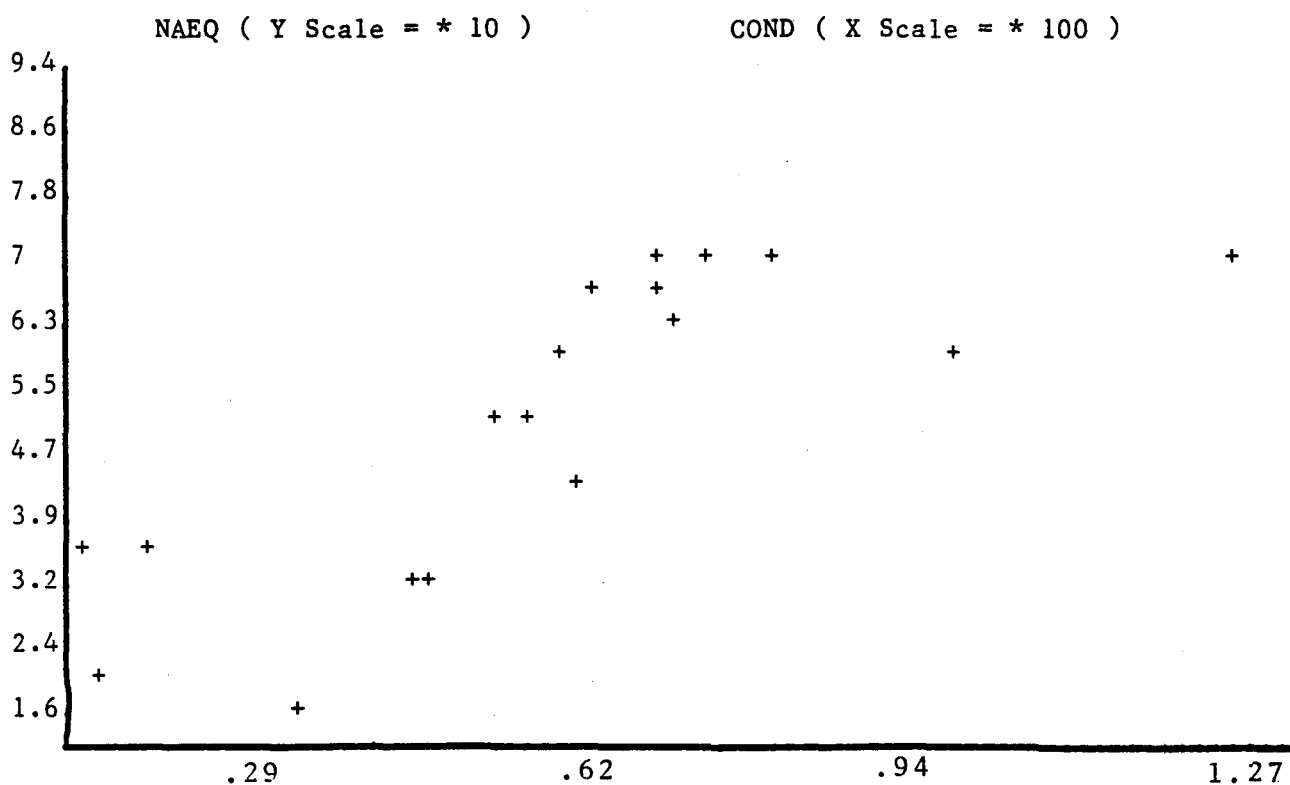


Fig. 62. Relation of K (μeq) to specific conductance.

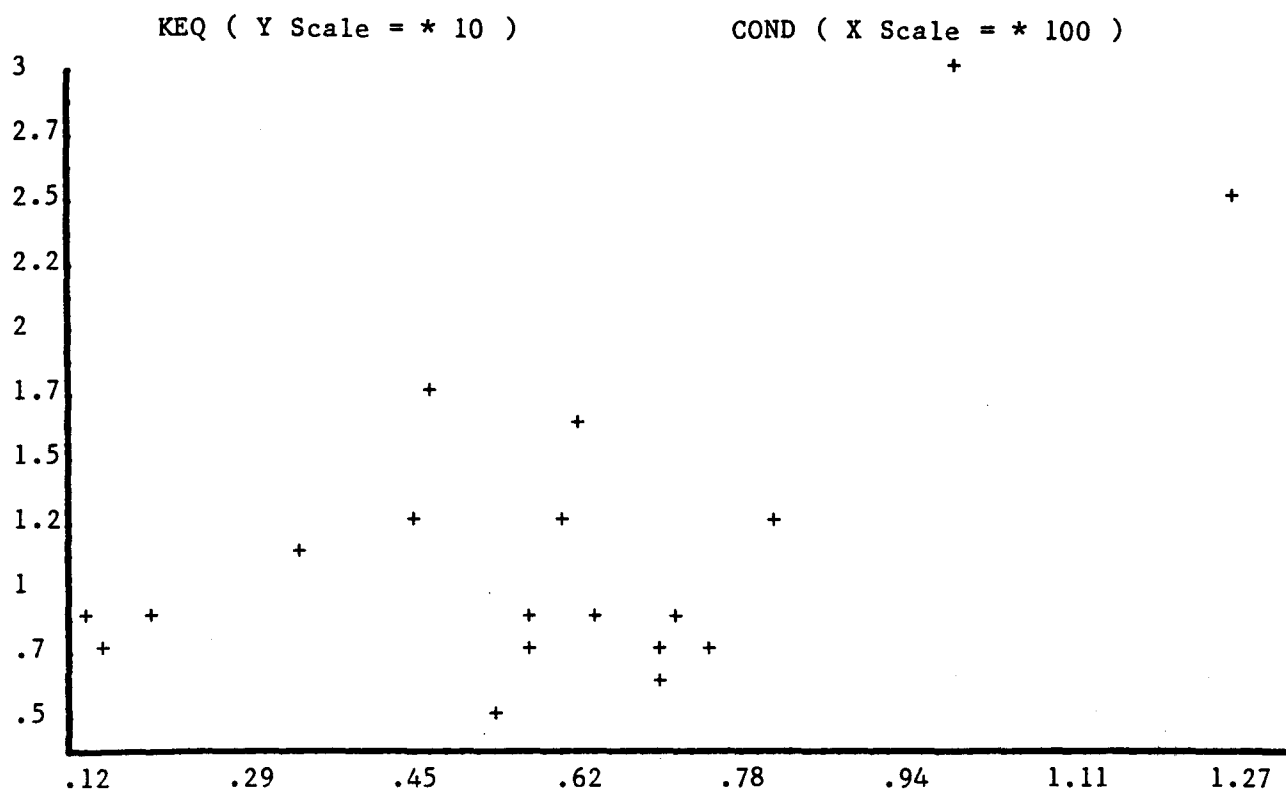


Fig. 63. Relationship of HCO_3 (μeq) to specific conductance.

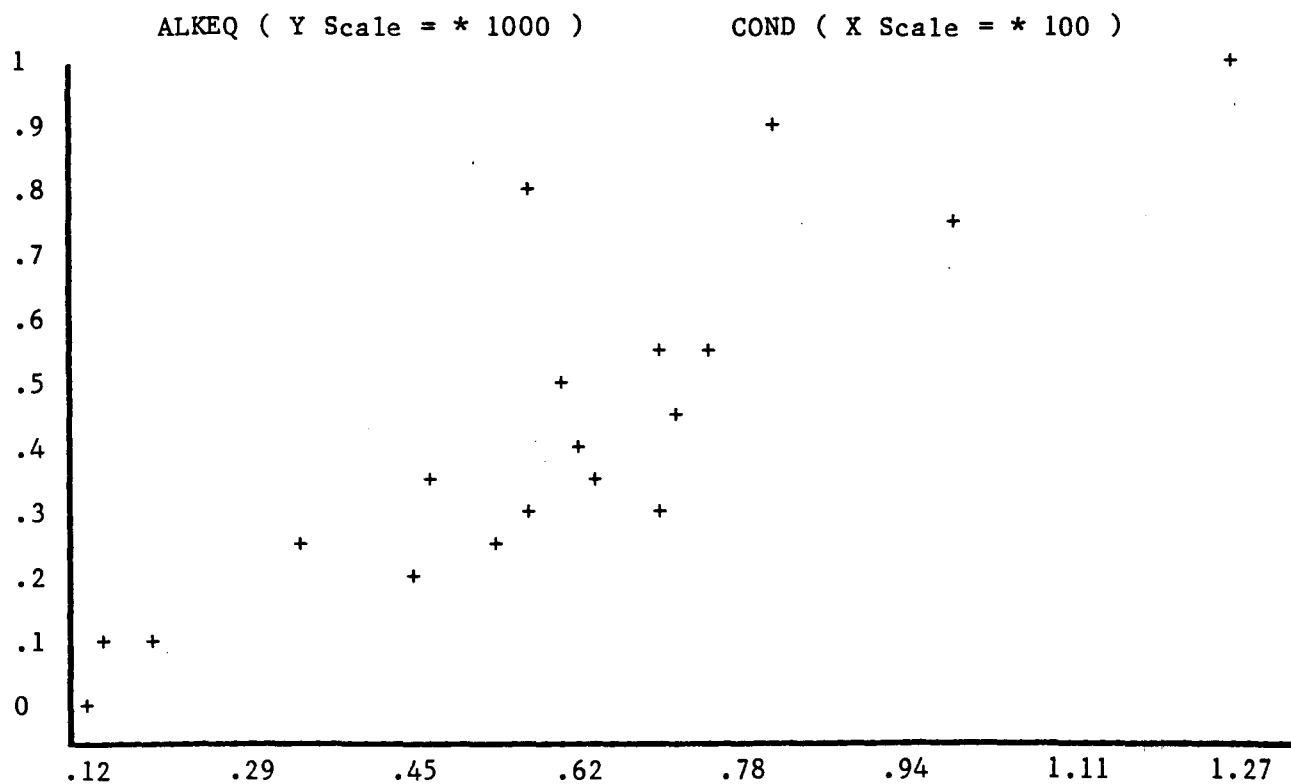


Fig. 64. Relation of sum of cations (μeq) to specific conductance.

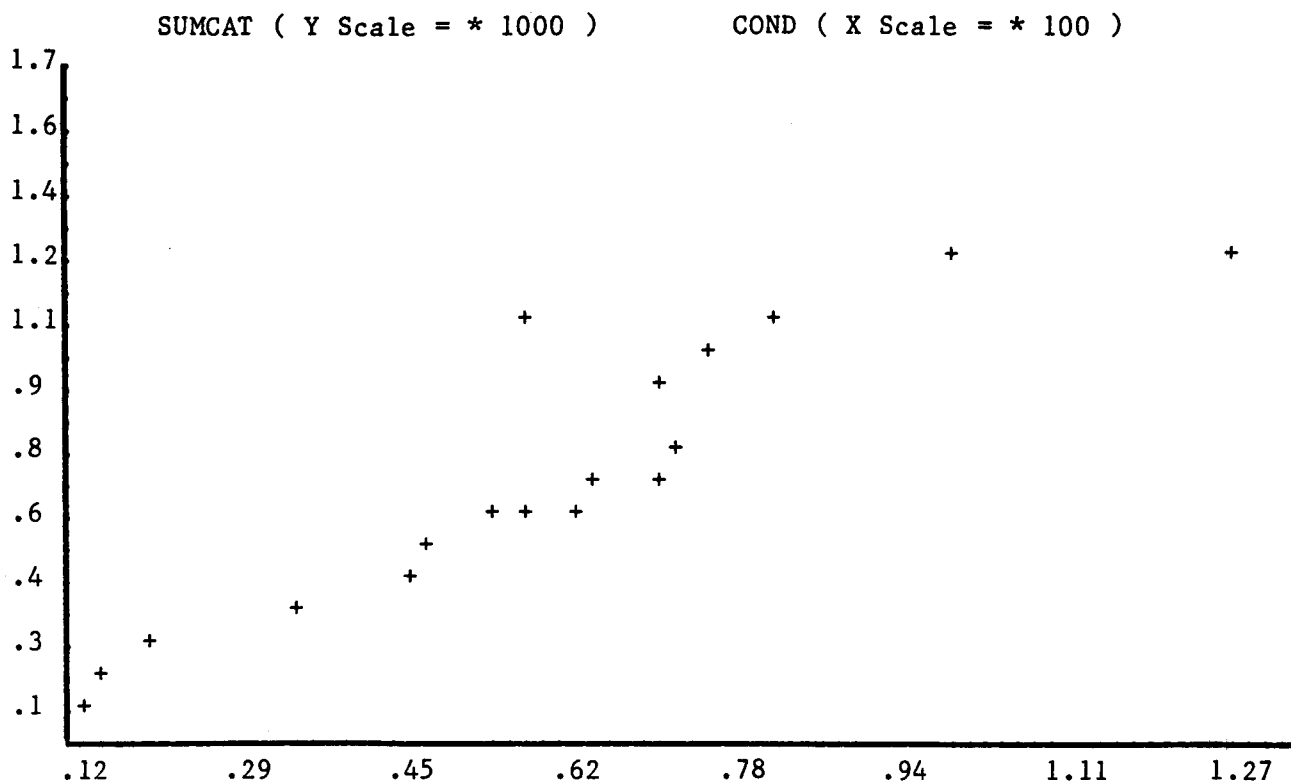


Fig. 65. Relationship of Cl (μeq) to specific conductance.

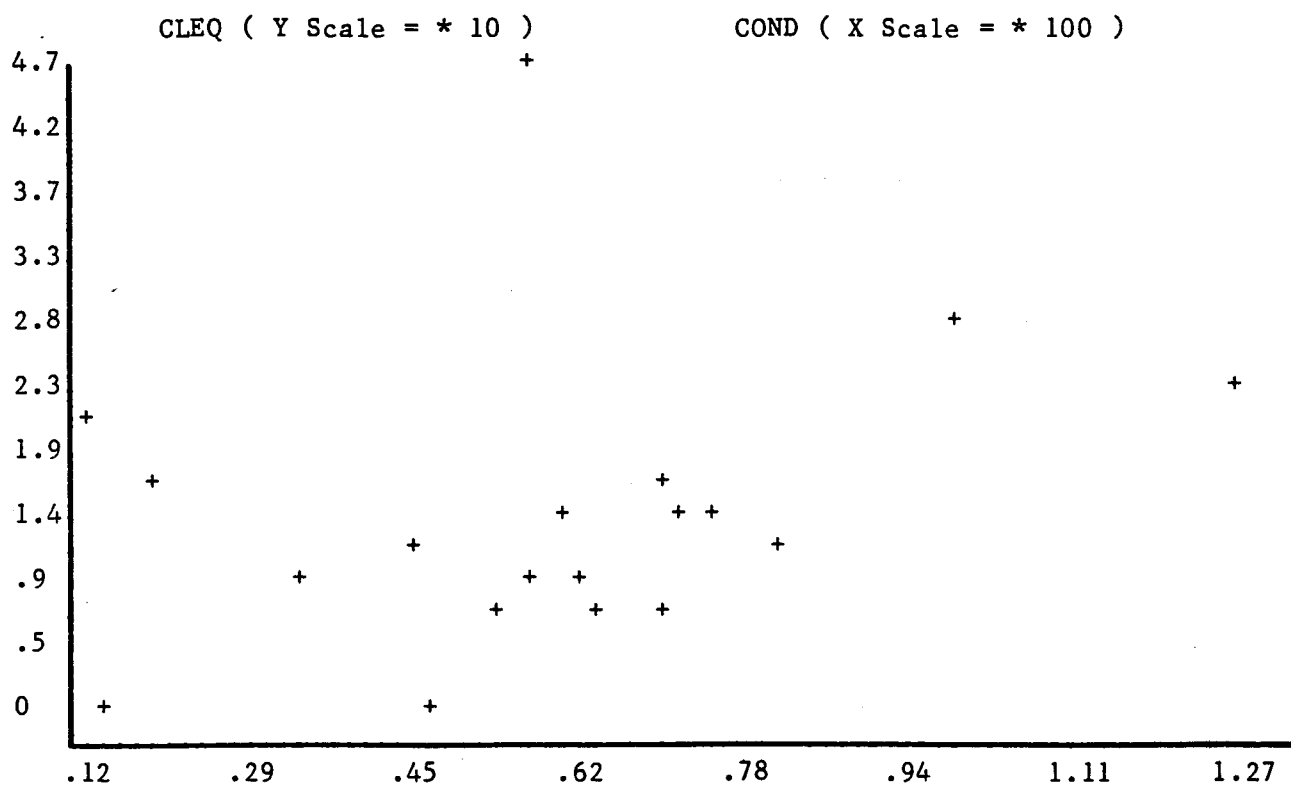


Fig. 66. Relation of SO_4 (μeq) to specific conductance.

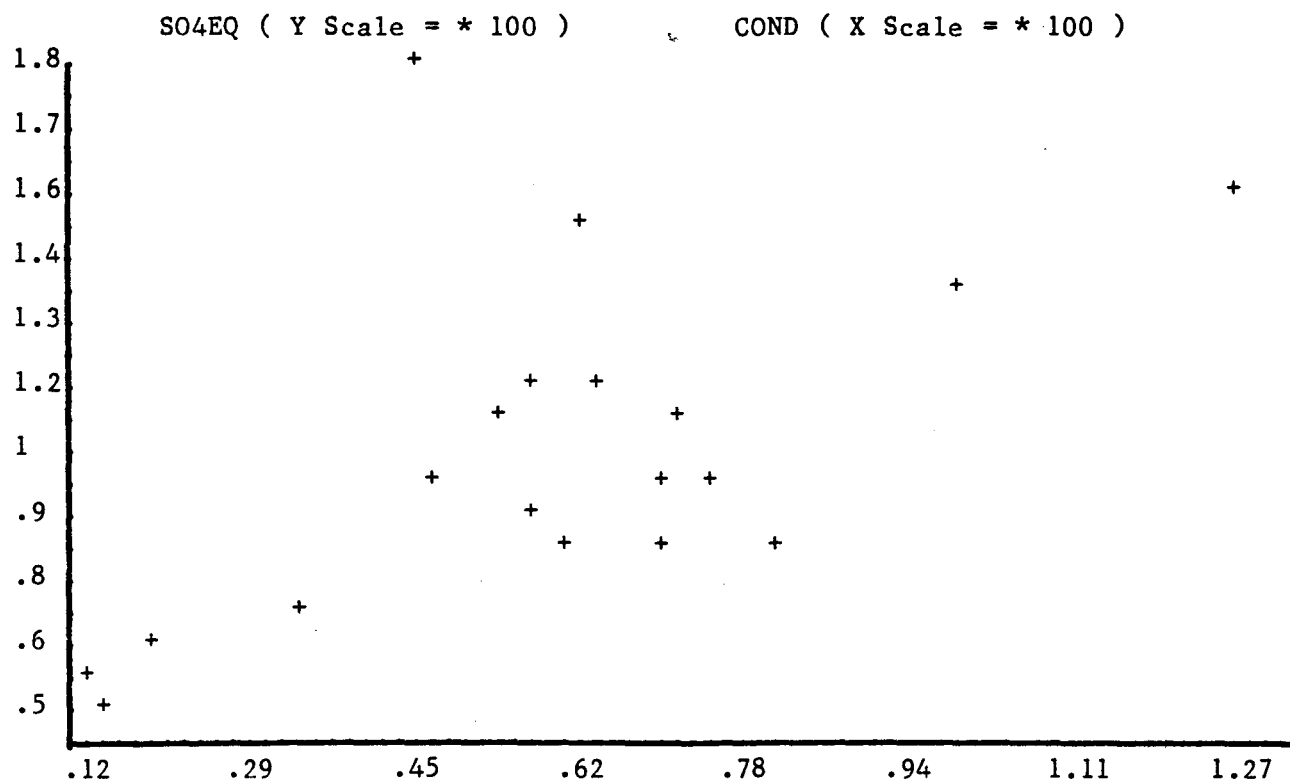
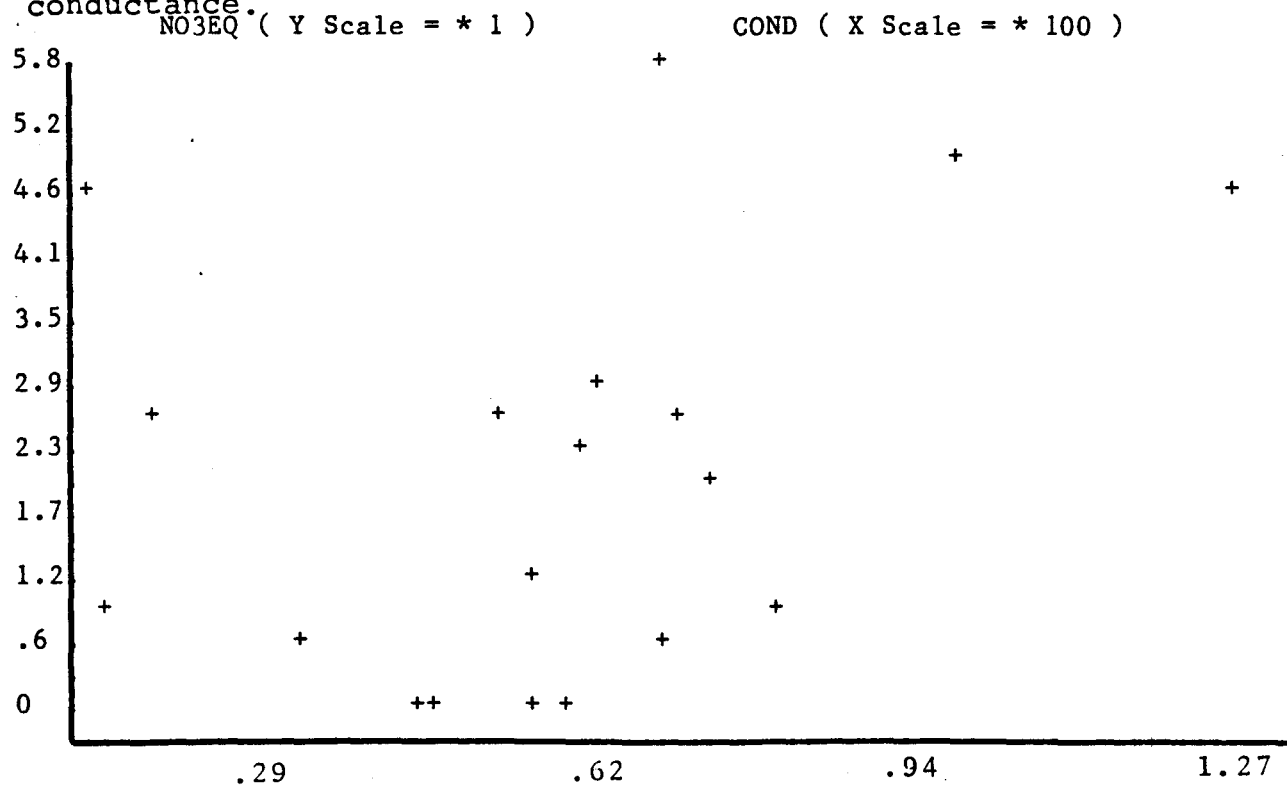


Fig. 67. Relationship of NO_3 (μeq) to specific conductance.



size sample set.

Discussion

As observed for the stream survey data set the lake chemistry has not yet been adequately analyzed for trends if such an analysis is even possible with the limited sample size. This was not the objective of the original survey however. Also one must consider, in some manner, the influence of differences in precipitation on these relatively small lakes most of which are fed by surface streams. In general lake water chemistry appears to be somewhat in between the concentrations observed by other investigators to the east and west.

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APPENDICES

APPENDIX A

Precipitation concentrations (mg/l) for selected ion species in weekly samples collected in Michigan's Upper Peninsula and on Isle Royale, June 1982 - August 1984.

Fig. 12.

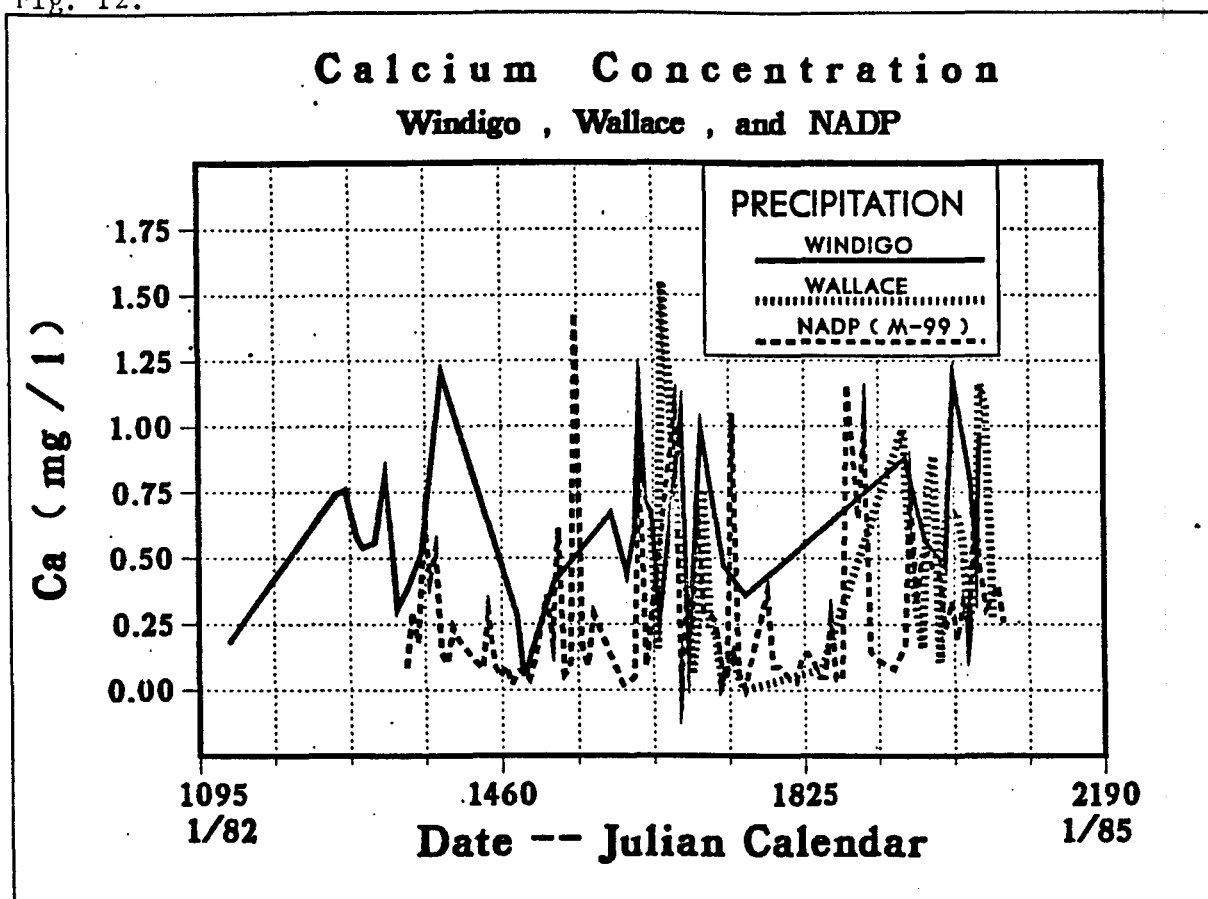


Fig. 13.

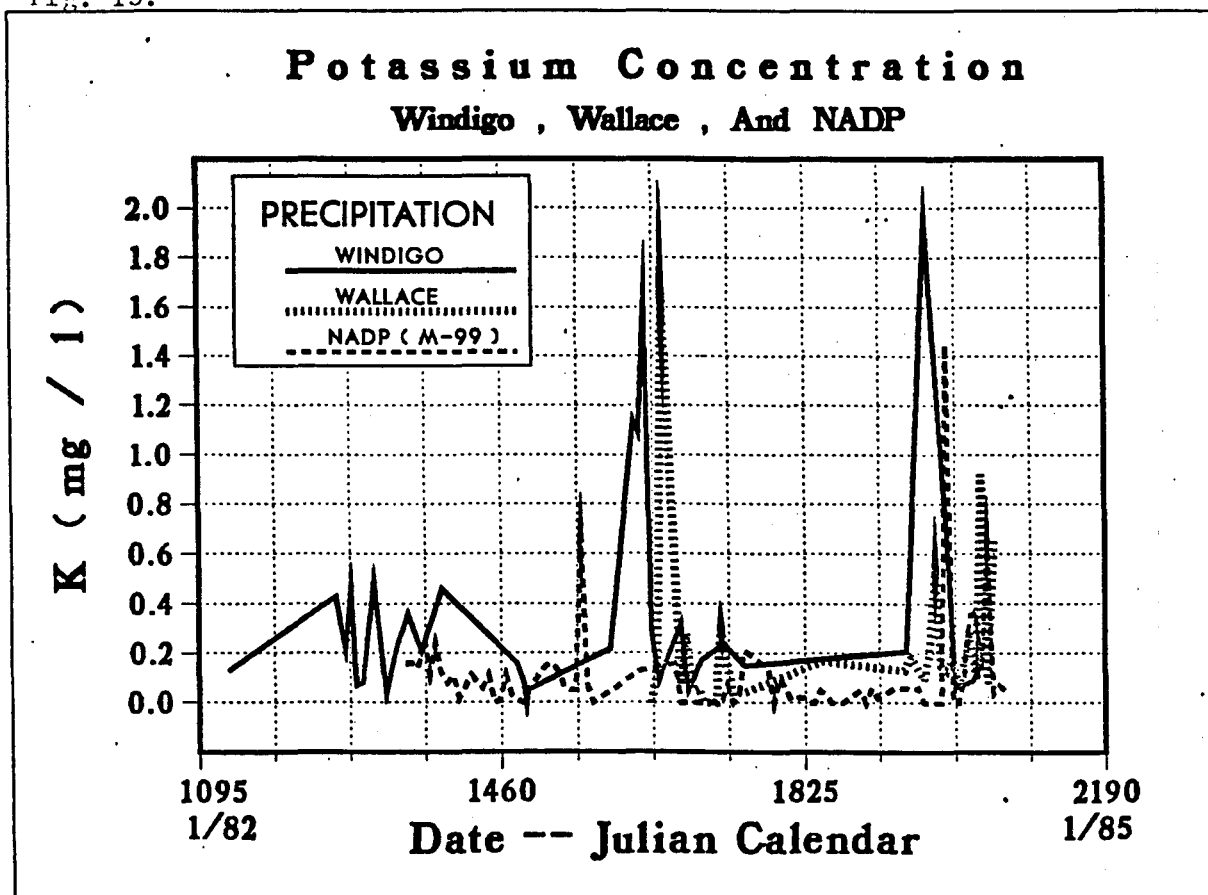


Fig. 14.

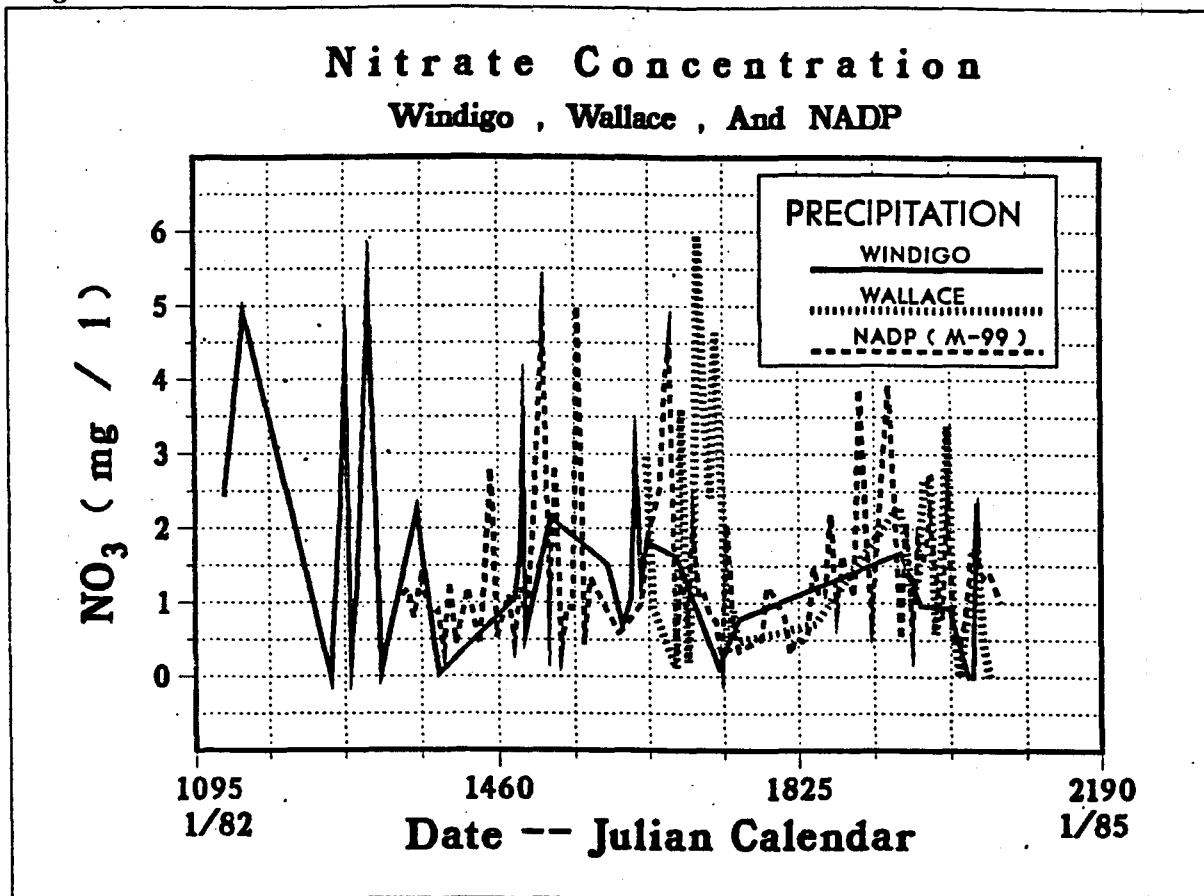


Fig. 15.

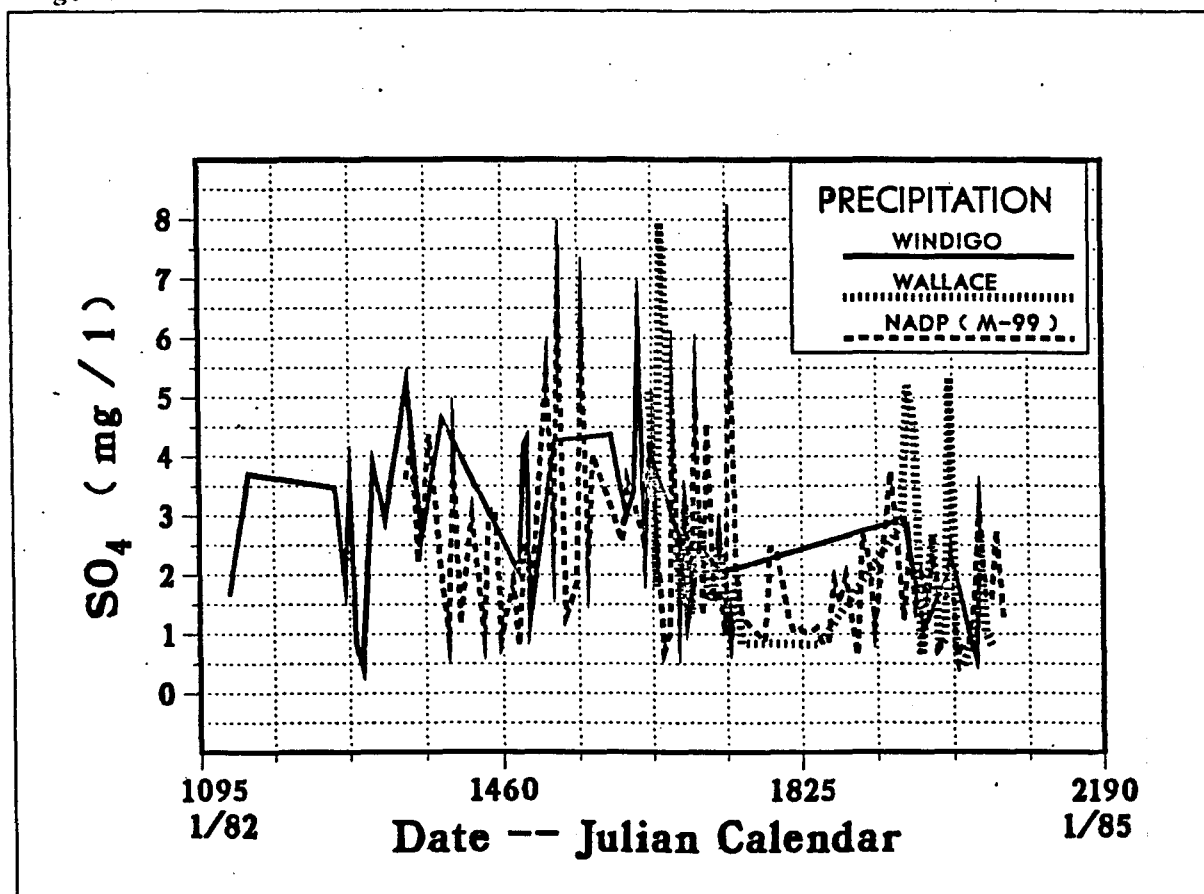
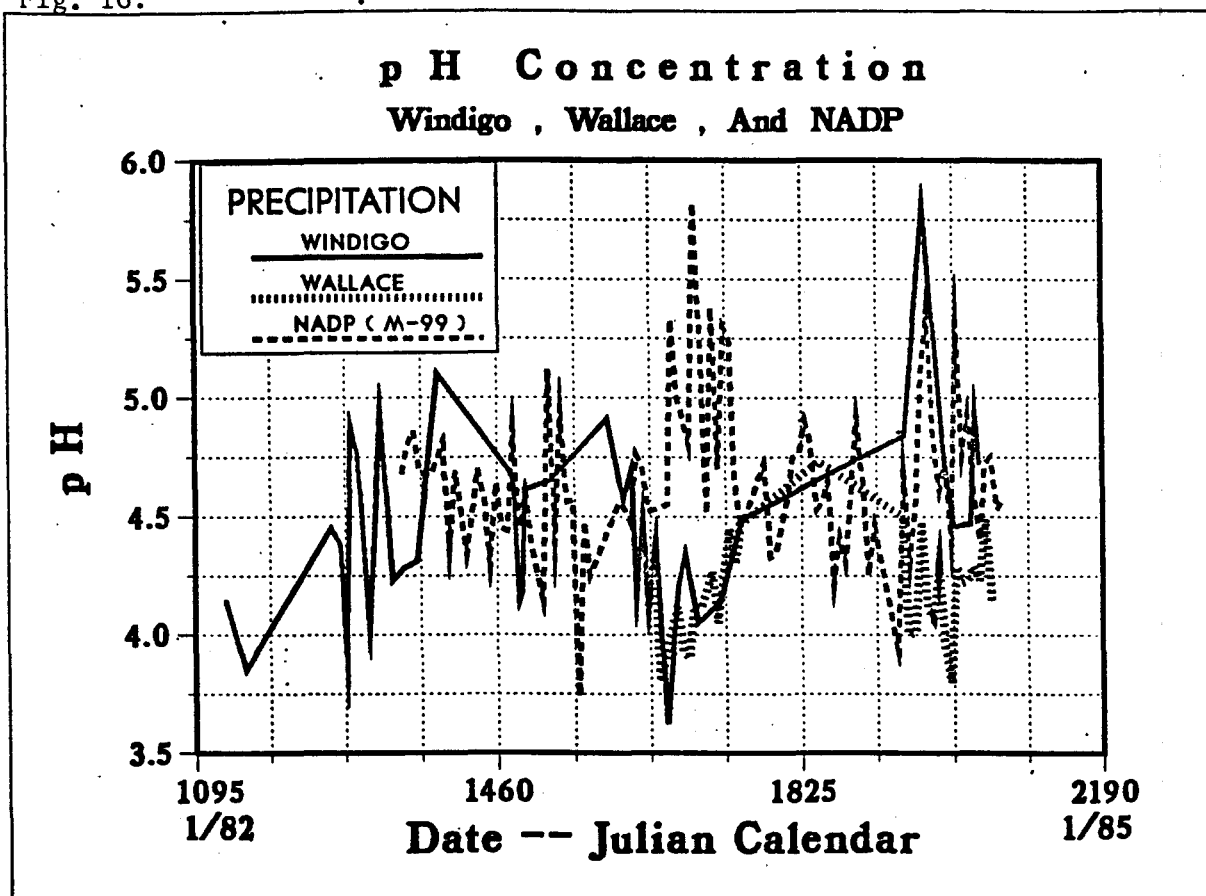


Fig. 16.



APPENDIX B. Species present in the sample plots of the four lake watersheds but contributing less than 3.0% to the aboveground current growth of the herb and shrub/tall herb strata.

WALLACE LAKE WATERSHED

HERBS

Actaea sp., *Anaphalis margaritacea*, *Botrychium* sp., *Chimaphila umbellata*, *Coptis groenlandica*, *Cornus canadensis*, *C. stolonifera*, *Corylus cornuta*, *Diervilla lonicera*, *Dryopteris spinulosa*, *Epilobium angustifolium*, *Fragaria virginiana*, *Galium triflorum*, *Goodyeara* sp., *Hepatica americana*, *Heracleum maximum*, *Lactuca* sp., *Lonicera dioica*, *Maianthemum canadense*, *Melampyrum lineare*, *Polygala paucifolia*, *Mitella nuda*, *Pteridium aquilinum*, *Pyrola secunda*, *Rosa acicularis*, *Rubus pubescens*, *R. strigosus*, *Sambucus pubens*, *Streptopus roseus*, *Taraxacum officinale*, *Trientalis borealis*, *Vaccinium* sp., *Viburnum edule*, and *Viola* spp.

SHRUBS/TALL HERBS

Actaea pachypoda, *Amelanchier* sp., *Aralia nudicaulis*, *Diervilla lonicera*, Grasses/Sedges, *Heracleum maximum*, *Lactuca* sp., *Lonicera canadensis*, and *Lonicera dioica*.

NONAME LAKE WATERSHED

HERBS

Achillea millefolium, *Aralia nudicaulis*, *Arctostaphylos uva-ursi*, *Chimaphila umbellata*, *Clintonia borealis*, *Coptis groenlandica*, *Dryopteris disjuncta*, *Epilobium angustifolium*, *Fragaria virginiana*, *Galium triflorum*, *Linnaea borealis*, *Lycopodium obscurum*, *Maianthemum canadense*, *Melampyrum lineare*, *Polygala paucifolia*, *Mitella nuda*, *Pyrola secunda*, *Rubus parviflorus*, *R. pubescens*, *R. strigosus*, *Solidaga* sp., *Streptopus roseus*, *Trientalis borealis*, *Vaccinium* sp., and *Viola* spp.

SHRUBS/TALL HERBS

Diervilla lonicera and *Rosa acicularis*.

SUMNER LAKE WATERSHED

HERBS

Actaea sp., Bidens cernua, Chimaphila umbellata, Clintonia borealis, Coptis groenlandica, Cornus canadensis, Diervilla lonicera, Dryopteris disjuncta, Epilobium angustifolium, Equisetum sylvaticum, Fragaria virginiana, Galium sp., Geocaulon lividum, Goodyera sp., Grasses/Sedges, Hepatica americana, Linnaea borealis, Lonicera canadensis, L. dioica, Lycopodium clavatum, Maianthemum canadense, Melampyrum lineare, Mitella nuda, Moneses uniflora, Orchis sp., Polygala paucifolia, Pyrola secunda, Rosa acicularis, Rubus pubescens, Streptopus roseus, Taxus canadensis, Trientalis borealis, Vaccinium angustifolium and Viola spp.

SHRUBS/TALL HERBS

Aralia nudicaulis, Bidens cernua, Diervilla lonicera, Equisetum palustre, E. sylvaticum, Grasses/Sedges, Lilium philadelphicum, Lonicera dioica and Ribes triste.

TROUT LAKE WATERSHED

HERBS

Botrychium simplex, Chimaphila umbellata, Hieracium sp., Lycopodium lucidulum, Melampyrum lineare, Mitchella repens, Rubus parviflorus, Trientalis borealis and Viola sp.

APPENDIX C

Soil pedon descriptions for samples collected immediately adjacent permanent plots in the Trout, Wallace, and Sumner Lake experimental watersheds, Michigan's Upper Peninsula and Isle Royale National Park.

Pedon Classification: n.a.
 Series Classification: n.a.
 Soil: n.a.
 Plot and study: Windigo, Isle Royale acid ppt. study
 Location: Keweenaw Co., Michigan
 Climate: Ave ann. ppt. about 850mm; mean ann. air temperature about 8°C.
 Vegetation and Land Use: Woodland; sugar maple
 Physiographic Position: Rolling Upland
 Parent Material: Glacio-fluvial over till
 Groundwater: n.a.

(All colors are for moist conditions; Pedon described under artificial light)

<u>Oi</u>	<u>1-0cm</u>	Undecomposed leaves and twigs
<u>A/E</u>	<u>0-8cm</u>	Gray/brown (SYR 3/2) loamy sand; weak granular structure; very friable; clear wavy boundary
<u>Bhs</u>	<u>8-22cm</u>	Dark reddish brown (SYR 3/3) loamy sand; weak granular structure; friable; gradual even boundary
<u>Bs1</u>	<u>22-43cm</u>	Dark reddish brown (SYR 3/3.5) loamy sand; weak subangular blocky structure; friable; clear gradual boundary
<u>Bs2</u>	<u>43-65cm</u>	Dark reddish brown (SYR 3/4) sand; platy structure (sesquioxide cementing); clear gradual boundary
<u>E'x</u>	<u>65- cm</u>	Dark reddish brown-yellowish red (SYR 3/5) sand; hard platy (fragipan?) boundary unknown

(pedon description for comparison purposes only)

Pedon Classification: Typic Haplorthod, sandy, mixed, frigid.
 Series Classification: Same
 Soil:
 Plot and Study: Calumet; Keweenaw Peninsula acid ppt. study
 Location: Keweenaw County, Michigan,
 Climate: Ave. ann. ppt. about 850mm; mean annual air temperature about 8°C.
 Vegetation and Land Use: Fir, yellow birch, aspen, hemlock, cedar woodland
 Parent Material: Glacio-fluvial over till.
 Physiographic Position: Rolling Upland Lake Terraces
 Groundwater: Below 120cm

(All colors are for moist conditions, Pedon described under artificial light)

<u>Oi</u>	<u>1-0cm.</u>	Undecomposed leaves and twigs.
<u>A</u>	<u>0-5cm.</u>	Black (SYR 2.5/1) loamy sand; weak fine granular structure; very friable; abrupt wavy boundary.
<u>E</u>	<u>5-13cm.</u>	Dark reddish gray (SYR 5/2-4/2) sand; weak granular structure; very friable; clear wavy boundary.
<u>Bhs</u>	<u>13-29cm.</u>	Dark reddish gray (SYR 3/2-2.5/2) loamy sand; weak subangular blocky structure; very friable; clear wavy boundary.
<u>Bs1</u>	<u>29-62cm.</u>	Dark reddish brown (SYR 3/3-3/4) loamy sand; weak fine subangular blocky structure; very friable; clear wavy boundary.
<u>BC</u>	<u>62-98cm.</u>	Dark reddish brown (SYR 4/4-3/4) sand; weak very fine crumb structure; very friable; clear wavy boundary.
<u>C</u>	<u>98- cm.</u>	Brown-dk brown (7.5YR 4/4) sand; single grain structure; loose

Pedon Classification: Lithic Alfie Haplorthod, sandy over loamy, mixed, frigid.
 Series Classifications: (Same)
 Soil:
 Plot and Study: W-1, acid ppt; Isle Royale
 Location: Keweenaw County, Michigan, SE, NW, Section 4, T66N, R34W. (Isle Royale National Park)
 Climate: Average annual precipitation is about 850 mm; mean annual air temperature is about 8°C.
 Vegetation and Land Use: Woodland
 Parent Material: Glacio-fluvial
 Physiographic Position: Rolling Upland (Post-Duluth lake stage)
 Topography: Single slope; 5% gradient; North 20° W aspect; convex; mid slope position; elevation is about 210 A.S.L.
 Groundwater: Below 150 cm.
 Sampled by: S.C. Shetron, R. Stottlemeyer, D. Putkowski, S. Freisen.
 Date: September 7, 1984

(All colors are for moist conditions, pedon described under cloudy-bright conditions).

O1 7 to 5 cm. Undecomposed leaves and twigs.

Oe 5 to 0 cm. Dark reddish brown (5YR 2.5/2) decomposed organic matter and mineral; weak fine granular structure; friable; slightly acid; abrupt smooth boundary.

A 0 to 5 cm. Dark reddish brown (5YR 3/2) sand and gravel; weak fine granular structure; very friable; slightly acid; abrupt smooth boundary; 90% pea size gravel.

Ehs 5 to 21 cm. Dark reddish brown (5YR 3/4) sand and gravel; weak fine granular structure; very friable; slightly acid; abrupt smooth boundary; 90% pea size gravel.

2Ea1 21 to 24 cm. Reddish brown (5YR 4/4) loamy sand; weak fine granular structure; very friable; slightly acid; abrupt smooth boundary.

2Ea2 24 to 49 cm. Yellowish red (5YR 4/6) loamy sand; weak fine subangular blocky structure; very friable; slightly acid; abrupt smooth boundary.

2E 49 to 65 cm. Pinkish gray (5YR 6/2) stratified fine sand, very fine sands and silts; moderate fine platy structure; very friable; reddish brown (5YR 5/4) clay flows and lenses; few fine faint yellowish red (5YR 5/8) and many coarse prominent dark yellowish brown (10YR 4/4) mottles; slightly acid; abrupt smooth boundary.

2E and Et 65 to 65 cm. Pinkish gray (5YR 6/2) E and brown (7.5YR 4/4) Et stratified very fine sands, fine sands and silts; moderate fine platy structure; very friable; abrupt smooth boundary.

2Et 65 to 69 cm. Reddish brown (2.5YR 4/4) stratified clays, silts and very fine sands; moderate fine platy structure; firm; slightly acid.

4R 69 cm. Bedrock - unknown.

Pedon Classification: Lithic Alfie Haplorthod, coarse loamy, mixed, frigid.
 Series Classifications: (Same)
 Soil:
 Plot and Study: W-2, acid ppt; Isle Royale
 Location: Keweenaw County, Michigan, SE, NW, Section 4, T66N, R34W. (Isle Royale National Park)
 Climate: Average annual precipitation is about 850 mm; mean annual air temperature is about 8°C.
 Vegetation and Land Use: Woodland (Aspen-Fir)
 Parent Material: Glacio-fluvial
 Physiographic Position: Rolling Upland (Post-Duluth Lake Terraces)
 Topography: Single slope; 5-12% gradient; aspect northwest (314°); convex; mid slope position; elevation is about 210 A.S.L.
 Groundwater: Below 150 cm.
 Sampled by: S.C. Shetron, R. Stottlemeyer, D. Putkowski, S. Freisen.
 Date: September 8, 1984

(All colors are for moist conditions, pedon described under cloudy bright conditions).

O1 7 to 6 cm. Undecomposed leaves and twigs.

Oe 6 to 0 cm. Partially decomposed leaves and twigs.

E 0 to 4 cm. Reddish gray (5YR 5/2) loamy very fine sand; weak fine subangular blocky structure; very friable; common fine, medium and coarse woody roots; very strongly acid; abrupt smooth boundary.

Ehs 4 to 14 cm. Dark reddish brown (5YR 3/4) loam; weak fine subangular blocky structure; very friable; common, fine medium and coarse woody roots; medium acid; clear wavy boundary.

Ea1 14 to 30 cm. Brown-dark brown (7.5YR 4/4) loam; weak fine subangular blocky structure; very friable; common fine, medium and woody roots; slightly acid; clear wavy boundary.

Ea2 30 to 47 cm. Strong brown (7.5YR 4/6) loam; weak fine subangular blocky structure; very friable; common medium and fine woody roots; slightly acid; clear wavy boundary.

2E 47 to 66 cm. Dark brown-brown (7.5YR 4/2) loamy very fine sand E and reddish brown (5YR 5/3) loamy very fine sand B; moderate fine platy structure; common, medium distinct dark grayish brown (2.5Y 4/2) and yellowish red (5YR 4/6) mottles in the lower 10 cm.; firm; slightly acid; abrupt smooth boundary.

2R 66 cm. Bedrock - unknown.

Pedon Classification: ~~Ammon~~ Alfic Haploquods, coarse loamy, mixed, frigid.
 Series Classification: (Same)
 Soil:
 Plot and Study: W-3, acid ppt; Isle Royale
 Location: Keweenaw County, Michigan, Section 4, T65N, R34W. (Isle Royale National Park)
 Climate: Average annual precipitation is about 850 mm; mean annual air temperature is about 8°C.
 Vegetation and Land Use: Woodland (Tag alder)
 Parent Material: Glacio-fluvial
 Physiographic Position: Rolling Upland (Post-Puluth lake stage)
 Topography: Single slope; 1% gradient; East (90°); concave; low slope position; elevation is about 210 m A.S.L.
 Groundwater: 31 cm.
 Sampled by: S.G. Shetron, R. Stottlemeyer, D. Putkowski, S. Freisen, D. Hansen
 Date: September 8, 1984

(All colors are for moist conditions, pedon described under shaded sunny conditions).

O1 0 to 2 cm. Partially and undecomposed leaves and twigs.

OF 2 to 0 cm. Black (5YR 2.5/1) organic matter; weak fine granular structure; very friable; strongly acid; abrupt smooth boundary.

A1 0 to 19 cm. Dark reddish gray (5YR 4/2) silt loam; weak fine subangular blocky structure; friable; common fine and medium woody roots; few faint yellowish red (5YR 5/6) mottles; slightly acid; abrupt smooth boundary.

E1 19 to 31 cm. Reddish brown (5YR 4/4) loam; weak fine subangular blocky structure; friable; few fine faint yellowish red (5YR 5/8) mottles; slightly acid; clear wavy boundary.

E / Bt 31 to 46 cm. Reddish brown (5YR 5/3) sandy loam E; and reddish brown (5YR 5/4) clay loam Bt; weak fine subangular blocky structure; common medium distinct strong brown (7.5YR 5/6 and 5/8) and yellowish red (5YR 5/6) and reddish yellow (5YR 6/8) mottles; friable, slightly acid; clear wavy boundary.

Bt 46 to 49 cm. Red (2.5YR 4/6) loam or clay loam; weak fine subangular blocky structure; friable; few fine faint strong brown (7.5YR 5/8) mottles; slightly acid; abrupt smooth boundary.

Note: to wet below 49 cm to remove soil materials.

Pedon Classification: Alfic Fragiorthod, ^{or Haploorthod} coarse loamy, mixed, frigid.
 Series Classification: (Same)
 Soil:
 Plot and Study: W-4, acid ppt; Isle Royale
 Location: Keweenaw County, Michigan, NE, SW, Section 4, T65N, R34W. (Isle Royale National Park)
 Climate: Average annual precipitation is about 850 mm; mean annual air temperature is about 8°C.
 Vegetation and Land Use: Open field and fir seedlings.
 Parent Material: Glacio-fluvial
 Physiographic Position: Rolling Upland (Post-Puluth lake stage)
 Topography: Single slope; 2-5% gradient; NW aspect (328°); convex; mid slope position; elevation is about 220 m A.S.L.
 Groundwater: Below 151 cm.
 Sampled by: S.G. Shetron, R. Stottlemeyer, D. Hansen, D. Putkowski, S. Freisen.
 Date: September 8, 1984

(All colors are for moist conditions, pedon described under full sun).

O1 5 to 4 cm. Undecomposed litter

OF 4 to 0 cm. Very dark gray (5YR 3/1) decomposed organic matter; weak fine granular structure; very friable; very strongly acid; abrupt smooth boundary.

E 0 to 3 cm. Dark reddish gray (5YR 4/2) fine sandy loam; weak fine granular structure; friable, many fine herbaceous roots; strongly acid; abrupt smooth boundary.

E1 3 to 36 cm. Dark reddish brown (5YR 3/4) loam; weak fine subangular blocky structure; friable, few fine herbaceous roots; strongly acid; abrupt smooth boundary.

2E1 36 to 56 cm. Brown (7.5YR 5/4) coarse sand; weak fine platy structure; friable to firm; slightly acid; clear wavy boundary.

2Bt 56 to 77 cm. Yellowish red (5YR 4/6) sandy loam; weak fine subangular structure; friable; neutral; abrupt smooth boundary.

3C 77 to 112 cm. Brown (7.5YR 4/4) gravelly loamy sand; massive; friable; neutral; clear wavy boundary.

3C2 112 to 151 cm. Reddish brown (5YR 4/3) gravelly loamy sands; massive; friable; neutral to alkaline.

NOTE: 2Bt weakly developed; at junction of 3C and 3C2 red (2.5YR 4/6) clay lenses 5-10 cm thick. C material appears to be till with E and B etc. shoreline material.

Pedon Classification: Lithic Alfisols: Haplorthod, coarse loamy, mixed, frigid.

Series Classification: (Same)

Soil:

Plot and Study: Spruce - Fir, acid ppt; Isle Royale National Forest

Location: Keweenaw County, Michigan, NW, SW, Section 4, T65N, R34W. (Isle Royale National Park)

Climate: Average annual precipitation is about 850 mm; mean annual air temperature is about 8°C.

Vegetation and Land Use: Wood - Spruce-fir.

Parent Material: Glacio-fluvial (Post Lake Duluth Lake Stage).

Physiographic Position: Rolling Upland - Lake Terraces

Topography: Single slope; 2-3% gradient; southwest (254°); convex; linear, mid upper slope position; elevation is about 220 m A.S.L.

Groundwater: Below 150 cms.

Sampled by: S.G. Shetron, R. Stottlemeyer, D. Rutkowski, S. Freisen.

Date: September 7, 1984

(All colors are for moist conditions, pedon described under shaded sunny conditions).

O1 7 to 2 cm. Undecomposed needles and twigs.

Ce 2 to 0 cm. Partially decomposed needles and twigs; very strongly acid.

E 0 to 5 cm. Dark reddish gray (5YR 4/2) loamy sand; weak fine granular structure; very friable; common fine and medium woody roots; strongly acid; abrupt smooth boundary.

Ehs 5 to 18 cm. Dark reddish brown (5YR 3/4) sandy loam; weak fine subangular structure; very friable; common fine and coarse woody roots; medium acid; clear wavy boundary.

Es1 18 to 27 cm. Reddish brown (5YR 4/4) sandy loam; weak fine subangular blocky structure; very friable; common fine woody roots; slightly acid; clear wavy boundary.

E / Et 27 to 39 cm. Reddish brown (5YR 5/3) moist and pinkish white (7.5YR 8/2) sandy loam E; red (2.5YR 5/6) moist and reddish brown (5YR 5/4) clay loam Et; moderate fine subangular blocky structure; friable; clear irregular boundary.

2Et 39 to 60 cm. Red (2.5YR 5/6) silty clay loam; moderate fine subangular blocky structure; friable; neutral; abrupt smooth boundary.

R-60cm Bedrock unknown

Pedon Classification: Terric Borosaprist, sandy, mixed, euic.

Series Classification: (Same)

Soil:

Plot and Study: Plot S1; Isle Royale Acid ppt Study.

Location: Keweenaw County, Michigan, SE, SW, NE Section 33, T66N, R34W. (Isle Royale National Park)

Climate: Average annual precipitation is about 850 mm; mean annual air temperature is about 8°C.

Vegetation and Land Use: Forest swamp conifer and tag alder.

Parent Material: Glacio-fluvial

Physiographic Position: Low area in rolling uplands.

Topography: Concave; single slope; 2-3% gradient, north aspect; low position; elevation is about 200 m.

Groundwater: 20 cms.

Sampled by: S.G. Shetron, R. Stottlemeyer, D. Hansen, D. Rutkowski, S. Friesen

(All colors are for moist conditions, pedon described under sunny conditions).

Oe 25-17 cm. Very dark brown (10YR 2/2) organic materials; weak fine granular structure; friable; abrupt smooth boundary; neutral.

Oe 17-1 cm. Black (10YR 2/1) organic materials; weak fine granular structure; friable; abrupt smooth boundary; neutral.

Ol 1-0 cm. Very dark gray (10YR 3/1) organic materials; abrupt smooth boundary, neutral.

Ps 0-70 cm. 50% yellowish red (10YR 5/8) and 50% brown (10YR 4/2) sand; single grain structure; non-plastic; abrupt smooth boundary, neutral.

C 70 cm. 80% weak red (2.5YR 5/2) and 20% strong brown (7.5YR 4/6) sand; single grain structure; non-plastic; neutral.

Note: 52 cms a 1 cm thick mixed bluish gray (5E 5/1) and greenish gray (5GR 5/1) lacustrine clay lens.

Pedon Classification: Entic Lithic Haplorthod; coarse loamy, mixed, frigid.

Series Classification: (Same)

Soil:

Plot and Study: Plot S2; Isle Royale Acid ppt Study

Location: Keweenaw County, Michigan, SE, SE, NE, Section 33, T61N, R34W.

Climate: Average annual precipitation is about 850 mm; mean annual air temperature is about 8°C.

Vegetation and Land Use: Spruce Fir and open field

Parent Material: Glacio-fluvial.

Physiographic Position: Ridge crest in rolling upland

Topography: Convex; complex slope; 3% gradient; N 38°W aspect; upper position; elevation is about 260 m.

Groundwater: Below 150 cms.

Sampled by: S.G. Shetron, R. Stottlemeyer, D. Rutkowski, S. Freisen, D. Hansen

(All colors are for moist conditions, pedon described under cloudy and sunny conditions).

Oi 7-4 cm. Undecomposed litter.

Oe 4-0 cm. Partially decomposed litter.

E 0-7 cm. Reddish gray (5YR 5/2) fine sandy loam; weak fine granular structure; very friable; clear wavy boundary; strongly acid.

Ps1 7-10 cm. Reddish brown (5YR 4/4) gravelly loam; weak fine subangular blocky structure; very friable; medium acid; clear wavy boundary.

Es2 10-32 cm. Reddish brown (5YR 4/6) gravelly sandy loam; single grain structure; loose; medium acid; abrupt smooth boundary.

R 32 cm.

Note: Roots were common fine and medium in all mineral horizons.

Pedon Classification: Entic Haplorthod, sandy, mixed, frigid.

Series Classification: (Same)

Soil:

Plot and Study: Plot D, Acid ppt study.

Location: Marquette County, Michigan, NW, SW, Sec. 32, T52N, R29W.

Climate: Average annual precipitation is about 850 mm; mean annual air temperature is about 7°C.

Vegetation and Land Use: Northern hardwood, sugar maple, hemlock, yellow birch

Parent Material: Glacio-fluvial.

Physiographic Position: Rolling upland (reworked glacial drift by Post-Duluth lake stages).

Topography: Linear; single slope; 2% gradient; northwest aspect (60°); convex; mid slope position; elevation is about 300 m A.S.L..

Groundwater: Below 170 cms.

Sampled by: S.G. Shetron, R. Stottlemeyer, D. Hansen.

(All colors are for moist conditions, pedon described under cloudy conditions)

O1 2-0 cm. Undecomposed leaves and twigs.

A 0-5 cm. Very dark gray (5YR 3/1) loamy sand; weak fine granular structure; very friable; slightly to medium acid; abrupt smooth boundary.

E 5-14 cm. Reddish brown (5YR 5/3) sand; single grain; loose; medium acid; clear wavy boundary.

Es1 14-19 cm. Reddish brown (5YR 4/4) loamy sand; weak fine subangular structure; friable; slightly acid; clear wavy boundary.

Es2 19-47 cm. Reddish brown (2.5YR 5/4) loamy fine sand, weak fine subangular structure, friable, medium acid; clear wavy boundary.

EC 47-65 cm. Reddish brown (5YR 5/4) sand; single grain; loose; clear wavy boundary, medium to slightly acid.

C1 65-91 cm. Yellowish red (5YR 5/6) sand; single grain; loose, abrupt smooth boundary; slightly acid.

C2 91-96 cm. Red (5YR 5/6) fine sand; single grain, loose; abrupt smooth boundary, slightly acid.

C3 96+ cm. Reddish brown (2.5YR 5/4) coarse sand; single grain; loose; slightly acid.

NOTE: Es1 contains discontinuous orstein; EC & C have weakly developed 1-2 mm fine textured lenses; Es2 has streaks of 1-2 mm sand lenses.

Pedon Classification: Entic Lithic Haplorthods; coarse loamy, mixed frigid.

Series Classification: (Same)

Soil:

Plot and Study: Plot C, Acid ppt study.

Location: Marquette County, Michigan, NW, SW, Sec. 32, T52N, R29W.

Climate: Average annual precipitation is about 850 mm; mean annual air temperature is about 7°C.

Vegetation and Land Use: Northern hardwood forest; sugar maple, hemlock.

Parent Material: Glacio-fluvial over sandstone bedrock.

Physiographic Position: Rolling upland (reworked glacial drift by Post Duluth lake stages).

Topography: Convex; single slope; slope gradient 20%; aspect northeast 60°; about 100 m long; elevation is about 310 m A.S.L.; plot mid slope position.

Groundwater: Below 170 cms.

Sampled by: S.G. Shetron, R. Stottlemeyer, D. Hansen.

(All colors are for moist conditions, pedon described under cloudy conditions)

O1 1-0 cm. Undecomposed leaves and twigs.

A 0-6 cm. Very dark gray (5YR 3/1) loam; moderate fine granular structure; friable; neutral; abrupt smooth boundary.

E 6-13 cm. Reddish brown (5YR 4/3) to dark reddish gray (5YR 4/2) loam; weak fine subangular blocky structure; friable; medium acid; clear smooth boundary.

Es1 13-56 cm. Reddish brown (2.5YR 4/4) gravelly loamy sand, single grain; loose; slightly acid, abrupt smooth boundary.

2Et 56-60 cm. Weak red (10R 4/3) sandy loam; moderate fine subangular blocky structure, friable; slightly acid.

2R 60 cm. Fractured sandstone bedrock.

NOTE: Pronounced worm activity A & E; 2Et till and discontinuous; sandstone fractures contain roots and clay coatings, clay coatings also on horizontal surfaces of sandstone.

Pedon Classification: Typic Haplorthod, sandy, mixed, frigid.
 Series Classification: (Same)
 Soil:
 Plot and Study: Plot A, Acid ppt study.
 Location: Marquette County, Michigan, SE, NE, Sec. 31, T52N, R29W.
 Climate: Average annual precipitation is about 850 mm. Mean annual air temperature is about 70C.
 Vegetation and Land Use: Woodland, northern hardwoods, hemlock, sugar maple, yellow birch (old growth).
 Parent Material: Glacio-fluvial reworked by Post-Duluth retreating lake levels.
 Physiographic Position: Rolling upland.
 Topography: Convex; single slope; southeast aspect (1450); slope gradient 6%; slope length about 50 meters; elevation about 280 m A.S.L., plot mid-low position.
 Groundwater: 119-120 cms.
 Sampled by: S.G. Shetron, R. Stottlemeyer, D. Hansen.

(All colors are for moist conditions, pedon described under cloudy conditions)

O1 3-2 cm. Undecomposed leafs and twigs.
 Oe 2-0 cm. Partially decomposed leafs and twigs.
 E 0-24 cm. Pinkish gray (5YR 6/2) sand; weak fine granular structure; very friable; few roots; moderately acid; abrupt wavy boundary; 17-24 cm thick.
 E_h 24-33 cm. Dark reddish brown (5YR 3/3) sand-loamy sand; weak fine subangular blocky structure; friable; moderately acid; clear wavy boundary; 8-15 cm thick; slightly cemented. (tongue to 58 cm; >4.2 kg/cm² on the penetrometer).
 E_h 33-45 cm. Dark reddish brown (2.5YR 3/4) sand; massive; very firm; slightly acid; clear wavy boundary; strongly cemented; (orstein, >4.2 kg/cm² penetrometer), moderately acid.
 E_{sm} 45-70 cm. Reddish brown (2.5YR 4/4) sand; massive; very firm; clear wavy boundary; strongly cemented (orstein, >4.2 kg/cm² penetrometer); moderately acid.
 EC 70-110 cm. Dark red (2.5YR 4/6) sand, single grain; loose; moderately acid; clear wavy boundary;
 C 110-150+ cm. Reddish brown (2.5YR 5/4) sand; single grain loose; slightly acid.

NOTE: Redness of profile reflects Jacksville sandstone influence in glacial drift materials; rooting abundant in E_h; very few to none in E_h & E_{sm}; water table 120-140 cms; C color shifts from reddish brown (2.5YR 5/4) to weak red (10YR 4/4) at 119 cms, E_h tongues to 116 cm.

Pedon Classification: Entic Lithic Haplorthods; loamy, mixed, frigid.
 Series Classification: (Same)
 Soil: Peshekee.
 Plot and Study: Plot B, Acid ppt study.
 Location: Marquette County, Michigan, SE, NE, Sec. 31, T52N, R29W.
 Climate: Average annual precipitation is about 850 mm. Mean annual air temperature is about 70C.
 Vegetation and Land Use: Woodland, red oak, white pine and brush.
 Parent Material: Eolian over granite bedrock.
 Physiographic Position: Rolling upland.
 Topography: Convex; complex slope; southwest aspect (2600); slope gradient 20%; about 50 m long; elevation is about 300 m A.S.L., plot mid-upper position.
 Groundwater: Below 170 cms.
 Sampled by: S.G. Shetron, R. Stottlemeyer, D. Hansen.

(All colors are for moist conditions, pedon described under cloudy conditions)

O1 1-0 cm. Undecomposed leaves and twigs.
 A 0-9 cm. Dark reddish gray (5YR 4/2) loam; moderate fine granular structure; friable; neutral to slightly acid; abrupt smooth boundary.
 E_s 9-19 cm. Reddish brown (5YR 4/4) loam; weak fine subangular blocky structure; friable; slightly acid; abrupt smooth boundary.
 2R 19 cm. Granite bedrock.

NOTE: Pronounced worm activity A & E_s; myc. threads 30% A & E_s; roots penetrate rock fractures; coatings on horizontal faces of bedrock; depth to 2R ranges from 19-25 cm.

Pedon Classification: Typic Lithic Haplorthod, silty, mixed, frigid.

Series Classification: (Same)

Soil:

Plot and Study: Plot S3; Isle Royale Acid ppt Study

Location: Keweenaw County, Michigan, SE, NE, SW, Section 33, T66N, R34W.

Climate: Average annual precipitation is about 850 mm; mean annual air temperature is about 8°C.

Vegetation and Land Use: Bush and Balsam fir, White spruce, rock knob.

Parent Material: Eolian over fractured bedrock.

Physiographic Position: Ridge crest

Topography: Convex; complex slope; 4 to 14% gradient; N68°W aspect; upper slope; elevation is about 260 m.

Groundwater: Below 150 cms.

Sampled by: S.G. Shetron, R. Stottlemeyer, D. Hansen, D. Rutkowski, S. Freisen.

(All colors are for moist conditions, pedon described under sunny conditions).

O1 4-3 cm. Undecomposed litter.

Oe 3-0 cm. Partially decomposed organic materials - charcoal fragments.

E 0-5 cm. Dark reddish brown (5YR 4/2) gravelly silt loam; weak fine granular structure; friable; slightly acid; abrupt smooth boundary.

Bhs 5-9 cm. Dark brown (7.5YR 3/4) gravelly silt loam; weak fine subangular blocky structure; friable, clear wavy boundary; slightly acid.

Ps 9-35 cm. Dark reddish brown (2.5YR 2.5/4) gravelly silt loam or loam; weak fine subangular blocky structure; friable; medium acid; abrupt smooth boundary.

R 35 cm. Bedrock, fractured with cracks filled with roots and Ps materials.

Pedon Classification: Entic Haplorthod, coarse loamy, mixed, frigid.

Series Classification: (Same)

Soil:

Plot and Study: Plot S4, Isle Royale Acid ppt Study.

Location: Keweenaw County, Michigan, SW, NE, SE, Section 33, T66N, R34W.

Climate: Average annual precipitation is about 850 mm; mean annual air temperature is about 8°C.

Vegetation and Land Use: Forested - trembling aspen

Parent Material: Glacio-fluvial over till

Physiographic Position: Rolling Upland

Topography: Convex; single slope; 3 to 12% gradient; N16°E aspect; mid to upper slope; elevation is about 260 m.

Groundwater: Below 150 cms.

Sampled by: S.G. Shetron, R. Stottlemeyer, D. Hansen, D. Rutkowski, S. Freisen.

(All colors are for moist conditions, pedon described under shade with full sun).

O1 5-4 cm. Undecomposed litter.

Oe 4-0 cm. Partially decomposed litter.

E 0-3 cm. Weak red (2.5YR 4/2) sandy loam; weak fine granular structure; very friable; many medium roots; strongly acid; abrupt smooth boundary.

Es1 3-26 cm. Reddish brown (5YR 4/4) loam; weak fine subangular blocky structure; friable; many medium roots; strongly acid; clear wavy boundary.

Ps2 26-35 cm. Dark brown or brown (7.5YR 4/4) very fine sandy loam; weak fine subangular blocky structure; very friable; common medium roots; medium acid; clear wavy boundary.

Ps3 35-54 cm. Strong brown (7.5YR 4/6) very fine sandy loam; weak fine subangular blocky structure; very friable; few to many medium roots; neutral; clear wavy boundary.

2E'x 54 to 76 cm. Yellowish red (5YR 5/6) loamy sand; medium fine platy structure; firm; few fine roots; slightly acid; clear wavy boundary.

2E/B 76 to 115 cm. Reddish brown (5YR 5/4) loamy sand Et, light reddish brown (5YR 6/3) sand E; weak fine subangular blocky structure; friable; slightly acid; clear wavy boundary.

2C 115 to 133 cm. Dark reddish brown (5YR 3/4) loamy sand; massive structure; friable; slightly acid; abrupt smooth boundary.

R 133 cm. Bedrock.

Appendix D: Regression equations and references used for predicting current aboveground biomass of trees in the four small lake watersheds.

SPECIES	FW or ODW	COMPONENT	PREDICTION EQUATION	N	R ² OR r	RANGE OF DBH IN CM	REFERENCE
<i>Abies balsamea</i>	ODW-lbs	Tree	$\log Y = 0.086 + 2.53 \log D_1$	101	.96(r)	2.5 - 25.0 cm	Baskerville, 1965
<i>Acer rubrum</i>	ODW-g	Foliage	$\log Y = 2.1237 + 1.8015 \log D_2$	30	.85	2.5 - 15.0 cm	Ribe, 1973
		Branches	$\log Y = 2.3088 + 1.9148 \log D_2$		.90		
		Stem	$\log Y = 2.8479 + 2.6522 \log D_2$		.99		
<i>Acer saccharum</i>	ODW-g	Foliage	$\log Y = 2.0383 + 1.6701 \log D_2$	30	.83	2.5 - 15.0 cm	Ribe, 1973
		Branches	$\log Y = 2.4004 + 1.5571 \log D_2$		.85		
		Stem	$\log Y = 3.0609 + 2.4927 \log D_2$		.99		
<i>Alnus rugosa</i>	ODW-g	Foliage	$\log Y = 2.1759 + 1.2463 \log D_1$	30	.67	2.5 - 7.5 cm	Ribe, 1973
		Branches	$\log Y = 2.4072 + 1.5184 \log D_1$		.78		
		Stem	$\log Y = 2.7051 + 2.5847 \log D_1$		.93		
<i>Betula alleghaniensis</i>	ODW-g	Foliage	$\log Y = 1.9962 + 1.9683 \log D_2$	30	.90	2.5 - 15.0 cm	Ribe, 1973
		Branches	$\log Y = 2.5345 + 1.6179 \log D_2$		.89		
		Stem	$\log Y = 2.9670 + 2.5330 \log D_2$		.99		
<i>Betula papyrifera</i>	ODW-g	Foliage	$\log Y = 2.1587 + 1.7020 \log D_1$	30	.89	2.5 - 15.0 cm	Ribe, 1973
		Branches	$\log Y = 2.4059 + 1.7304 \log D_1$		.88		
		Stem	$\log Y = 2.4481 + 3.2640 \log D_1$		.99		
	FW-lbs	Tree	$\ln Y = .8025 + 2.2234 \ln D_1 + .3390 \ln H_1$	17	.97	15.3 - 29.0 cm	Young, 1964
	ODW-lbs	Tree	42% of FW		.97		
<i>Picea glauca</i>	ODW-lbs	Tree	$\log Y = 0.150 + 2.48 \log D_1$	13	.99	2.5 - 25.0 cm	Baskerville, 1965
<i>Picea mariana</i>	ODW-lbs	Tree	$\log Y = 0.150 + 2.48 \log D_1$	13	.99	2.5 - 25.0 cm	Baskerville, 1965
<i>Pinus banksiana</i>	ODW-kg	Tree	$\log Y = -1.0368 + 2.4206 \log D_2$	77	.99	2.9 - 31.7 cm	Hegyi, 1972
<i>Pinus strobus</i>	FW-lbs ODW-lbs	Tree (above a 6" stump)	$\ln Y = .2150 + 2.1679 \ln D_1 + .4292 \ln H_1$ 36% of FW	27	.98	14.5 - 24.5 cm	Young et al., 1964
<i>Populus tremuloides</i>	ODW-kg	Tree	$\log Y = -3.2198 + 0.8993 \log D_2$	49	.99(r)	4.5 - 33.0 cm	Peterdon, Chan and Cragg, 1970
<i>Quercus rubra</i>	ODW-g	Tree	$\log Y = 2.3948 + 2.1900 \log D_2$	15	.99	Not available	Whittaker and Woodwell, 1968
<i>Salix</i> spp.	ODW-g	Foliage	$\log Y = 2.1879 + 1.6442 \log D_1$	30	.67	2.5 - 7.6 cm	Ribe, 1973
		Branches	$\log Y = 2.4822 + 1.6624 \log D_1$		.77		
		Stem	$\log Y = 2.7610 + 2.3391 \log D_1$		.91		
<i>Thuja occidentalis</i>	ODW-g	Foliage	$\log Y = 1.59 + 2.07 \log H_1$	36	.94	< 14.0 cm	Dyer, 1967
		Branches	$\log Y = 0.59 + 2.37 \log H_1$		.89		
		Stem	$\log Y = -0.32 + 3.07 \log H_1$		.95		
	ODW-lbs	Tree	$\log Y = 0.037297 D_6$	113	.90	2.5 - 120 cm	Kurucz, 1961
<i>Tsuga canadensis</i>	FW-lbs ODW-lbs	Tree (above a 6" stump)	$\ln Y = .1798 + 2.1679 \ln D_1 + .4292 \ln H_1$ 31% of FW	28	.98	14.0 - 37.8 cm	Young et al., 1964

Where: D_1 = Diameter at breast height (in.)
 D_2 = Diameter at breast height (cm)
 D_6 = $(D_1^2 H)$ = Diameter at breast height squared (in²) x height (ft.)
 D_9 = $(D_1^2 H)$ = Diameter at breast height squared (cm²) x height (cm)
 H_1 = Height above ground (ft.)