CHANGES IN SNOWPACK, STREAM, AND LAKE CHEMISTRY
DURING SNOWMELT IN THE TURKEY LAKES WATERSHED

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ABSTRACT

The effect of snowmelt on the chemistry of surface waters in the Turkey Lakes watershed was studied for 1981 and 1982. In 1982, a mid-February melt preceded the major runoff event that was initiated by heavy rainfall in late March. The runoff hydrograph contained several sharp peaks of intense stream discharge. In 1982, a large snowpack accumulated and was affected by 2 small melt periods in April prior to maximum runoff. The hydrograph was characterized by broad, low intensity peaks in stream flow. Ionic pollutants stored in the snowpack were rapidly and preferentially (with respect to water) removed at the beginning of melting periods. The loss of acid from the snowpack was reflected in streamwater pH depressions. The magnitude of the depression was a function of stream discharge. Maximum H^+ concentrations in 1981 followed peaks in stream discharge rather than preceding them as has been observed in Norwegian studies. Interaction of the acidic meltwaters with the deeper, unfrozen soils present in the Turkey Lakes Watershed may account for the different observations in the two locations. In 1982, Batchawana Lake experienced 2 separate periods when surface water pH declined to <5.0 from mid-winter values of approximately 6.2. Sulphate, Ca^{2+}, NO_3^- and NH_4^+ also varied in a predictable manner given the relative concentrations in the snowpack and lake water.

Changes in Snowpack, Stream and Lake Chemistry During
Snowmelt in the Turkey Lakes Watershed

I.   INTRODUCTION

A large fraction of the annual input of materials to lakes situated in acid sensitive, silicate terrain, often accompanies spring snowmelt. During this period of high hydrologic flux, the snowpack, stream and lake waters experience rapid and sometimes large changes in composition. In particular, an increase in H^+ content (pH depression) in stream waters associated with snowmelt has been documented in Norway (Gjessing et al. 1976; Henriksen and Wright 1977; Johannessen et al., 1980), Sweden (Odén and Ahl 1970; Hultberg 1976), Finland (Haapla et al. 1975), the northeastern USA (Schofield 1977; Galloway et al. 1980), the north-central USA (Siegel 1981), and central Ontario, Canada (Jeffries et al. 1979; Jeffries and Snyder 1981). This rapid fluctuation in stream water pH coupled with increases in Al concentration (Driscoll 1980; Johannessen 1980) can have deleterious effects on the biota inhabiting both the streams and the littoral zones of lakes receiving the drainage waters. Reports of the loss of fish populations in these acid sensitive areas are now widespread, for example, Muniz and Leivestad 1980; Harvey 1980; and Schofield 1976.

The mechanisms controlling the degree and rate of stream water pH depression during snowmelt are poorly understood. The first

meltwaters leaving the snowpack are relatively enriched in acids and other contaminants. Johannessen and Henriksen (1978) and Colbeck (1981) both suggest that soluble impurities in the first meltwaters may be 5-fold more concentrated than the bulk snowpack from which they emerged. Melt-freeze cycles tend to concentrate these impurities in the lower portion of the snow cover thereby preparing them for rapid removal. The most important factors governing the magnitude of the acid pulse leaving the snowpack are the effectiveness of pre-melt freeze-thaw cycles in concentrating the acid, and the rate of water release once the runoff period has been initiated (Colbeck 1981). The second factor is influenced by both the rate of melting and the input of rain into an already saturated snowpack. Johannessen and Henriksen (1978) conducted laboratory and field experiments in Norway and found that in the case where ion release was not affected by the input of rain, 50-80% of the snowpack pollutant load was released with the first 30% of the water.

In the case where the soils beneath the snowpack are impermeable or very thin, the acid released from the snowpack may pass directly to streams with minimal neutralization and provide temporal variations in ion content similar to those observed by Johannessen et al. (1980) in Norway where maximum H^+, SO_4^{2-} and Ca^{2+} concentrations in the streamwater preceded peak water flow. In studies of headwater streams in central Ontario, Canada, Jeffries et al. (1979) and Jeffries and Snyder (1981) observed maximum H^+ concentrations which

coincided with maximum flow and also very little variation in SO_4^{2-} levels throughout the runoff period. The differences between the Norwegian and Canadian observations may reflect the greater influence of the thicker, generally unfrozen soil cover present at the latter location.

A new study has been initiated near Sault Ste. Marie, Ontario, Canada in the Turkey Lakes Watershed with the purpose of developing a more quantitative understanding of the interation of factors (climatic and geochemical) which controls the magnitude and temporal course of short-term surface water acidification. Data on snowpack, lakewater, and lake outlet composition and attendant meteorological information have been collected during the melt periods of 1981 and 1982 and will be discussed here. Since this is a continuing study, the observations and conclusions given here should be considered preliminary in nature.

II.   STUDY AREA

The morphological, geological and biological characteristics of the Turkey Lakes Watershed have been previously described (Jeffries and Semkin 1982; Semkin and Jeffries 1983). Briefly, the Turkey Lakes Watershed (Figure 1) is a completely forested, headwater drainage basin located 50 km north of Sault Ste. Marie, Ontario. It is
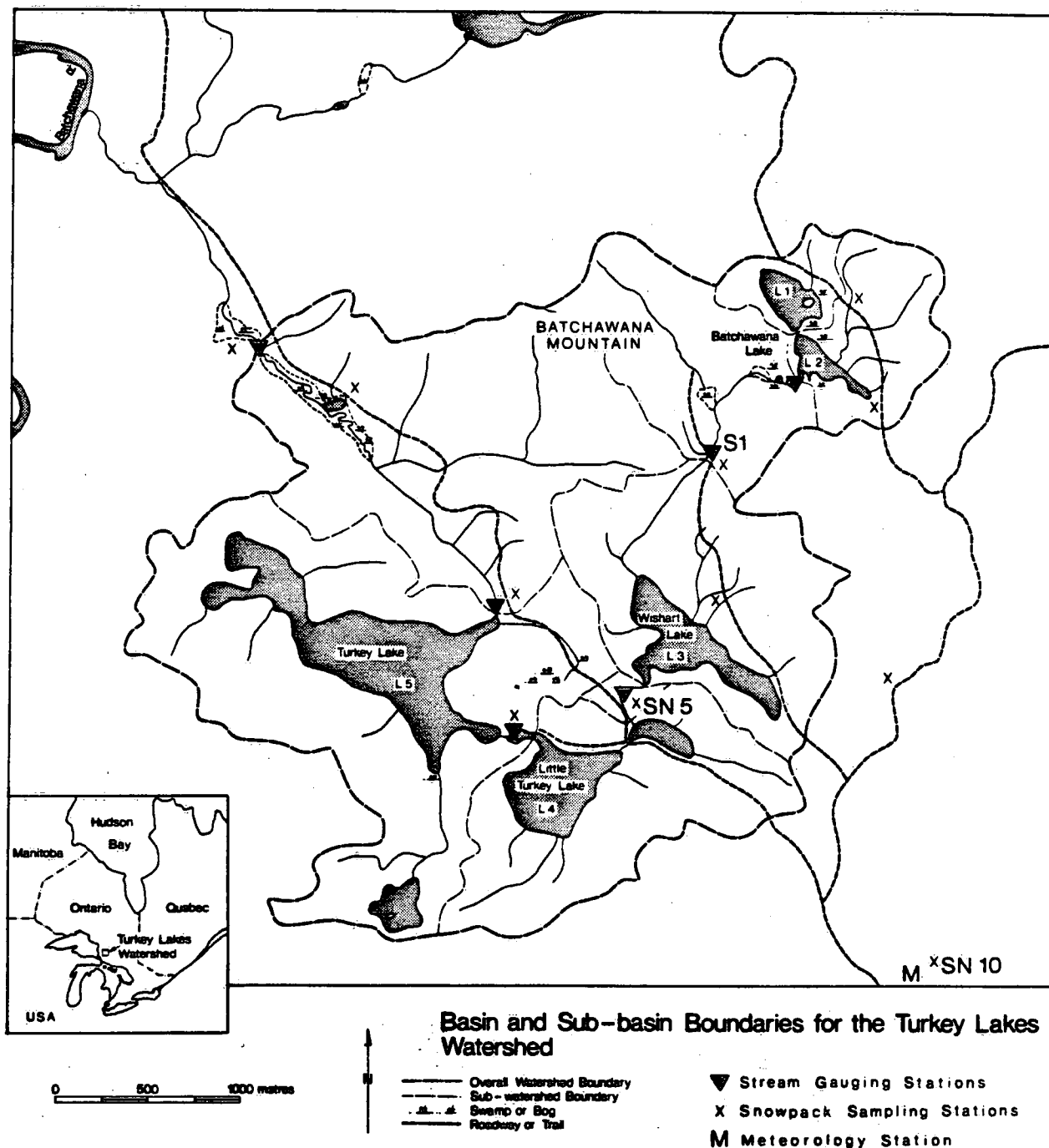
Figure 1: Study area location map. Location of stream gauging stations, snowpack sampling stations, and meterological monitoring station are indicated.

10.5 km^2 in area and contains 5 inter-connected lake basins with numerous small streams. It is entirely underlain by silicate bedrock of basaltic composition and is overlain by a glacial basal till which is generally < 1 m thick in the upper portions of the watershed and > 1 m thick in the lower portions. The forest is a mixed hardwood type. The lakes are all clear and exhibit a gradient in composition (Table 1) with the upper lakes having the lowest pH, Ca^{2+} and alkalinity and thus the highest potential for acidification. Sulphate concentrations are uniform from lake to lake. Compared to other parts of northeastern North America, atmospheric deposition of acids is moderate in this area. Precipitation pH is approximately 4.5 on average (Barrie et al. 1982) although occasional events have values less than 4.0.

III   METHODS

All elements of the hydrological cycle are routinely monitored on a year-round basis in the Turkey Lakes Watershed. During the winter and subsequent spring-melt periods of 1981 and 1982, meteorological conditions (e.g. air temperatures, vapour pressure, winds, solar radiation, etc.) were monitored continuously while wet precipitation was sampled daily for both quality and quantity. The snowpack was sampled at the locations shown on Figure 1 at regular intervals throughout this period of time using a tubular, plastic coring device.

Table 1. Median pH and concentration (meq L^{-1}) of ionic parameters
for lakes located in the Turkey Lakes Watershed. The lakes
are listed in order of decreasing elevation. Median values
are for all samples (n = 300 to 400) collected from February
1980 to July 1982.

	Lake[1]				
	Batchawana				
Parameter	North	South	Wishart	L. Turkey	Turkey
pH	6.02	6.11	6.57	6.55	6.72
Ca^{2+}	0.116	0.158	0.200	0.259	0.286
Mg^{2+}	0.037	0.042	0.042	0.047	0.043
Na^+	0.021	0.021	0.024	0.025	0.025
K^+	0.008	0.007	0.007	0.008	0.007
NH_4^+	0.006	0.005	0.006	0.003	0.001
Alkalinity	0.048	0.070	0.112	0.166	0.190
SO_4^{2-}	0.114	0.127	0.132	0.137	0.135
Cl^-	0.011	0.012	0.011	0.011	0.009
NO_3^-	0.007	0.010	0.012	0.012	0.014

[1]see Figure 1

Stream and lake waters were sampled on a variable schedule which reflected the hydrologic flux in the system. Thus in winter, stream and lake sampling occurred every 2-3 weeks while in spring, it occurred every 1-2 days. Stream samples were collected as grab samples at each of the flow gauging stations indicated on Figure 1. Each of the gauging stations has a water level recorder to provide a continuous record of water flow.

The lakes were sampled at their deepest points using a peristaltic pump. In 1981, samples were collected at the top, middle and bottom of the water column; while in 1982, samples were collected at 1 m intervals so that the spread of snowmelt waters over the surface of the lake could be better defined. Access to the sampling sites was achieved by snowmobile or all terrain vehicle during winter and early spring melt, and by helicopter during the later melt period.

Chemical analyses were performed using standard methods as given in the Department of the Environment (1979). Alkalinity data were obtained using a microprocessor controlled titrator which utilizes methodology equivalent to the Gran technique. It is particularly important to use such an alkalinity procedure for the low conductivity waters typical of the Turkey Lakes Watershed (Jeffries and Zimmerman 1980).

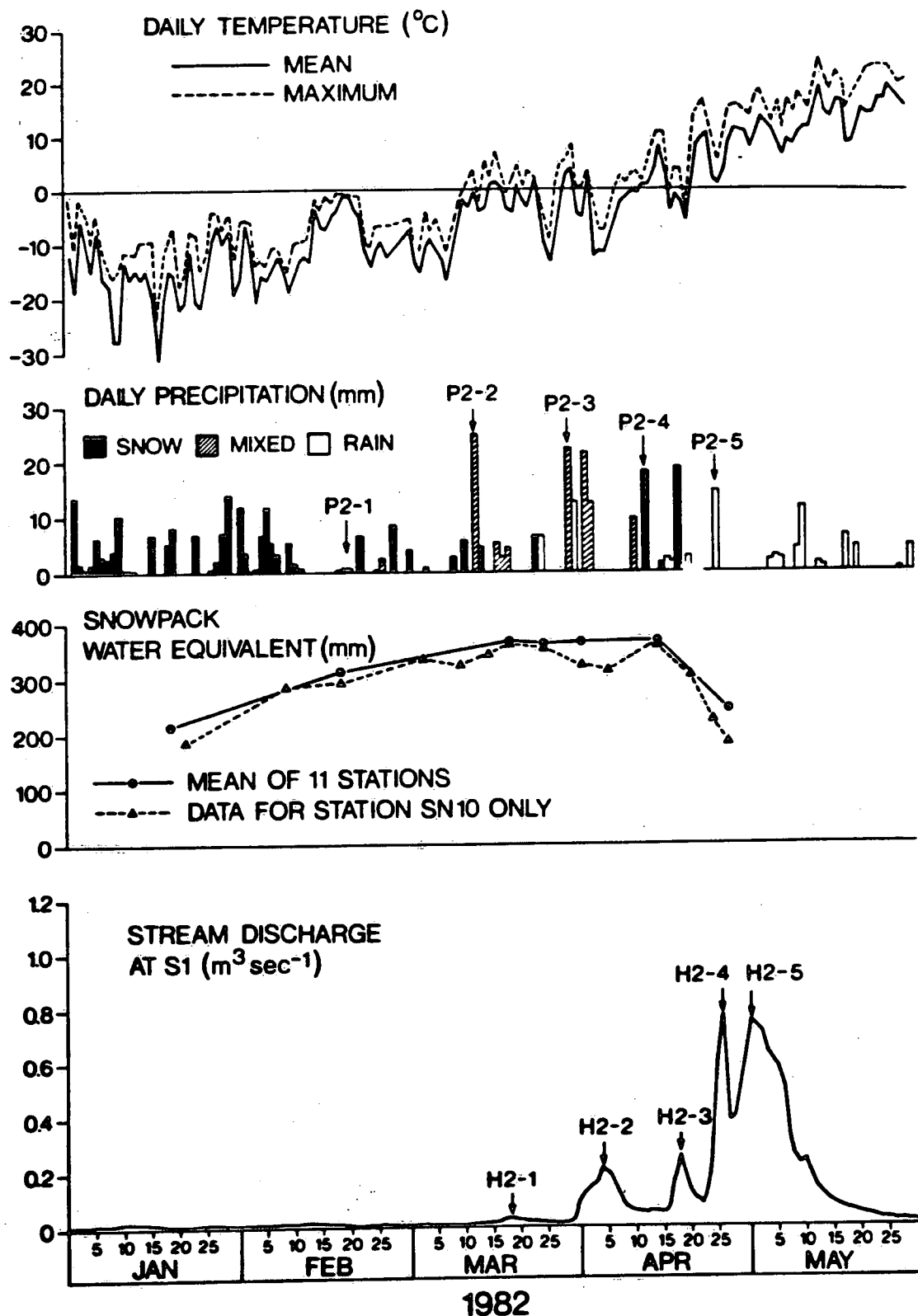## IV RESULTS AND DISCUSSION

IV-1 Meteorology and Hydrology

The meteorological conditions affecting snow accumulation, melt and the resultant stream hydrograph at station S1 are given in Figures 2 and 3 for 1981 and 1982 respectively. In 1981, the normally cold winter temperatures were interrupted from February 15 to 23 by unusually warm weather when mean daily temperatures exceeded 0°C and a small amount of rain or mixed precipitation (eg. rain and snow) fell. Most the meltwaters produced by these conditions primarily served to saturate the snowpack and underlaying soils since only a relatively small increase in stream flow was observed and the baseflow which remained after the melt was higher than pre-melt values or corresponding periods in 1982. The next and most important melt period of 1981 began March 21 and except for a few brief ocassions, mean daily temperatures remained above 0°C after this date. Heavy rainfall occurred between March 27 and April 1, 1981 (labelled P1-2 on Figure 2) and this input coupled with the snowmelt waters resulted in a rapid increase in stream flow to the maximum value measured for the year. Several other sharp peaks present in the hydrograph (Figure 2) were similarly caused by superposition of input from rain events on the "tail" of the snowmelt hydrograph.
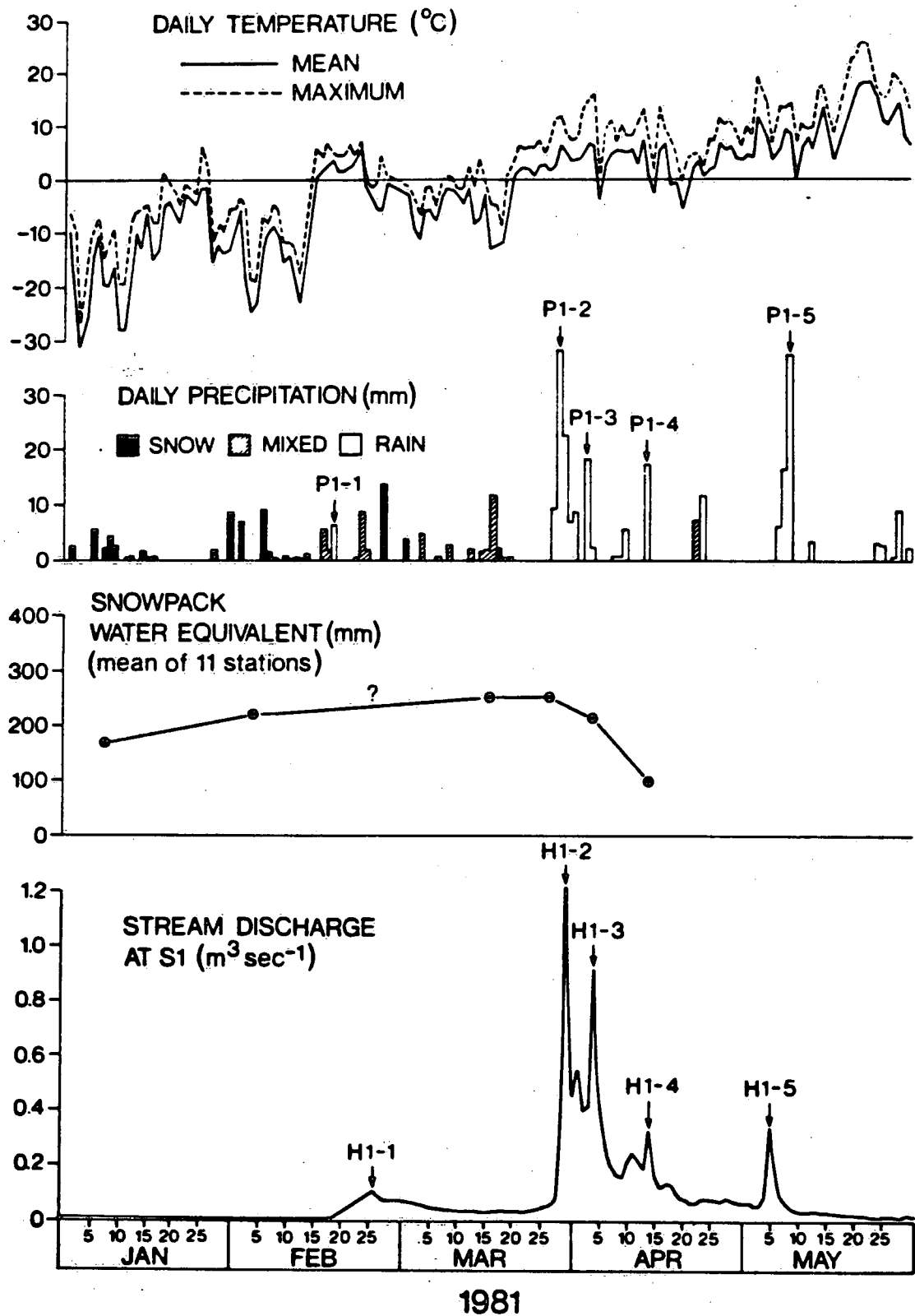
Figure 2: Meteorological and hydrological conditions from January to May 1981. Important precipitation events and hydrograph peaks have been labelled.

DAILY TEMPERATURE (°C)
— MEAN
---- MAXIMUM

DAILY PRECIPITATION (mm)
■ SNOW ▨ MIXED ☐ RAIN

P2-1 P2-2 P2-3 P2-4 P2-5

SNOWPACK
WATER EQUIVALENT (mm)
—●— MEAN OF 11 STATIONS
--▲-- DATA FOR STATION SN10 ONLY

STREAM DISCHARGE
AT S1 ($m^3 sec^{-1}$)

H2-1 H2-2 H2-3 H2-4 H2-5

5 10 15 20 25 JAN
5 10 15 20 25 FEB
5 10 15 20 25 MAR
5 10 15 20 25 APR
5 10 15 20 25 MAY

1982

METEOROLOGICAL AND HYDROLOGICAL CONDITIONS

Figure 3: Meteorological and hydrological conditions from January to
May 1982. Important precipitation events and hydrograph
peaks have been labelled.

Conditions experienced in 1982 (Figure 3) were different
from those in 1981. First, no air temperature values above freezing
occurred until March 11, 1982, and then for the next 4 weeks, tempera-
tures generally remained near freezing with day-time values above 0°C
and night-time values below 0°C. During this interval, the highest
temperatures occurred on March 30 to April 1, 1982 (daily mean = +3°C)
and were accompanied by rain or mixed precipitation and a loss of
water from the snowpack (see data for station SN 10 in Figure 3).
Stream flow increased slowly (H2-2); however, it declined once again
as daily mean temperatures dropped to -12°C on April 4-7, 1982 and did
not rise above 0°C until April 13. Snowfall increased the snowpack
water equivalent during this early April period of cold weather.
Another cycle of warm and cold weather produced a second small, broad
hydrograph peak (H2-3).

After April 21, 1982, daily mean temperatures did not fall
below 0°C and the period of major spring runoff commenced. The hydro-
graph contained 2 peaks (H2-4 and H2-5) of nearly equivalent height
with the first sharp peaks influenced by the input of 15 mm of rain on
April 25, and the second due almost entirely to meltwater runoff.
Very little rain occurred as the spring runoff subsided in 1982 so
that the falling limb of the hydrograph has a near perfectly shaped
tail.

In summary, the most important differences between the snow accumulation and melt periods of 1981 and 1982 in the Turkey Lakes Watershed were a) the mid-February melt period experienced in 1981 only, b) the greater snowpack water equivalent which accumulated in 1982 (maximum = 250 mm in 1981 and 370 mm in 1982), c) the generally warmer winter and spring experienced in 1981 coupled with numerous large rainfalls, and d) short term, intense flow pattern of the 1981 hydrograph compared to the broad, lower flow pattern of 1982.

IV-2   Snowpack Chemistry

The snowpack water equivalent (mm) and ion content (H^+, NH_4^+, SO_4^{2-}, NO_3^- in $meq \cdot m^{-2}$) are shown in Figures 4 and 5 for 1981 and 1982. The date of important precipitation events which were noted on Figures 2 and 3 have been marked on Figures 4 and 5 also. Note that the frequency of snowpack sampling was much shorter in 1982 than in 1981. The snowpack composition prior to melting is given in Table 2.

The greater variability in snowpack content present in Figure 5 compared to Figure 4 can be attributed, in part, to the shorter sampling frequency used in 1982. The frequency of sampling in 1982 was suitable for detecting small losses and additions to the water equivalent of the snowpack in response to changing meteorological conditions. The major differences between the 2 years were simply
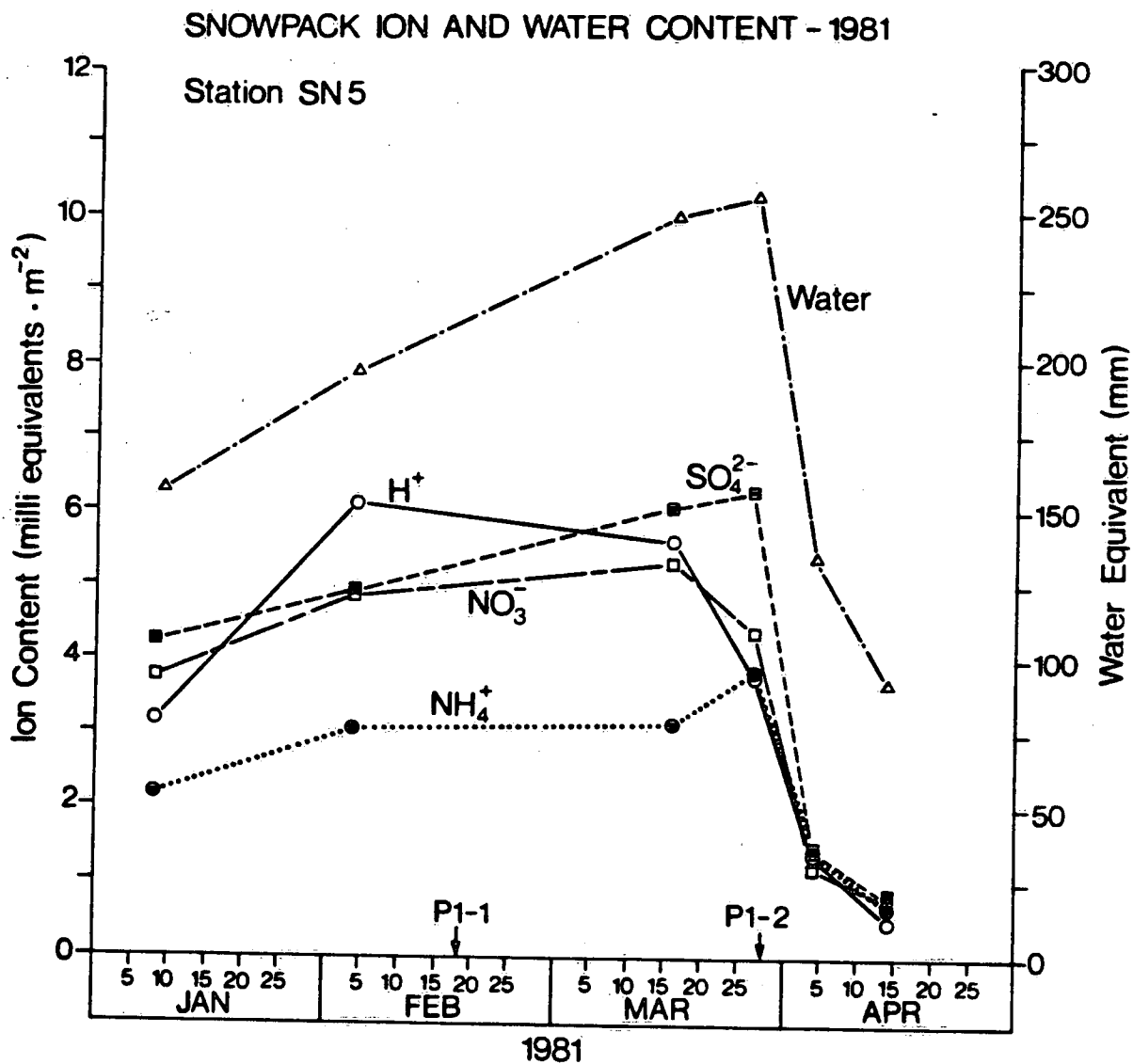
Figure 4: Hydrogen ion, SO_4^{2-}, NO_3^-, NH_4^+ (meq.m^{-2}), and water (mm) content of the snowpack at station SN 5 from January to April, 1981. Dates of important precipitation events are indicated on the horizontal axis.
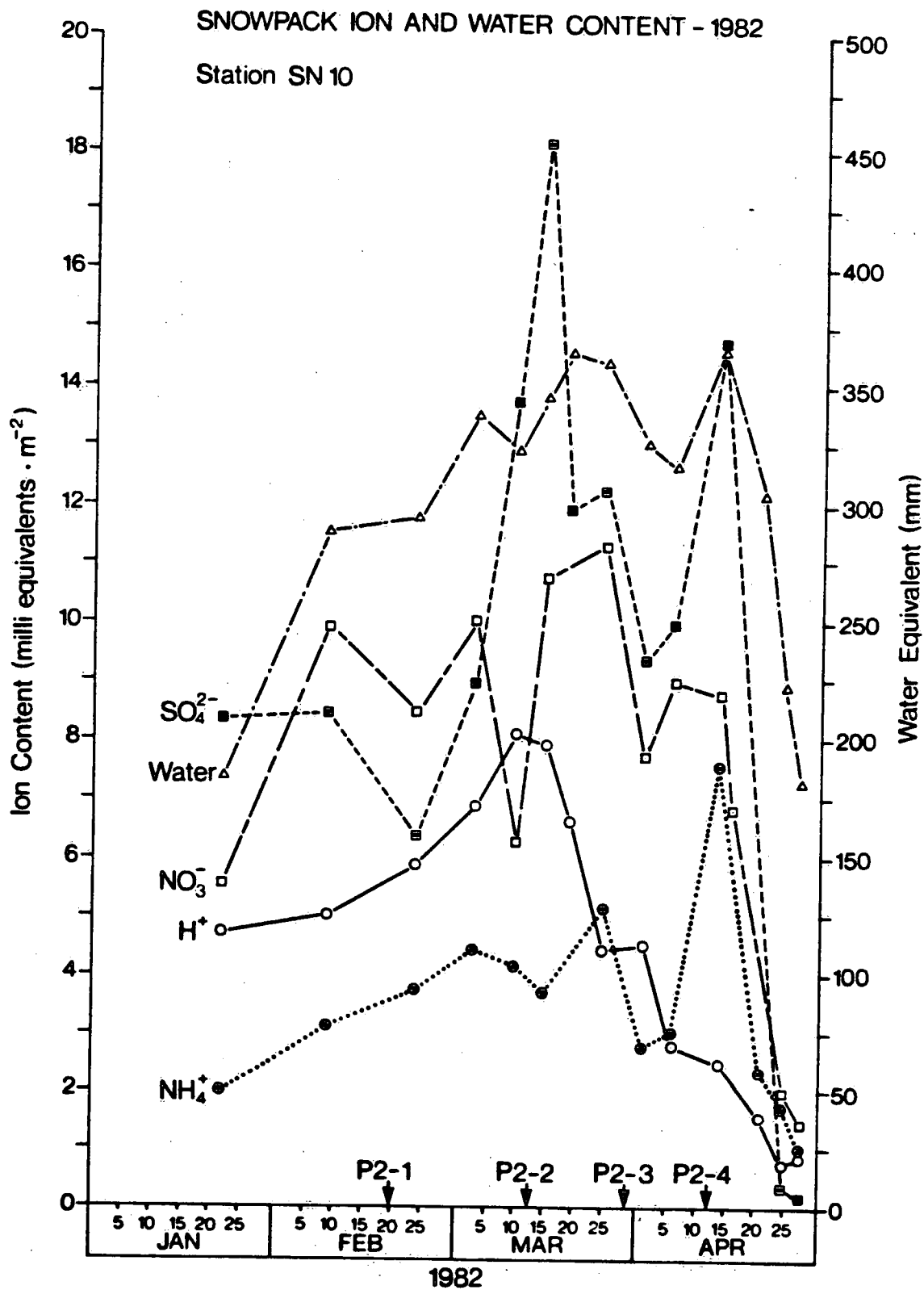
Figure 5: Hydrogen ion, SO_4^{2-}, NO_3^-, NH_4^+, (meq.m^{-2}), and water (mm) content of the snowpack at station SN 10 from Januauy to April, 1982. Dates of important precipitation events are indicated on the horizontal axis.

Table 2. Ionic composition (meq L^{-1}) of the snowpack in the Turkey Lakes Watershed prior to melting in 1981 and 1982. Data are means from 11 stations.

Parameter	1981	1982
H^+ (pH)	0.025 (4.60)	0.024 (4.62)
Ca^{2+}	0.004	0.007
Mg^{2+}	0.001	0.003
Na^+	0.005	0.010
K^+	0.001	0.001
NH_4^+	0.014	0.010
SO_4^{2-}	0.026	0.028
Cl^-	0.009	0.011
NO_3^-	0.024	0.027

the approximately 1.5 fold greater accumulation of materials in the snowpack in 1982 and the much later date of major melting also in 1982. Despite these differences, there are some strong similarities in the behavior of individual ionic species across the 2 years of this study.

All ions were quickly removed from the snowpack with the beginning of the major melting periods in both years. Ion loss was contemporaneous with release of the first meltwater in agreement with the observation of Johannessen and Henriksen (1978) and Colbeck (1981). A lesser but significant loss of ions (particularly H^+) was associated with the earlier mid-March melt in 1982 (Figure 5) and it is probable that a similar loss occurred in mid-February 1981.

This differential release of ions compared to water is often strongly influenced by rain. Rain supplies both the heat and the liquid "carrier agent" required to enhance the movement of materials down through the snowpack. All of the occasions of rapid ion loss from the snowpack in 1981 and 1982 were associated with inputs of rain or mixed precipitation.

Almost all of the ions deposited in the heavy rains that occurred from March 28 to April 1, 1981 were immediately released from the snowpack since there was virtually no increase in ion or water content over this time period except for NH_4^+ (Figure 4).

As the snowpack accumulated, the SO_4^{2-} content was generally slightly greater than NO_3^- in both years. Peaks in the SO_4^{2-} and sometimes NH_4^+ content along with relatively smaller increases in water equivalent often correspond to specific "high concentration" precipitation events. No similar correlation between NO_3^- and individual events was apparent however. After removal of most ions during early-stage melting, the residual snowpack, which still contained 220 mm of water equivalent on April 25, 1982, had a composition approaching distilled water with a specific conductivity < 10 μS, pH > 5.0, and NO_3^- higher in concentration than SO_4^{2-}.

IV-3   Stream Chemistry

The concentrations of Ca^{2+} + Mg^{2+}, SO_4^{2-}, alkalinity, NO_3^- and H^+ (μeq L^{-1}) in stream water at station Sl (see Figure 1) are illustrated in Figures 6 and 7 for February through May of 1981 and 1982 respectively. Stream waters at station Sl are derived principally from 2 sources, eg. from the outflow of Batchawana Lake and from terrestrial drainage from the east side of Batchawana Mountain.

Each of the parameters shown in Figures 6 and 7 exhibited roughly the same response to snowmelt in both 1981 and 1982, while the year to year differences which do exist may be attributed to the varying meteorological-hydrological conditions.
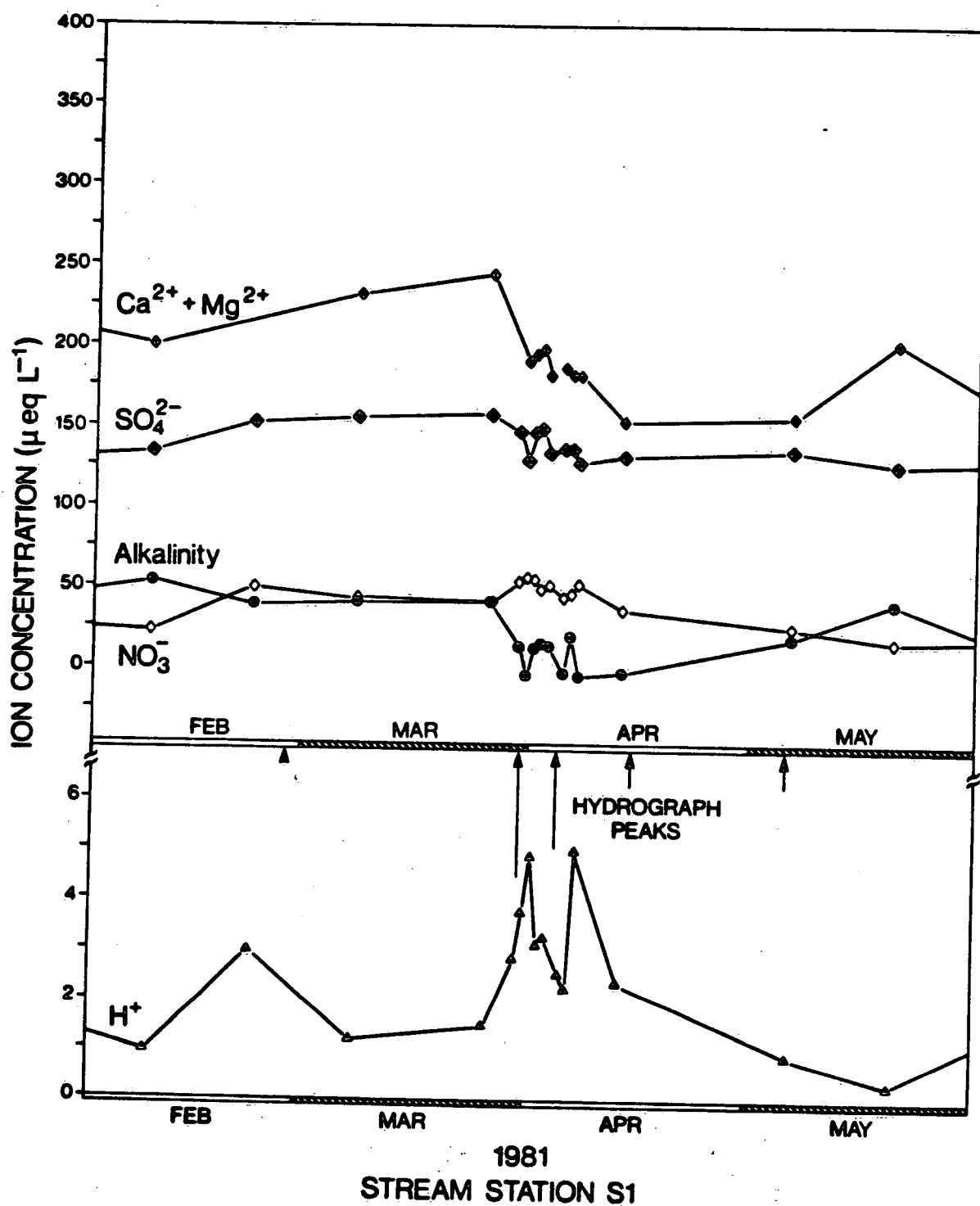
Figure 6: Variation in the concentration ($\mu eq \ L^{-1}$) of $Ca^{2+} + Mg^{2+}$, SO_4^{2-}, Alkalinity, NO_3^-, and H^+ at stream station S1 from February to May, 1981. Note that the scale for H^+ is different from the rest. Dates and relative size of the hydrograph peaks are also indicated.
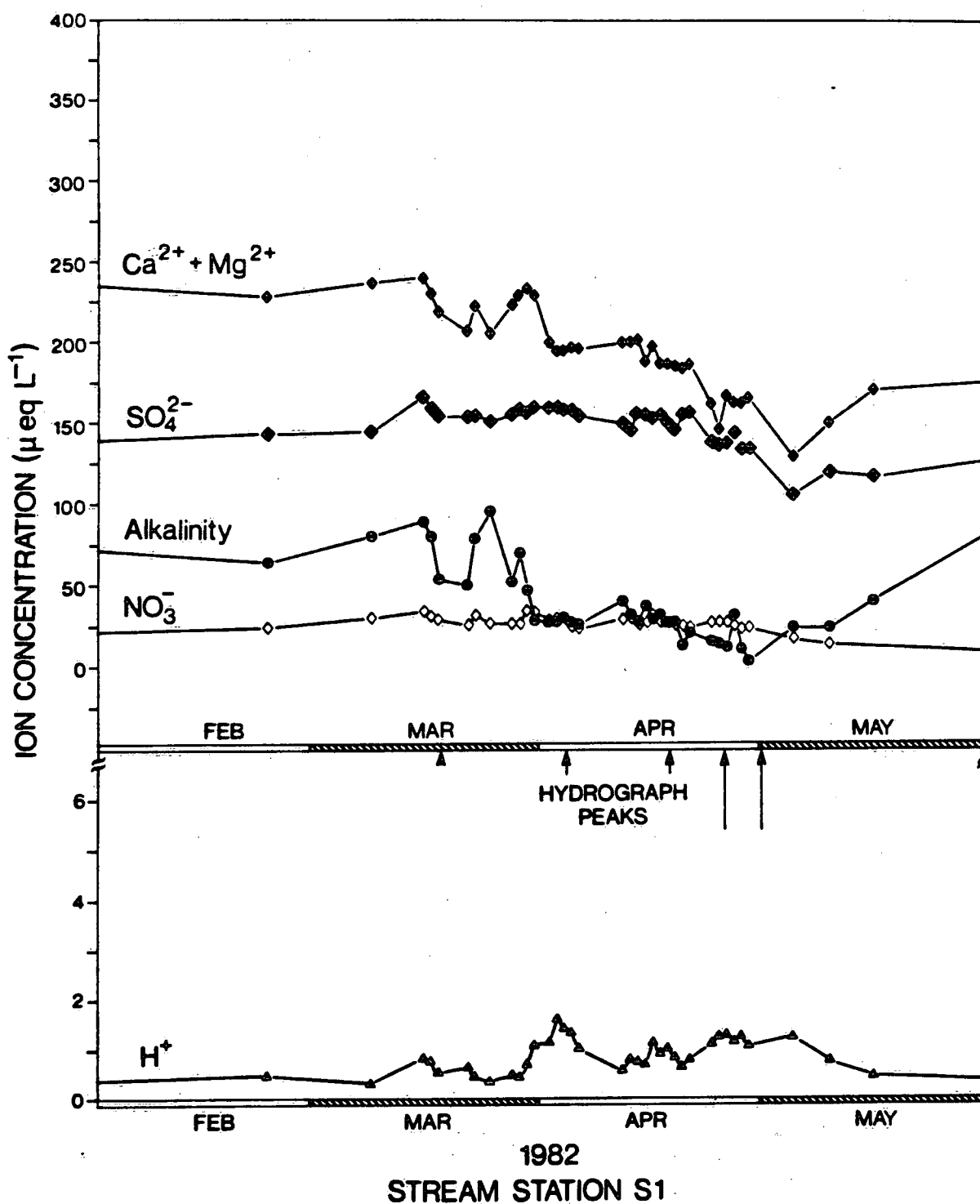
Figure 7: Variation in the concentration ($\mu eq\ L^{-1}$) of $Ca^{2+} + Mg^{2+}$, SO_4^{2-}, Alkalinity, NO_3^-, and H^+ at stream station S1 from February to May 1982. Note that the scale for H^+ is different from the rest. Dates and relative size of the hydrograph peaks are also indicated.

The greatest between-year difference is in the magnitude of the H^+ peak(s) where a 5-fold increase (relative to pre-melt H^+ concentrations) was observed in 1981 and only a 2-fold increase in 1982. This is surprising for 2 reasons. First, as discussed above, a greater mass of H^+ was stored in the 1982 snowpack awaiting removal during the early stages of melting. Second, Colbeck (1981) determined that the meteorological scenario which would most likely produce melt-waters of highest acidity was a succession of freeze-thaw events followed by a slow melt or rain. These conditions were more closely approximated in 1982 than in 1981. In the Turkey Lakes Watershed, it is apparent that the magnitude and/or rate of change of the hydrological flux is also an important factor influencing the degree of pH depression.

The sum of Ca^{2+} and Mg^{2+} exhibited ~ 25% reduction in concentration over both melt periods with post-melt baseflow values being lower than the corresponding pre-melt concentrations. In 1981, the decrease was rapid and sustained whereas in 1982, the decrease was slow and variable once again reflecting the differing hydrological conditions. Alkalinity concentrations varied in parallel with $Ca^{2+} + Mg^{2+}$ and decreased to negative values (e.g. positive strong acidity) at the time of maximum flow in both years.

Sulphate and NO_3^- did not vary to such a large degree although it should be noted that whereas NO_3^- and SO_4^{2-} concentrations

were almost equivalent in the snowpack, NO_3^- in the stream waters was
approximately 5-fold lower than SO_4^{2-}. There is evidence of a small,
sustained increase in NO_3^- during the runoff period of both years and
in SO_4^{2-} during 1982 only. In both years, post-melt SO_4^{2-} concentra-
tions at S1 were slightly lower than the pre-melt values.

Johannessen et al. (1980) proposed a 3-stage model to
explain the variations in stream chemistry found during snowmelt in
southern Norway. The three stages included 1) the pressing out of
soil water in which elevated concentrations of basic cations are
observed, 2) a peak in the concentration of many ions due to the
preferential release of ionic contaminants during the early stages of
snowmelt, and 3) a dilution stage resulting from the runoff of the
remaining snowpack water which now contains few ions. Stream waters
draining 3 different catchments in Norway all exhibited peak concen-
trations of Ca^{2+}, H^+, and SO_4^{2-} which preceded the maximum water flow
and fit the conceptual model very well. Our results presented here
for the Turkey Lakes Watershed and those of Jeffries et al. (1979) and
Jeffries and Snyder (1981) for Muskoka-Haliburton, Ontario do not fit
the model so well.

In 1981, (Figure 6) maximum H^+ concentrations closely
followed rather than preceded the hydrograph peaks and there is little
evidence of elevated Ca^{2+} + Mg^{2+} or SO_4^{2-} occurring during release of
the early meltwaters. These results are similar to those observed in

Muskoka-Haliburton. In 1982 (Figure 7), when the hydrologic flux never reached the magnitudes experienced in 1981, the small H^+ peaks preceded the hydrograph maxima by 1 or 2 days and the alternate periods of freezing and thawing are clearly reflected in the H^+, $Ca^{2+} + Mg^{2+}$, and alkalinity plots. The dilution stage of the model is manifested at all locations.

What physical conditions can account for the temporal and spatial differences in observations? First, the primary difference between 1981 and 1982 in the Turkey Lakes Watershed was the rate of snowmelt and the influence of rainfall. The rapid melt in 1981 was triggered by heavy rainfall, an event which is common in central and southern Ontario. Second, a major difference between the Norwegian and Ontario watersheds is the amount of overburden. It is probable that the extremely thin soil cover found in the Norweigan catchments accounts for both the higher H^+ concentrations present in many of the stream waters in that area and the immediate response of the stream water chemistry to ion removal from the snowpack.

In the Turkey Lakes Watershed, most of the meltwaters have an opportunity to interact with thicker, generally unfrozen and perme-able soils before entering the streams. The more substantial overbur-den provides both a site for neutralization or cation exchange of the acids and an initial time delay as this near surface aquifer becomes saturated. Once saturated, the H^+ concentration of waters entering

the streams will be a function of the rate of supply; that is, if the supply of meltwater to the soils either exceeds the infiltration capacity or forces the water to pass through quickly, the chance for acid neutralization will be minimized. This scenario existed in 1981 when heavy rainfall initiated rapid runoff and a larger pH depression was observed.

In 1982, water loss from the snowpack occurred very slowly, particularly during the early stages, and these meltwaters would have had ample opportunity for neutralization in the soils. The small pH depressions which slightly preceded the hydrograph peaks in 1982 may have been caused by a small fraction of the overall meltwater which was able to enter the stream without soil interaction, e.g. via within snowpack flow or by some other mechanism.

Another consequence of the neutralization and ion exchange which occurs as the meltwaters pass through the soil layer is a buffering of other ionic species. Hence, peaks in Ca^{2+} and SO_4^{2-} concentrations which are observed preceding maximum flow in Norway, are obscured in the Ontario situation.
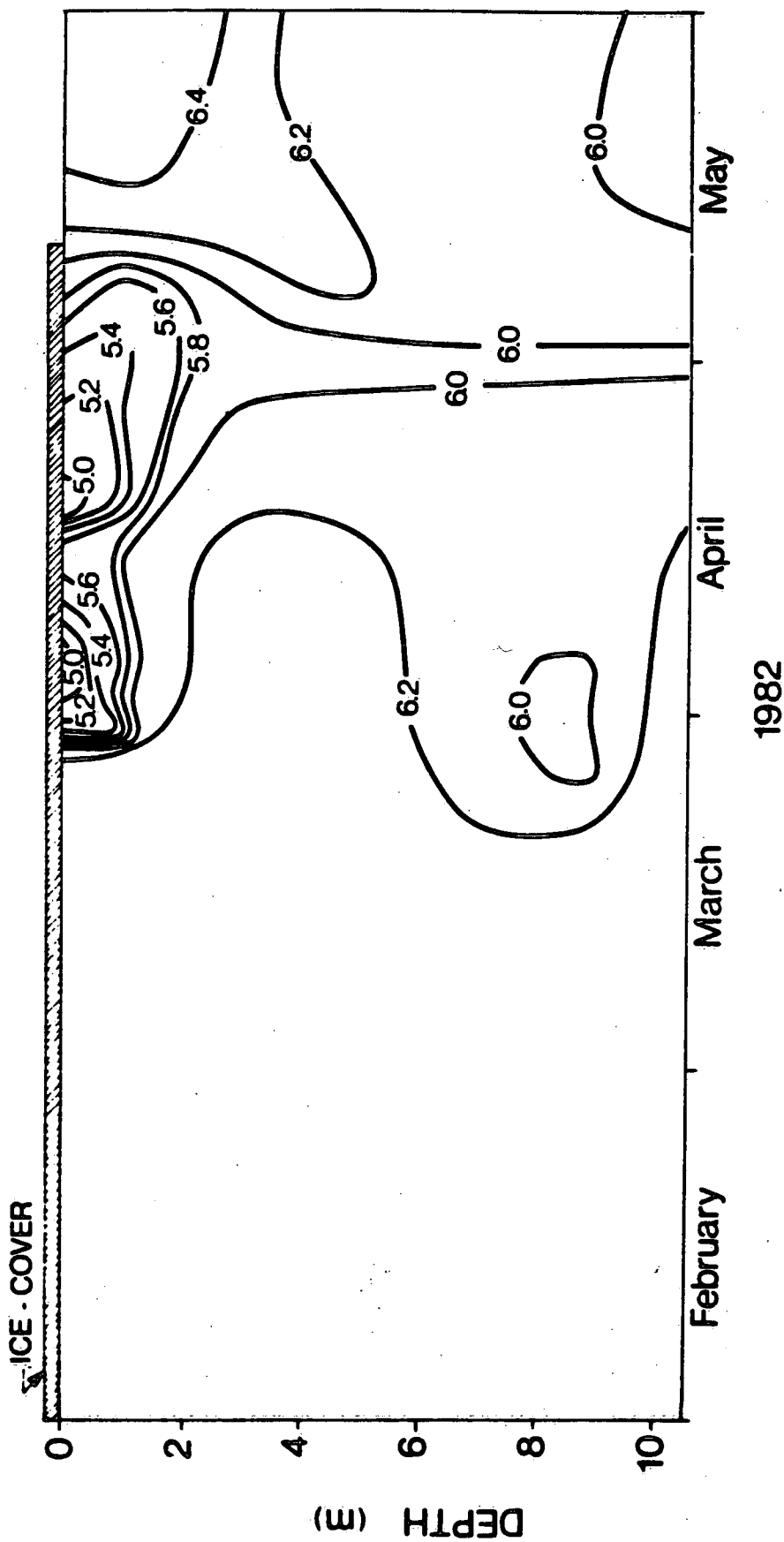
IV-4   Lake Chemistry

In 1982, the lakes were sampled in 1 m intervals at their deepest points. Data for pH, alkalinity, SO_4^{2-}, NO_3^-, Ca^{2+}, and NH_4^+

have been evaluated to determine the influence of the snowmelt runoff

on the lake chemistry and, as an example, information for Batchawana

Lake (South Basin) will be presented here for discussion. Figures 8,

9 and 10 present concentration isopleths for pH, alkalinity and NO_3^-

(latter two in $\mu eq\ L^{-1}$) for February to May, 1982.

Inspection of Figures 8 to 10 shows that there was a 2 phase

effect on the lakes, the first resulting from the small melt which

occurred in early April (hydrograph peak H2-2 in Figure 3) when H^+

concentrations were maximum (Figure 7), and the second which occurred

in late April-early May when the major portion of the spring runoff

was observed. The pH of the surface waters which were 6.0 to 6.2

prior to melt, were reduced to < 5.0 during both acidification

phases. The relatively small quantity of water associated with the

first phase produced strong pH, alkalinity and NO_3^- (also SO_4^{2-}, Ca^{2+},

NH_4^+) gradients in the top 1 meter of the water column. Since the

surface water pH decreased below 5.0, the acidity of the headwater

streams entering Batchawana Lake must have been greater than

$10\ \mu eq\ L^{-1}$, eg. much greater than acidity measured at S1 (Figure 7).

The two acidification phases were separated by a reduction

in runoff caused by freezing temperatures from April 4-13, 1982. As

the hydrograph began to rise once more (peak H2-3 in Figure 3), pH of

the surface water in Batchawana Lake once again decreased to <5.0 for

a short period of time before rising fairly steadily to a summer value

BATCHAWANA LAKE (south) - pH ISOPLETHS

ICE - COVER

DEPTH (m)

Axis labels: 0, 2, 4, 6, 8, 10

Contour labels: 6.4, 6.2, 6.0, 5.8, 5.6, 5.4, 5.2, 5.0, 60

Month labels: February, March, April, May

1982

CONTOUR INTERVAL = 0.2 pH units

Figure 8: pH isopleth map for Batchawana Lake (south basin) from February to May, 1982.

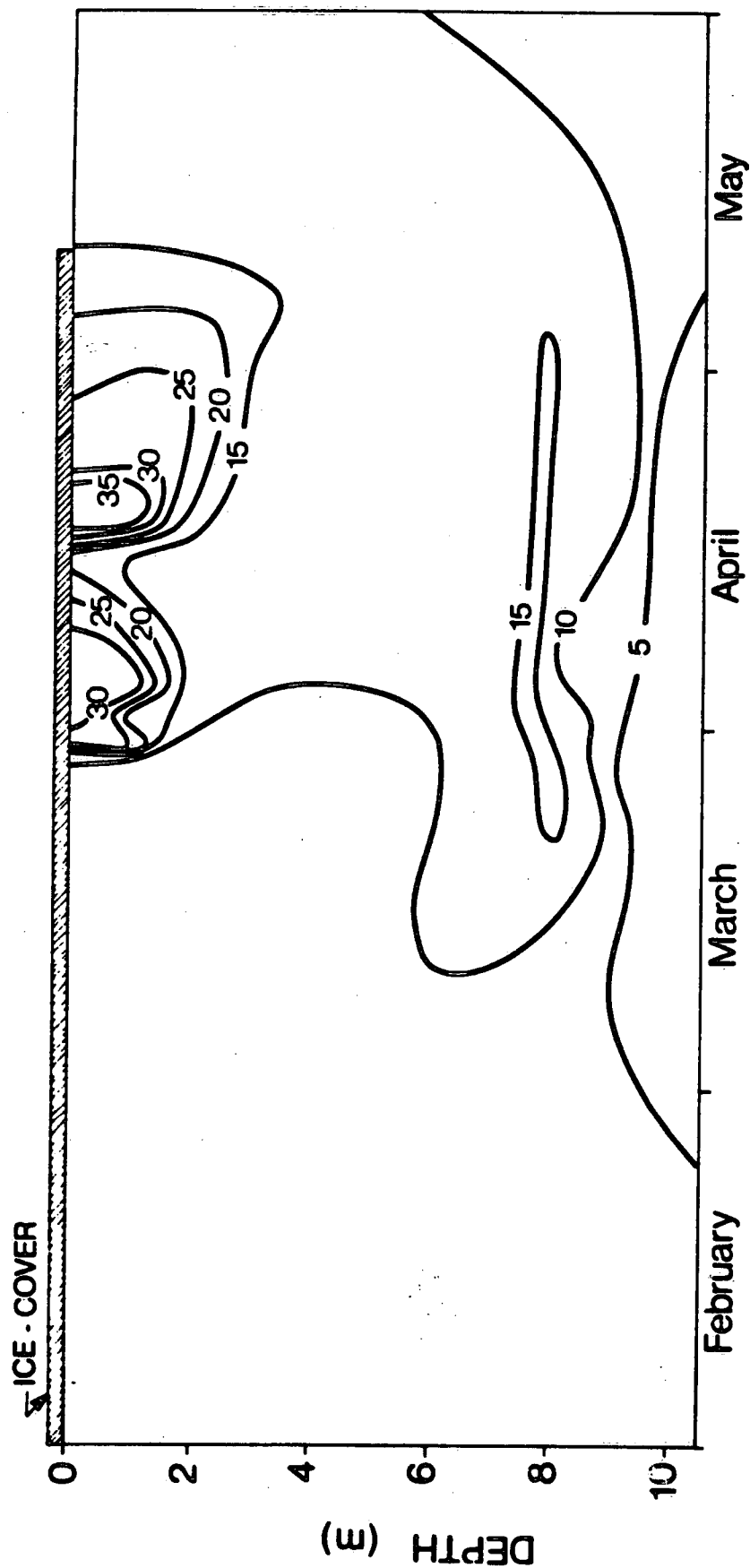**BATCHAWANA LAKE** (south) - **ALKALINITY ISOPLETHS** (μeq L^{-1})

DEPTH (m)

1982

February   March   April   May
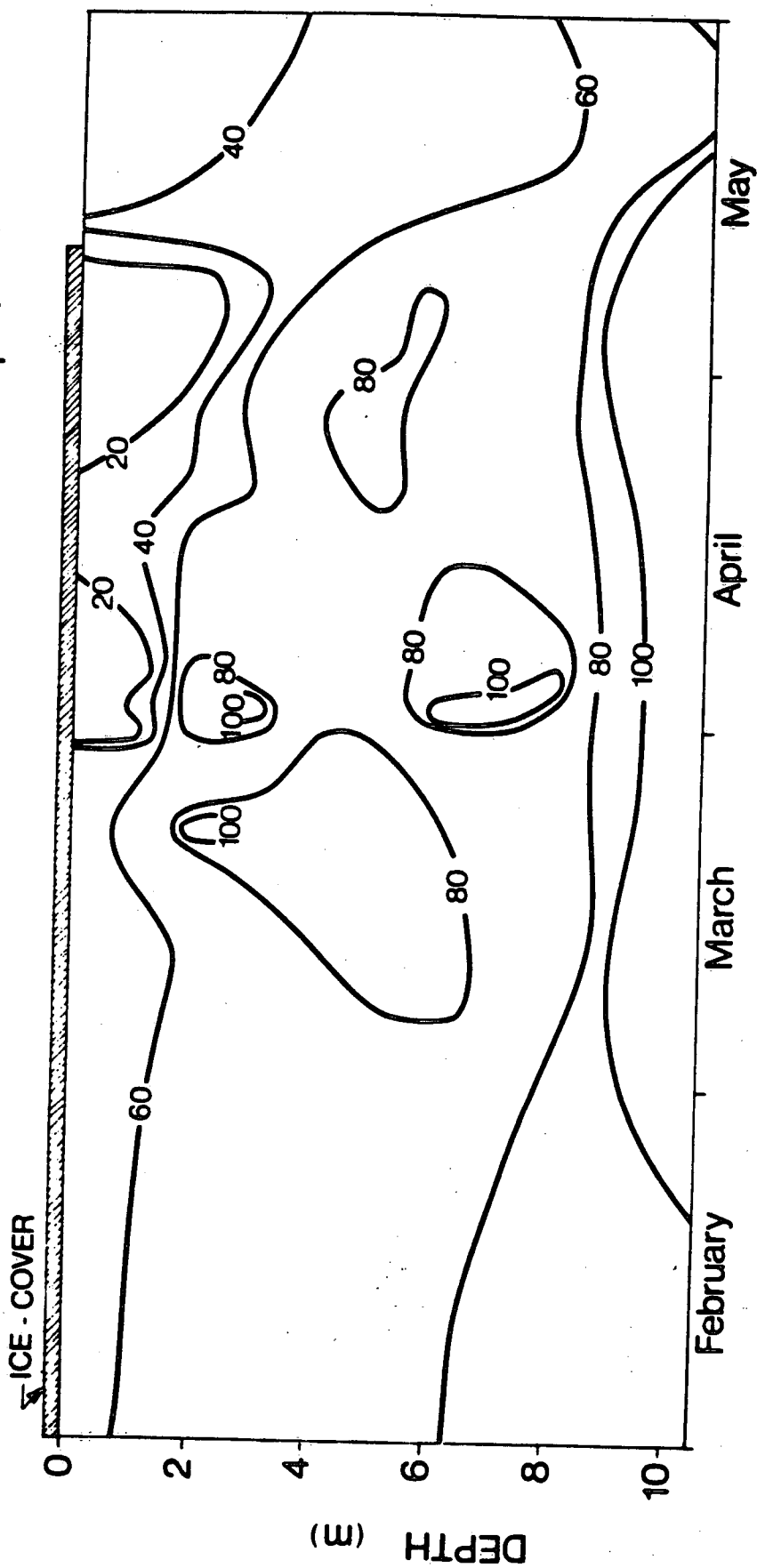
CONTOUR INTERVAL = 20 μeq L^{-1}

Figure 9: Alkalinity isopleth map for Batchawana Lake (south basin) from February to May, 1982.

BATCHAWANA LAKE (south) – NITRATE ISOPLETHS (μeq L^{-1})

Figure 10: Nitrate isopleth map for Batchawana Lake (south basin) from February to May, 1982.

CONTOUR INTERVAL = 5 μeq L^{-1}

of 6.4. The major runoff of water at the beginning of May (peak H2-5) caused the layer of affected lake water to deepen to approximately 3 meters. This was true for all parameters assessed.

Surface water concentrations of other ions varies in a predictable way depending on their relative concentrations in the snowpack and in the lake. Hence Ca^{2+} (and the other basic cations) and SO_4^{2-} decreased in concentration in the surface water of Batcha-wana Lake and reached minimum values during the late stages of melting in early May. Specific conductance of these waters decreased from the "normal" values of 25-30 μS to < 10 μS. With alkalinity = 10 μeq L^{-1} and pH = 5.6, these surface waters would be extremely susceptible to yet another pH depression in the event of a large rain input as occurred in 1981.

Nitrate and NH_4^+ both had higher concentrations in the snow-pack than in the lake. Therefore, spring runoff produced elevated surface water concentrations for these parameters (see Figure 10 for NO_3^-). The highest NO_3^- concentrations measured in the lake in 1982 were approximately 30% higher than the pre-melt snowpack values (Table 2) and occurred at the beginning of the second phase of acidi-fication.

V SUMMARY

The effect of snowmelt on the surface waters of the Turkey Lakes Watershed was studied for 1981 and 1982. Meteorological conditions leading to spring melt were different between the 2 years. In 1981, a short-term melt occurred in mid-February and the major period of runoff was initiated by heavy rainfall in late March. The spring hydrograph was characterized by sharp peaks of intense stream discharge. In 1982, no mid-winter melt occurred and a large snowpack accumulated. Following 2 minor periods of melting, the major runoff event began in late April and since little rain was involved, protracted low intensity peaks in stream flow were observed.

Collection of snow cores throughout the accumulation and melting phases of each year showed that ionic pollutants stored in the snowpack were rapidly and preferentially (with respect to water) removed at the beginning of melting periods. The extremely dilute residual snowpack which remained after the initial ion loss still contained over half of the water. Both of these observations support the conclusions of laboratory and field studies by Johannessen and Henriksen (1978) and Colbeck (1981).

In response to snowmelt, stream waters exhibited a pH depression and decreases in the concentration of alkalinity and basic cations. The magnitude of pH depression was greatest in 1981 and

occurred immediately after intense maxima in stream flow. In 1982, smaller pH depressions slightly preceded smaller peaks in discharge (eg. relative to 1981). Sulphate and NO_3^- concentration exhibited only slight variation throughout the snowmelt period. The sequence of minimum pH and peak streamflow, and the lack of Ca^{2+} or SO_4^{2-} peaks are different from observations made in Norway and a conceptual model proposed by Johannessen et al. (1980). We suggest that the deeper, unfrozen soils present in the Turkey Lakes Watershed compared to catchments in Norway act to neutralize and/or delay the appearance of acid in the streams after it is released in from the snowpack. The magnitude of the pH depression is a function of hydrologic flux.

In 1982, Batchawana Lake experienced 2 separate periods when surface water pH declined to < 5.0 from normal mid-winter and mid-summer values of approximately 6.2. Surface water alkalinity also decreased to negative values at this time. Sulphate, Ca^{2+}, NO_3^- and NH_4^+ all varied in a predictable manner given the relative concentrations in the snowpack and lake water.

This study of snowmelt effects in the Turkey Lakes Watershed is continuing. Meteorological conditions in 1983 were once again different from those in 1981 and 1982 and the data is now being compiled. The investigation will be broadened to include the headwater streams entering Batchawana Lake and other important parameters, particularly Al.

VI   ACKNOWLEDGEMENTS

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