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RM-314**

Biogeochemical Fluxes in the Glacier Lakes Catchments

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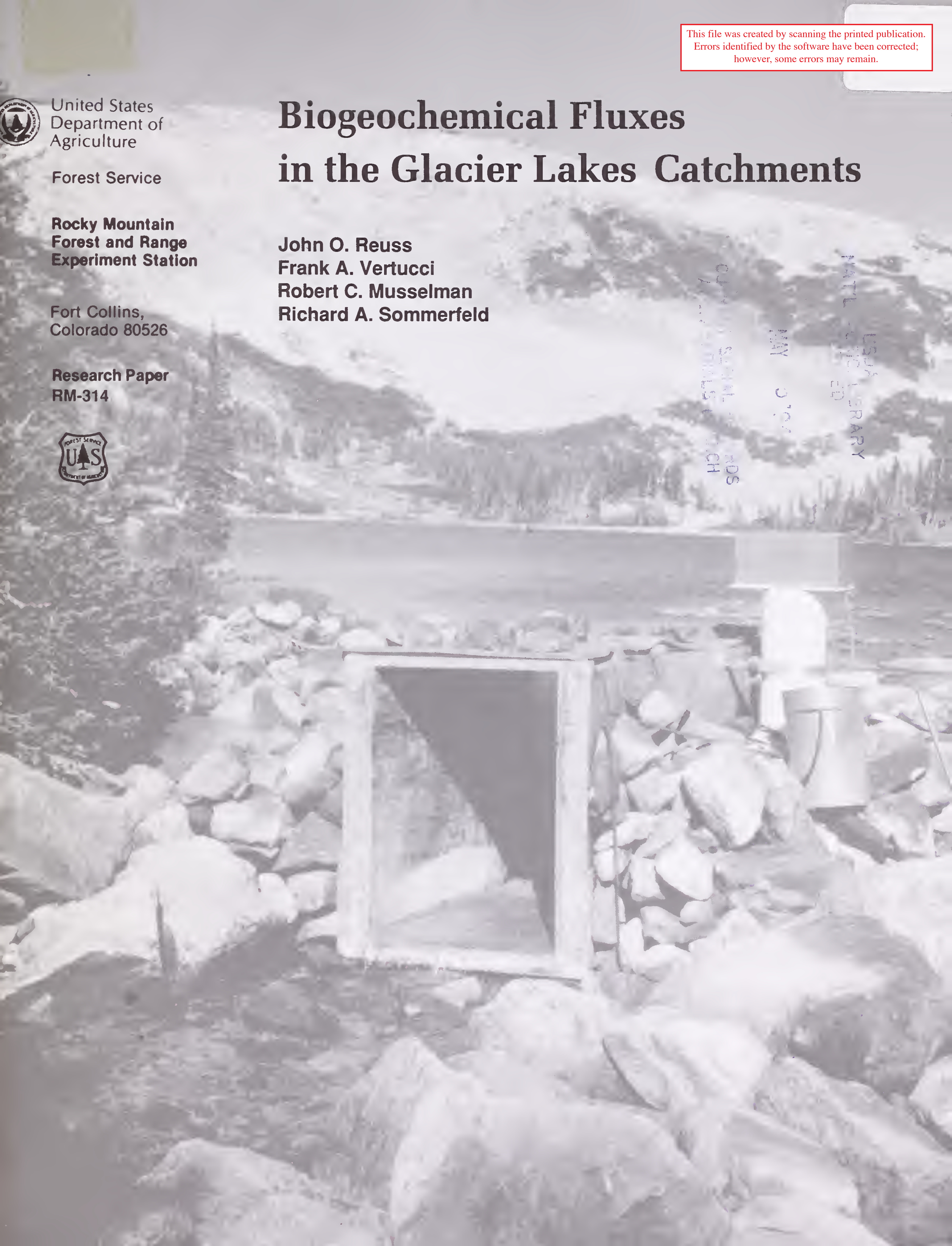

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Abstract

These lakes are moderately sensitive to acid deposition; acidification would require precipitation at least as acidic as that presently found in the more heavily impacted areas of eastern North America. Because most snowpack contaminants are released early in the melting process, seasonal acidification pulses would probably occur at much lower levels of acidic inputs.

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Management Implications

This paper presents 3-year mean inputs and outputs of the major chemical components contributing to water acidification and acid neutralizing capacity for 2 high-altitude lakes in southern Wyoming. A preliminary evaluation of the sensitivity to increases in acid deposition suggests that these lakes are moderately sensitive to acid deposition. This evaluation suggests that it would require increased precipitation acidity of about 50 to 70 ueq/1, or a final precipitation pH of about 4.1 to 4.3, for these lakes to become acidic, where acidity is defined as an annual average acid neutralizing capacity less than zero. Thus, acidification of these lakes would require precipitation at least as acidic as that presently found in the more heavily impacted area of eastern North America, such as the Adirondack Mountains. However, the tributary streams to these lakes are much more sensitive, and would likely become acidic if precipitation acidity increased by only 10 ueq/1, which in these systems would occur with a final precipitation pH of approximately 4.8 to 4.9. Also, because most snowpack contaminants are released early in the melting process, seasonal acidification pulses would probably occur at much lower levels of acidic inputs than would be required for acidification on an annual average basis.

Introduction

To evaluate the probable impact of any future changes in the levels of acidic deposition, we must first understand the present fluxes of chemical components that contribute to both the acidity and alkalinity of the system. In this paper we examine the hydrological and chemical fluxes for East and West Glacier Lakes, adjacent high-altitude catchments in the Snowy Range of southern Wyoming, and a pair of first-order high-gradient steams, Meadow and Cascade Creeks. The catchments are fully contained within the borders of the Glacier Lakes Ecosystem Experiments Site (GLEES). A preliminary evaluation of the sensitivity of these catchments to acidic deposition using the Henriksen model (Henriksen 1979, 1980; Wright 1983; Brakke et al. 1990) is also included. While not contained in a federally designated wilderness area, this site is similar in many respects to the high altitude wilderness areas in the Rocky Mountains.

Chemical inputs and outputs were previously evaluated for the West Glacier Lake catchment and tributaries by Rochette et al. (1988). However, as flow data and direct measurements of precipitation chemistry were largely lacking at that time, inputs were calculated from the composition of meltwater emerging from a snowfield, and output volumes were estimated. Additional data are now available to help characterize the chemical fluxes into and out of the system. Flow measurements and chemical analyses are now available for 1988, 1989, and 1990 from East Glacier Outlet (EGO), West Glacier Outlet (WGO), and the West Glacier Lake tributaries Cascade Creek (CSC) and Meadow Creek (MDW). A National Atmospheric Deposition (NADP) site was initiated in 1986, and four year's data on precipitation amounts and chemical composition are available. Additionally, published data are available on snow chemistry for 1988 (Bales et al. 1990), and unpublished data for 1989 and 1990. Data from these sources are summarized in this report and utilized to calculate input and output fluxes.

Site Description

The GLEES is an area of approximately 1200 ha located at 3200 to 3700 m elevation in the Medicine Bow National Forest in the Snowy Range of southern Wyoming at latitude 41°22'30" N and longitude 106°15'30" W. Both East and West Glacier Lakes are located in small glacial cirque basins. East Glacier Lake lies at an elevation of 3282 m. It has a surface area of approximately 2.9 ha, a catchment area of 28.65 ha, and a mean volume of about 41.3 x 10^3 m^3. The elevation of West Glacier Lake is 3276 m. It is approximately 3.3 ha in size with a catchment area of 60.65 ha and a volume of about 45.2 x 10^3 m^3. Mean depths (volume/surface area) are 1.45 m and 1.37 m for East and West Glacier, respectively.

The site is located on the southeast facing side of a NE to SW trending quartzite ridge, which includes Medicine Bow Peak (3661 m). A permanent snowfield exists at the top of the West Glacier Lake cirque. Vegetation is primarily alpine meadow, krummholtz, and spruce-fir forest. While the bedrock is primarily quartzite, it is heavily fractured and crossed with weatherable mafic intrusions, primarily amphibolite, which comprise some 15%-20% of the area (Rochette et al. 1988).

Soils are primarily Typic Cryoborals, Dystric Cryochrepts, and Lithic Cryochrepts, although small areas of Cryumbrepts and Cryaquepts may be found (Hopper and Walthall 1987). There are also substantial areas of rock outcrops and rubbleland. Taken together these two categories comprise about 19% of the East Glacier catchment and 61% of the West Glacier catchment area (Reuss 1991).

Methods

Flow Measurements

Flows were measured using Parshall flumes installed at the outlets of East and West Glacier Lakes and near the mouths of Cascade and Meadow Creeks. Most of the flow data were recorded on strip charts and hand converted to daily or 6 hr readings from which flows were calculated. Detailed descriptions of the flume installation and flow measurements are available in Hasfurther et al. (1990). In addition to the strip charts, visual readings were recorded at the time of collection of most samples for chemical analyses. These readings were used to calculate flows when the strip charts were not operative, such as prior to chart installation in the spring or during a few malfunctions of the recorders. During these periods linear interpolations were used for days where no measurements were available.

Sampling

Water samples for chemical analyses were collected at the measuring flumes. Samples were collected on a daily to weekly basis in May and June, weekly in the summer, and weekly to bi-weekly in the autumn when flows were relatively low and changes in composition moderate. Part of each sample was passed through a 0.45 micron filter (Gellman “Supor”). The filtered sample was split, and one portion acidified with ultrapure nitric acid for the determination of calcium, magnesium, sodium, potassium, and ammonium, while the unacidified filtered sample was used for determination of chloride, sulfate, nitrate, and dissolved organic carbon (DOC). An unfiltered subsample was retained for determination of acid neutralizing capacity (ANC) and pH.

Laboratory

Samples are currently analyzed by the biogeochemistry laboratory at the Rocky Mountain Forest and Range Experiment Station. In general, the methods followed are those recommended by the USEPA for acid deposition studies (USEPA 1987). ANC is determined by Gran titration using an automated Acid Rain Analysis System (ARAS), which is also used for pH. Calcium, magnesium, sodium, and potassium are currently determined using an atomic adsorption-atomic emission spectrophotometer. Earlier analyses for calcium and magnesium were done using an Inductively Coupled Plasma (ICP) emission spectrophotometer at the Colorado State University soil testing laboratory, but no differences in results due to the change in methods can be discerned. Chloride, sulfate, and nitrate were determined by ion chromatography. Phosphorus, ammonium, and silica were determined using an automated flow injection analyzer. DOC and DIC analyses were performed by means of an automated infrared carbon analyzer using uv facilitated persulfate digestion.

Calculation and Quality Control

Stream Samples.—Data were examined for ion balance and general consistency with prior and later values. Generally, ion balance, calculated as % difference,

$$\%\text{diff} = 100(\text{anions} - \text{cations}) / (\text{total ions}), \qquad [1]$$

(all in ueq/l), was required to be within -20% to +15%. The midpoint of the acceptable range is below zero because most samples have a small anion deficit due to the negative charge of dissociated organic acids. Missing or incorrect values were handled as follows. For minor constituents such as Cl or NH_4, the value was interpolated from the previous and next later values. Generally, if ion balance was unsatisfactory or a major constituent such as Ca, SO_4, or ANC was missing, the record was deleted. In a very few cases where deleting the record would create a gap of two or more weeks in the data, SO_4 was interpolated or a missing (or obviously incorrect) ANC value was replaced with an estimate based on the regression of C_B - C_A (i.e. sum of bases minus sum of acids) on ANC.

Fluxes were calculated on a daily basis. If an interval where no samples were taken contained an even number of days, the first prior analytical values were projected forward for half the period and the first later values projected back for the remainder. If the period contained an odd number of days, the earlier value was used for the extra day. Monthly or annual concentration values reported are volume weighted means. Three-year means are simple means of the three annual volume weighted means. However, there was very little difference between these simple means and three-year volume weighted means.

Precipitation Samples.—Snow pit chemistry for 1988 was taken from table 1 of Bales et al. (1990). For the 1989 and 1990 data, quality control procedures were similar to those followed for the stream data. For the 1990 data, the amount of each constituent was calculated for each layer by multiplying the concentration by

Table 1.—Hydrological summary for East and West Glacier catchments.

	Discharge	Input			Output	
		Snow	Rain	Total	Stream	ET
	m³x10³	cm				
East Glacier						
1988	211	109.0	11.5	120.5	73.7	46.8
1989	165	74.8	19.0	93.8	57.6	36.2
1990	199	77.6	26.2	103.8	69.5	34.3
Mean	192	87.1	18.9	106.0	67.0	39.1
S.E.	14	11.0	4.2	7.8	4.8	3.9
West Glacier						
1988	802	223.0	11.5	234.5	132.3	102.2
1988adj	1003	223.0	11.5	234.5	165.3	69.2
1989	866	164.8	19.0	183.8	142.8	41.0
1990	1025	152.7	26.2	178.9	169.1	9.8
Mean	965	180.2	18.9	199.1	159.1	40.0
S.E.	50	21.7	4.2	17.8	8.2	19.4
Cascade Creek						
1988	181				199.0	
1989	173				190.6	
1990	211				231.9	
Mean	188				207.1	
S.E.	11				12.6	
Meadow Creek						
1988	135				175.5	
1989	116				150.5	
1990	114				148.1	
Mean	121				158.0	
S.E.	7				8.8	
Areas (ha)						
	EGL - 28.65	CSC - 9.08				
	WGL - 60.65	MDW -7.68				

** See text for adjustments to 1988 WGO*

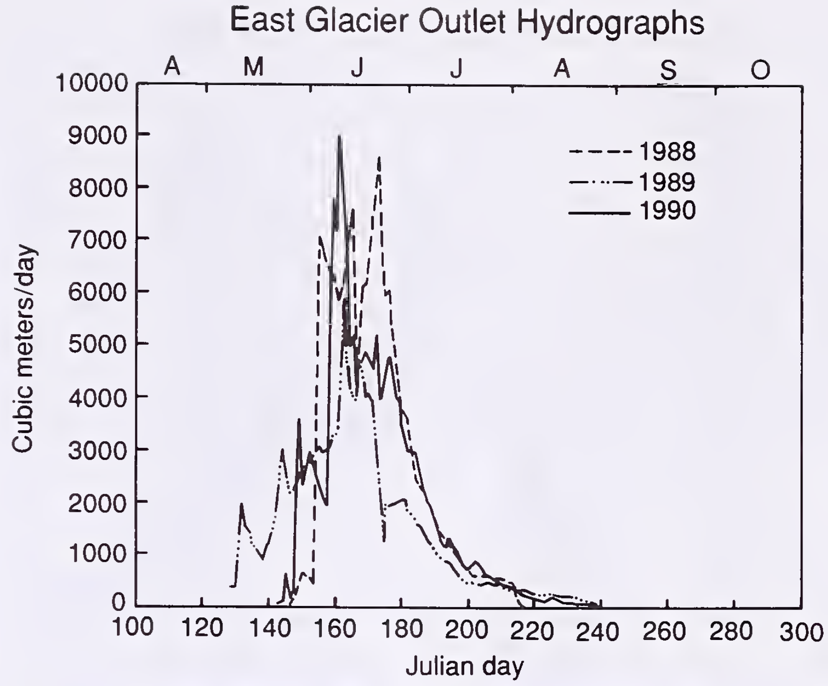

Figure 1. East Glacier outlet hydrographs for 1988, 1989, and 1990.

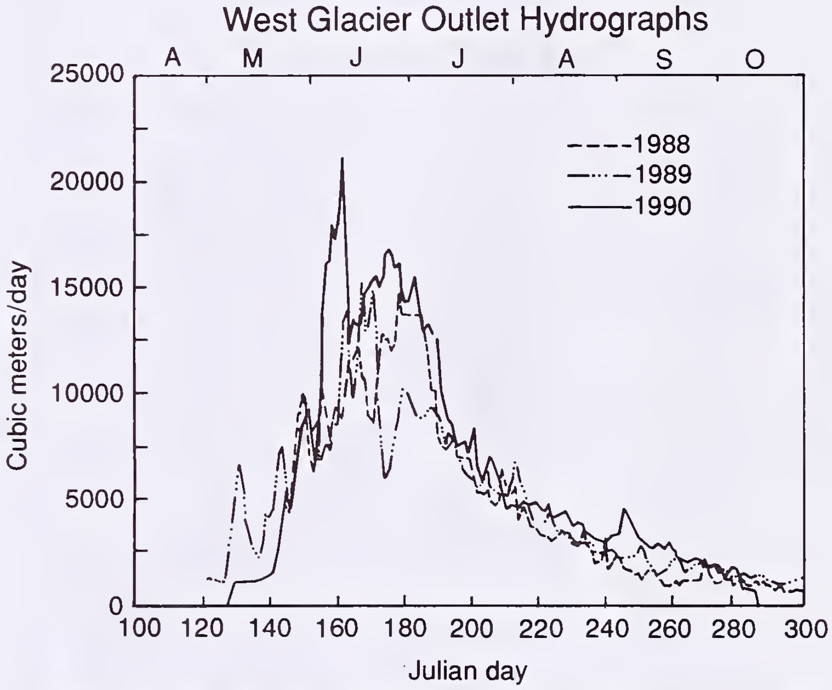

Figure 2. West Glacier outlet hydrographs for 1988, 1989, and 1990.

the water equivalent of the snow in that layer. These were then summed and divided by the total water in the profile to obtain the volume weighted means. Appropriate water equivalent values were not available for the 1989 data so simple means of all samples meeting quality control criteria were used.

The NADP data (National Atmospheric Deposition Program 1991) are from the Snowy Range site, which is located within the West Glacier catchment. Monthly deposition was calculated from the reported monthly concentrations and the reported precipitation. These deposition values were then summed and divided by the precipitation amounts for the period of interest to obtain volume weighted mean concentrations.

Results

Hydrology

Hydrographs for EGO, WGO, CSC, and MDW are shown in figures 1-4. In general, the earliest readings were prior to installation of the chart recorders in the spring, and rely on staff gauge readings taken at the time of sampling. As these readings were not always recorded each day, some interpolation was necessary. East Glacier outlet flows tend to peak in the range of 6 x 10^3 to 9 x 10^3 m^3/day in mid to late June, dropping to zero some time in August. West Glacier outlet flow peaks in late June or early July, and typically reaches levels of 14 x 10 ^{3} to 20 x 10^3 m^3/day. Peak flows are maintained somewhat longer in West Glacier outlet than at East Glacier, and some flow continues throughout the summer and late fall. Peak Cascade Creek flows are in the range of 2.3 x 10^3 to 3.5 x 10^3 m^3/day and occur in late June and early July. The peak is relatively broad and the decline to near zero in late October is nearly linear. This broader peak with a relatively slow decline undoubtedly reflects the late-melting snows at high altitude and the presence of a permanent snow field. Meadow Creek peak flows are in the range of 1.8 x 10^3 to 2.5 x 10^3 m^3/day, declining to near zero in late October.

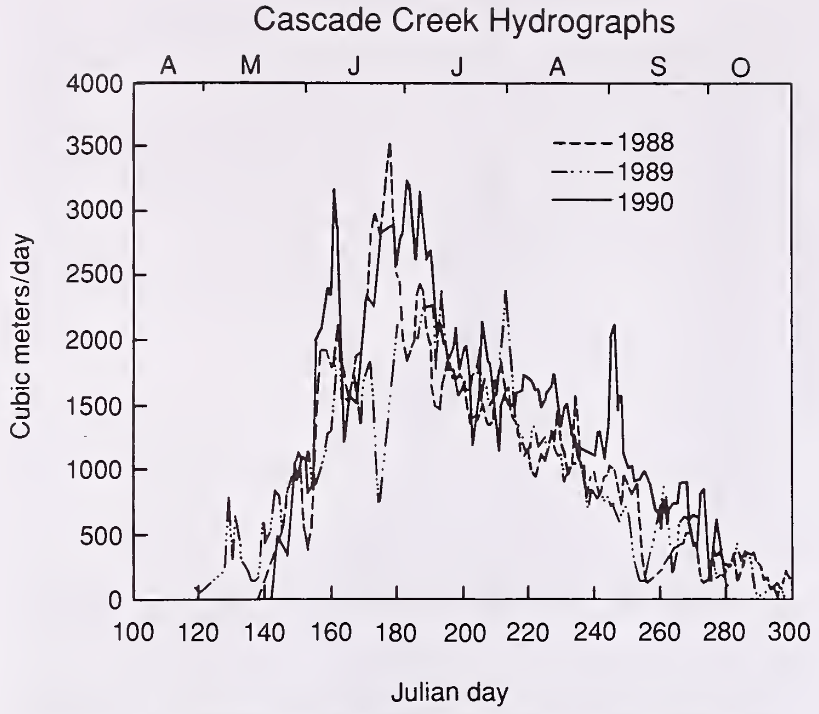

Figure 3. Cascade Creek hydrographs for 1988, 1989, and 1990.

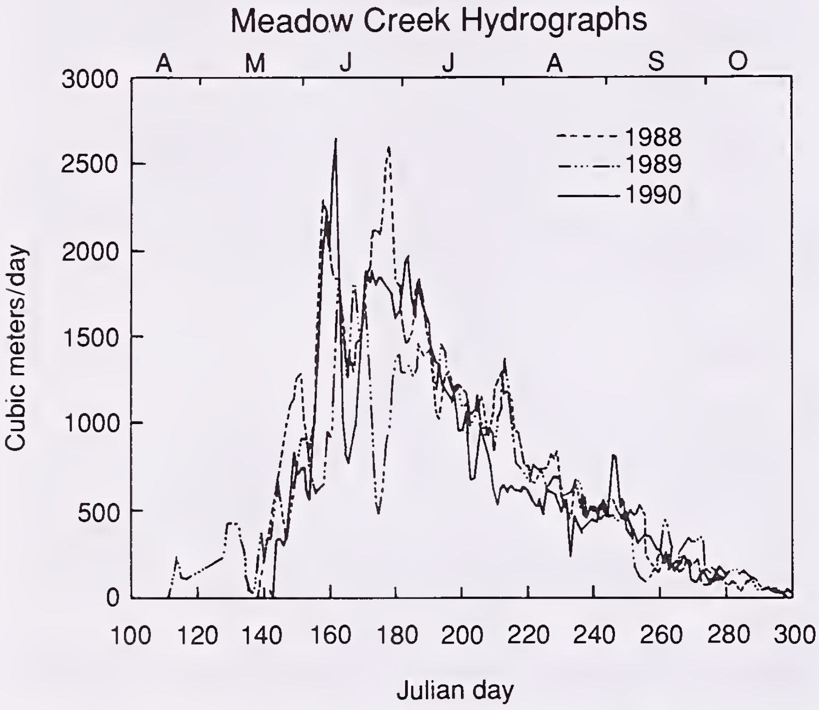

Figure 4. Meadow Creek hydrographs for 1988, 1989 and 1990.

An hydrological summary is shown in table 1. Due to the extreme spatial variability in snowfall amounts and the precipitous nature of the terrain, accurate measurements of snow accumulation and water content were impractical. Therefore, snow inputs were calculated using a degree day model (Martinec and Rango 1986) combined with aerial photographs of snow cover recession during the melt period (Sommerfeld et al. 1991). Summer inputs are from the NADP precipitation measurements during June through September of each year.

A major inconsistency is apparent for the WGO data in 1988. Even though total precipitation is much higher in 1988 (234.5 cm) than in 1989 (183.8 cm) the 1989 flow of 866 x 10^3 m^3 substantially exceeds the measured 1988 value of 802 x 10^3 m^3. As a result, the estimate of evapotranspiration (ET), calculated by the difference between precipitation and outflow, is 102.2 cm, well above the 1989 value of 41.1 cm and the East Glacier catchment values of 46.8 and 36.2 cm for 1988 and 1989, respectively. Two major sources of error were identified for the 1988 WGO flow. Hasfurther et al. (1990) detected leakage around the flume, which they estimated as 1.225 x 10^3 m^3/day (0.5 cfs) during high flow and 0.611 x 10^3 m^3/day (0.25 cfs) during low flow. Taking high flow as in excess of 4.0 x 10^3 m^3/day we estimate the leakage as 160 x 10^3 m^3 or about 20% of the measured flow. The other identifiable source of error is unmeasured springtime flow. The initial measurement occurred on Julian day 144 when discharge was about 4.0 x 10^3 m^3/day. Extrapolating the hydrograph to zero over a period of 20 days results in an estimate of 40 x 10^3 m^3, or about 5% of the measured annual discharge. Considering these estimates, an adjusted discharge for WGO in 1988 was calculated as 125% of the measured discharge (table 1). Subsequent calculations of chemical fluxes based on 1988 WGO discharge were made using the adjusted value.

Total annual discharges as shown in table 1 are reasonably consistent from year to year. Relative standard errors of the 3-year means (S.E./mean) range from 5% to 7% of the means for the 4 catchments or subcatchments. The mean annual discharge of East Glacier (192 x 10^3 m^3) is about 4.7 times lake volume, while the West Glacier discharge (965 x 10^3 m^3) is more than 21 times lake volume. The annual inflow to West Glacier Lake from Cascade Creek and Meadow Creek total about 308 x 10^3 m^3, or approximately one-third of the total West Glacier lake discharge. No completely adequate explanation is available for the low calculated evapotranspiration in 1990, but it is most likely simply due to the inherent problems associated with estimation by subtraction of two relatively large numbers.

Precipitation Inputs

The two estimates of precipitation chemistry are shown in table 2, and additional detail is provided in the Appendix (tables A1 and A2). Data from both NADP and snow pits are subject to severe limitations. Collection efficiency is very low in the NADP collectors during the winter months, often less than 10%. These low efficiencies seem to be related to snow blowing out of the collection buckets and/or to failure of the automatic opening device during snow events. This device is designed to open only during precipitation events, thus excluding most dry deposition. Use of the NADP data then requires the implicit assumption that the snow collected is of the same composition as the snow that

Table 2.—Summary of estimates of chemical composition (ueq/l) of precipitation inputs at GLEES, and at two high altitude sites in the Colorado Front Range. Snow pit data for 1988 taken from summary of Bales et al. (1990).

	Snow Pit (3 yrs)[1]		NADP (4 yrs)		Univ WY[2]	Loch Vale[3]	Green Lakes[4]
Ion	Mean	Std Err	Mean	Std Err	Mean	Mean	Geom. mean
Cations							
H^+	4.0[5]		4.4	0.91	2[5]	7.0	9.3
Ca	9.4	0.04	9.3	0.21	18	8.5	9.3
Mg	2.2	0.17	2.2	0.08	5	2.3	0.7
Na	2.4	0.06	8.0	1.11	3	3.3	1.8
K	1.7	0.42	0.4	0.05		0.5	2.6
NH_4	4.0	0.36	6.4	1.51		6.0	
Anions							
Cl	2.6	0.18	3.7	0.18	4	2.4	4.3
SO_4	9.7	1.47	15.0	1.20	11	13.5	13.0
NO_3	10.2	0.63	10.2	1.12	10	10.9	5.5
[ANC]					14		
Cb-Ca	-2.7		-2.7		1	-6.2	-8.4
Water (cm)			99.5				
pH	5.4		5.4		5.7	5.2	5.0

[1] *Snow pit data include summer values (June-Sept) from NADP.*

[2] *Rochette et al. (1988).*

[3] *Baron et al. (1991).*

[4] *Caine and Thurman (1990).*

[5] *H^+ for snow pits and Univ. of WY data calculated from C_B-C_A assuming 350 ppm CO_2 (Reuss 1977).*

was not collected. The basic problem with snow pit data is the tendency for differential elution during melting. Solution concentrations in very early melt water may be three to five times as high as those observed later in the melt period (Bales et al. 1990; Rochette et al. 1988). Thus, a very small amount of melting may alter the chemical composition. If early measurements are used in an attempt to minimize this problem, significant snow events may not be included. Snow pit data used in our evaluation were collected between Julian days 83 and 138. As summer precipitation is not included in the snow data, NADP values were used for June through September for both amount and chemical composition.

Table 2 includes values previously reported for this site by Rochette et al. (1988) and from 2 high-altitude sites in the Colorado Front Range, i.e Loch Vale (Baron et al. 1991) and Green Lakes (Caine and Thurman 1990). The Loch Vale data are from an NADP site in the Loch Vale catchment and the Green Lakes samples were from open buckets collected on a monthly basis. For the most part, the precipitation at these two sites is quite similar to that found at GLEES. The University of Wyoming data indicate levels of Ca and Mg about twice those found at this site by either NADP or analysis of snow samples, and also about twice those observed at Loch Vale and Green Lakes. The University of Wyoming estimates were obtained by sampling snowmelt water that had only limited contact with rock, which was predominantly quartzite, and thus presumably was only slightly altered. However, the comparatively high levels of Ca and Mg observed suggest that some contamination may have occurred.

Table 2 shows reasonable agreement between snow pit and NADP results for Ca, Mg, Cl, NH_4, and NO_3. The snow pit mean annual concentration for K (1.7 ueq/l) is higher than the NADP mean (0.4 ueq/l) but in either case the precipitation input is very low and this difference is probably not very important. The concentrations of these components are also reasonably consistent with those reported from the other sites, except that Mg and NO_3 values for Green Lakes are somewhat lower than those found at either Loch Vale or at GLEES.

The snow pit mean Na concentration of 2.4 ueq/l is similar to the value of 3.0 ueq/l reported by Rochette et al.(1988), but much lower than the NADP value of 8.0 ueq/l. The Na values reported from Loch Vale (3.3 ueq/l) and Green Lakes (1.8 ueq/l), are similar to the GLEES snow pit values.

Sulfate is a key parameter, and the difference between the annual values as determined from the NADP data (15.0 ueq/l) and that obtained from snow pits supplemented with summer NADP data (9.7 ueq/l) is somewhat disturbing. Sulfate values reported by Rochette et al. and those from both Loch Vale and Green Lakes are intermediate between the GLEES snow pit and NADP values. While there is no adequate basis for choosing between the snow pit and NADP input data sets, as explained below our presentations of flux data are based on the chemical composition from the snow pits plus summer values from NADP.

Monthly concentration and deposition values for SO_4, Ca, and Na, are shown in figures 5-7. Upper and lower 95% confidence intervals shown in these figures were calculated using a logarithmic transformation, as monthly standard deviations were found to be roughly proportional to the monthly means. This procedure avoids the absurdity of negative lower confidence limits. SO_4 concentrations are highest in April, remain high through August, and then decline rapidly through December. However, the precipitation pattern is such that the maximum total deposition occurs in late winter and early spring. The pattern of Ca concentrations and deposition is fairly similar to that of SO_4, with maximum concentrations occurring in April, and the highest total deposition in late winter and early spring.

Na values also appear to be higher in winter than in summer, and are noticeably more variable during the periods of high concentration. The source of the Na is not known. Regression of Cl on Na is highly significant ($r^2 = 0.65$). However, the slope of 0.45 (fig. 8) is substantially less than the value of 1.19 that would be expected for marine sources (Reuss 1975). Desert areas upwind include the extensive Bonneville salt flats and large areas of saline and sodic soils. Deposits of sodium carbonate minerals are also actively mined although these are at least 200 km away.

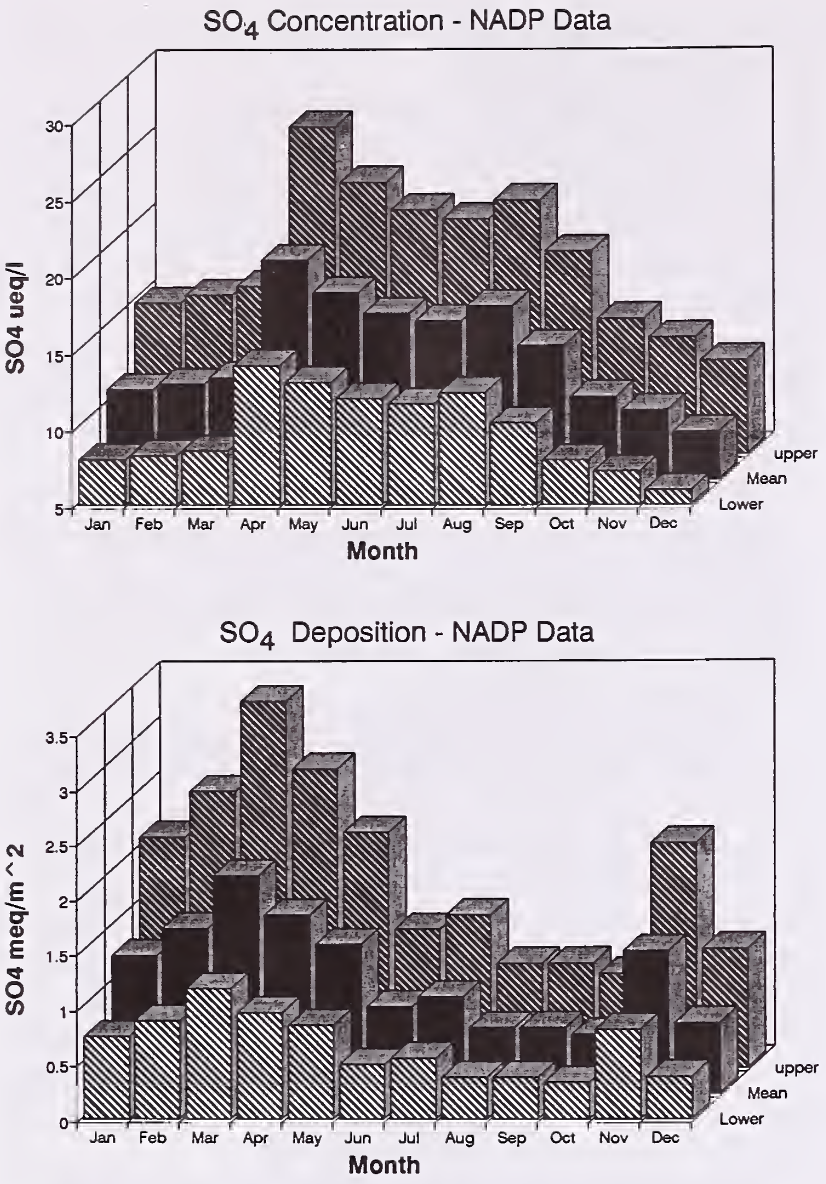

Figure 5. Concentration (ueq/l) of SO_4 in precipitation and SO_4 deposition (meq/m^2) by month. Means and 95% confidence intervals.

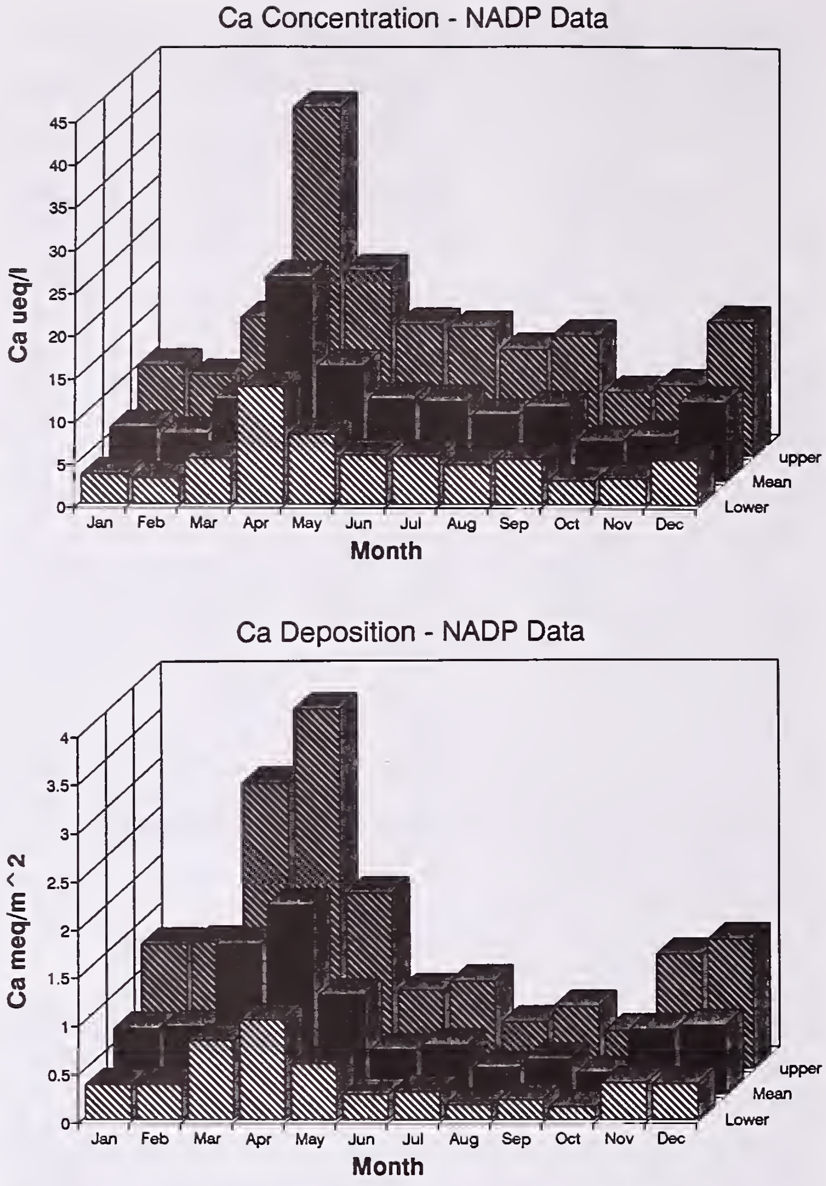

Figure 6. Concentration (ueq/l) of Ca in precipitation and Ca deposition (meq/m^2) by month. Means and 95% confidence intervals.

This evaluation of input chemistry is limited to rain and snow chemistry, and includes dry deposition only to the extent that it is included in the snowpack. Both snow pits and rainfall collectors are located in clearings where dry deposition would be expected to be at a minimum. The major contribution of dry deposition probably occurs in the forested areas where the surface areas for collection is much higher than in the clearings.

Surface Water Chemistry

A summary of the stream chemistry, averaged over the two years, is shown in tables 3 and 4. Summaries by year (table A3), monthly summaries for each year (tables A5-A15), and monthly means (table A16) are shown in the Appendix. East Glacier Lake outlet clearly has the highest ANC, averaging about 50 ueq/l as compared to 39 ueq/l for West Glacier, and less than 10 ueq/l for the 2 West Glacier tributaries. These ANC values are quite low for the region. Landers et al. (1987) estimate that only 6.9% of lakes in the Central Rockies have an ANC of ≤ 50 ueq/l. However, the East and West Glacier Lakes values are quite comparable to the median ANC of 42.6 ueq/l reported by Baron (1991a) for Loch Vale, a 5 ha lake located in the Colorado Front Range at an elevation of 3050 m in a catchment dominated by biotite gneiss. ANC values (HCO_3) reported by Caine and Thurman (1990)for the Green Lakes area, a high-altitude catchment in the Colorado Front Range where the bedrock is dominated by granites and quartz monzonites, range from 34 to 133 ueq/l at the various sampling points. The relatively large increase of ANC at West Glacier outlet over that found in the tributary streams is likely due to the contribution of groundwater and the fact that the two ungauged streams tend to flow along mafic dikes (Rochette et al. 1988). The ANC for samples collected from Boulder Creek over the three-year period averaged 42 ueq/l.

An interesting aspect is the enrichment of bases and ANC in the tributary streams and the lake outlets over that found in the precipitation input as determined from snow pits and summer NADP values. The equations for

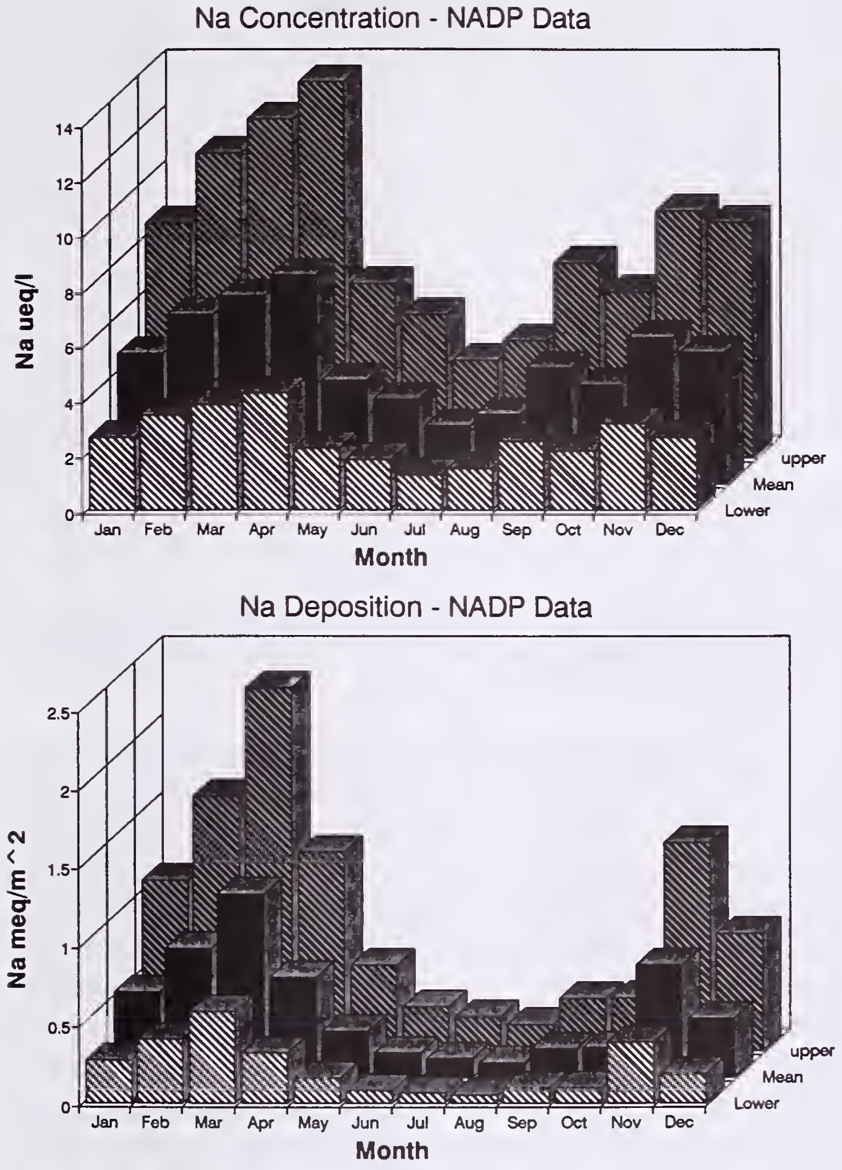

Figure 7. Concentration (ueq/l) of Na in precipitation and wet deposition (meq/m²) by month. Means and 95% confidence intervals.

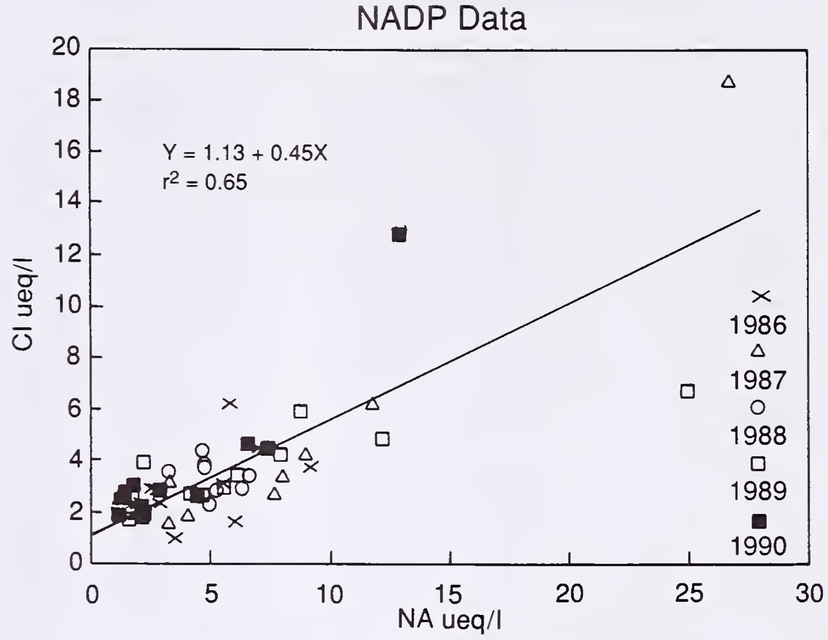

Figure 8. Regression of precipitation Cl on Na.

Table 3.—Mean chemical composition for East and West Glacier Lake outlets.

	East Glacier			West Glacier		
	No. Years	Mean	Standard Error	No. Years	Mean	Standard Error
Ions		——ueq/l——			——ueq/l——	
H (Calc)	3	0.11	0.005	3	0.14	0.063
Ca	3	46.41	0.958	3	37.74	1.692
Mg	3	17.55	0.326	3	15.05	0.286
Na	3	10.73	0.257	3	8.91	0.781
K	3	2.97	0.274	3	3.52	0.714
NH_4	3	0.34	0.068	3	0.55	0.063
Sum(+)	3	78.11	1.328	3	65.91	3.475
Cl	3	2.85	0.772	3	3.10	0.249
SO_4	3	16.80	0.421	3	17.22	0.426
NO_3	3	0.61	0.124	3	4.93	1.053
[ANC]	3	50.39	2.257	3	38.62	2.352
Sum(-)	3	70.76	1.473	3	64.01	2.986
Anion deficit	3	7.35	2.312	3	1.90	2.662
Other		——mgm/l——			——mgm/l——	
SiO_2	2	1.48	0.059	2	1.16	0.088
P	3	0.008	0.001	3	0.009	0.003
Al	2	0.042	0.005	2	0.029	0.004
DIC	2	0.60	0.066	1	0.48	
DOC	2	2.24	0.418	1	1.26	
Charge (ueq/mgm DOC)		3.29			1.51	

the regression of the change in base concentration on change in ANC are:

$$\Delta[\mathrm{Ca}] = 6.51 + 0.557\ \Delta\ [\mathrm{ANC}] \qquad (r^2=0.994)$$
$$\Delta[\mathrm{Mg}] = 3.16 + 0.231\ \Delta\ [\mathrm{ANC}] \qquad (r^2=0.998)$$
$$\Delta[\mathrm{Na}] = 2.03 + 0.099\ \Delta\ [\mathrm{ANC}] \qquad (r^2=0.925)$$
$$\Delta[\mathrm{K}] = 0.83 + 0.025\ \Delta\ [\mathrm{ANC}] \qquad (r^2=0.669)$$
$$\Delta[\mathrm{Sum\ Bases}] = 12.53 + 0.912\ \Delta\ [\mathrm{ANC}](r^2=0.997).$$

While only four points are available for each line, the fit for Ca, Mg, and sum of bases is very good ($P<0.01$). This need not surprise us as the enrichment of bases from sources in the catchment is the major process contributing to the generation of ANC. The relationship for Na is not as good ($P<0.05$) but still indicates a contribution of Na from the catchment to lake ANC. The contribution of catchment K to lake ANC cannot be shown to be significant.

The slopes provide us with an estimate of the relative contribution of each component to the total ANC generation. While the ANC in stream or lake waters increased from about 9 ueq/l over the ANC of the snow in Cascade Creek to some 55 ueq/l over that of the snow in East Glacier Lake, some 56% of this increase is due to Ca enrichment, 23% to Mg, and 10% to Na. The relationships are shown graphically in figure 9. The ratio of the slopes for Ca and Mg also shows that a consistent 2.4 times as much Ca as Mg is weathered from the catchments. The intercept for the sum of the bases indicates that an initial enrichment of about 12.5 ueq/l (s.e. = 1.2 ueq/l) of base cations occurs without a concurrent increase in ANC, i.e. processes are occurring that result in lower ANC than would be expected strictly on the basis of the increase in bases. Processes that may contribute to this decrease include the loss of

Table 4.—Mean chemical composition for Cascade and Meadow Creeks.

	Cascade			Meadow		
	No. Years	Mean	Standard Error	No. Years	Mean	Standard Error
Ions		——ueq/l——			——ueq/l——	
H (Calc)	3	0.83	0.091	3	0.58	0.026
Ca	3	21.38	1.203	3	21.90	0.657
Mg	3	7.56	0.310	3	7.78	0.134
Na	3	5.76	0.848	3	6.20	0.827
K	3	1.92	0.652	3	2.43	0.621
NH_4	3	0.50	0.050	3	0.33	0.086
Sum(+)	3	37.94	2.703	3	39.23	1.958
Cl	3	2.60	0.333	3	2.66	0.348
SO_4	3	13.75	0.406	3	13.05	0.214
NO_3	3	11.11	1.085	3	9.60	0.597
[ANC]	3	5.89	0.781	3	8.73	0.433
Sum(-)	3	34.17	1.832	3	34.61	0.730
Anion deficit	3	3.77	1.416	3	4.61	1.480
Other		——mgm/l——			——mgm/l——	
SiO_2	2	0.96	0.074	2	0.84	0.080
P	2	0.010	0.002	2	0.008	0.003
Al	2	0.041	0.010	2	0.036	0.001
DIC	1	0.12		1	0.24	
DOC	1	0.90		1	1.54	
Charge (ueq/mgm DOC)		4.20			3.00	

nearly 4 ueq/l NH_4 between snowfall and the sampling points on Cascade and Meadow Creeks, and the formation of organic anions, estimated by charge deficit at approximately 4 to 5 ueq/l in these creeks. These total slightly less than the observed difference, a discrepancy that may be due to random error, analytical error, or unidentified processes.

The fact that the slope of the sum of bases line (0.912, s.e. = 0.036) is less than 1.0, implies an additional source of ANC. This is most likely due to biological removal of NO_3. The NO_3 levels in Meadow and Cascade Creeks are 11.1 and 9.6 ueq/l respectively, about the same as those found in the precipitation. The average lake outlet concentrations are 4.9 ueq/l and 0.6 ueq/l for WGO and EGO, respectively. This implies virtually complete immobilization of NO_3 in East Glacier and partial immobilization in West Glacier Lake. Apparently there is a higher level of biological uptake of NO_3 in East Glacier, which is consistent with the higher observed DOC, i.e. 2.2 mg/l at EGO and 1.3 mg/l at WGO.

The observed NO_3 levels are below the median value of 16.4 ueq/l reported by Baron (1991a) for Loch Vale. They are also generally lower than those found by Caine and Thurman (1990) in the Green Lakes area, where means ranged from 3.5 ueq/l to 22.7 ueq/l. Their lowest values were observed at the outlet of the largest lake, which was located low in the watershed, with higher NO_3 values at the higher sampling points. This trend is consistent with that observed at GLEES but was much less pronounced at Loch Vale.

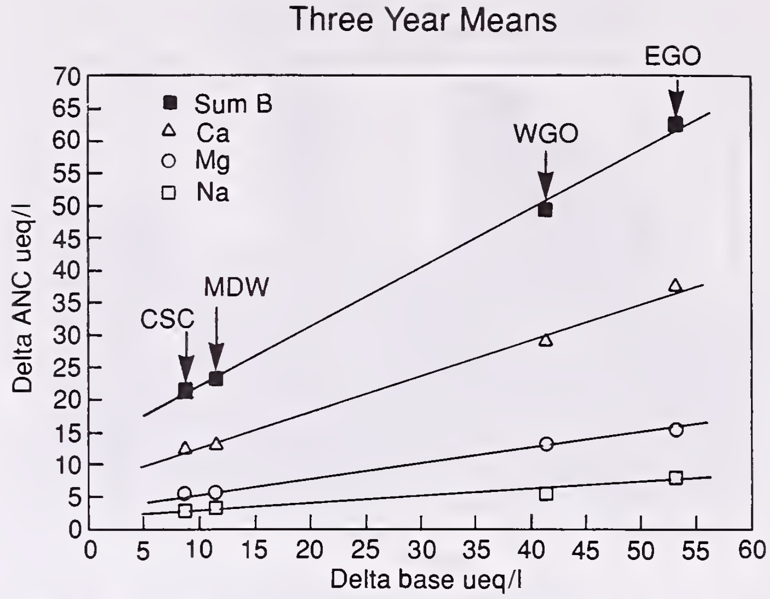

Figure 9. Regression of change in sum of bases, Ca, Mg, and Na concentrations on change in ANC. Changes were calculated using snow pit chemistry as input.

The observed mean SO_4 concentrations of ca 17 ueq/l (table 3) are very near the same for both lakes. Again these are lower than most lakes in the Central Rockies where Landers et al. (1987) estimates that 20% of the lakes are below 19.1 ueq/l. However, judging from the frequency distributions of Turk (1988) and Turk and Spahr (1991), the SO_4 concentrations are slightly below the median for lakes in the Colorado Front Range to the south, and slightly above the median for lakes in the Mt. Zirkel Wilderness to the southwest. The mean SO_4 concentrations in Cascade and Meadow creeks were 13.8 and 13.1 ueq/l, respectively. As with NO_3, the SO_4 concentrations at GLEES are substantially below the median Loch Vale value of 36.0 ueq/l (Baron 1991a), and below most of the values reported for Green Lakes. However, concentrations reported for various sampling points within the catchment at the latter site were highly variable, with ranging means from 9.2 to 85.6 ueq/l.

Seasonal changes in sum of bases (C_B), sum of acids (C_A), ANC, and pH are shown in figures 10-13. At East Glacier outlet (fig. 10) high initial concentrations drop off rapidly as the snowmelt proceeds. Concentrations increase again later in the season. The high initial concentrations are apparently due to holdover water, and to some degree to differential elution of ions from the snowpack, resulting in high concentrations in the early snowmelt. As melting proceeds concentrations drop due to dilution. Later in the season, concentrations again rise as the proportion of surface inflow decreases and the groundwater influence increases. During this period the increase in bases (Ca, Mg, Na, K, and NH_4) is greater than the increase in strong acid-forming anions (SO_4, NO_3, and Cl), so that ANC and pH increase. The 1990 data (fig. 10) seem to suggest an increase in lake ANC very early in the spring prior to the rapid drop off. These early values may be influenced by local melting of ice and snow near the outlet so that interpretation in

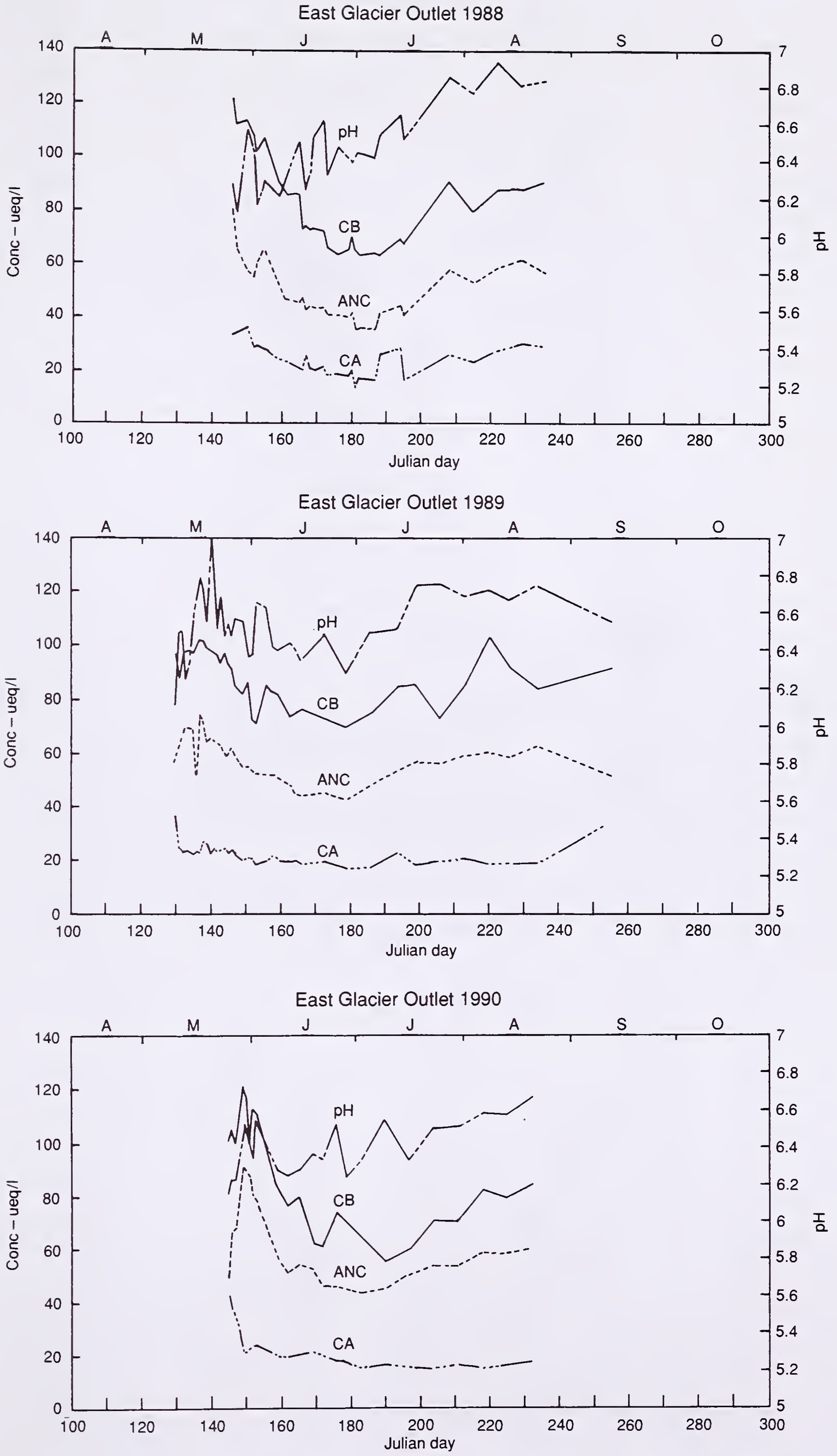

Figure 10. Sum of bases (C_B), sum of acids (C_A), ANC and pH by Julian day for East Glacier outlet.

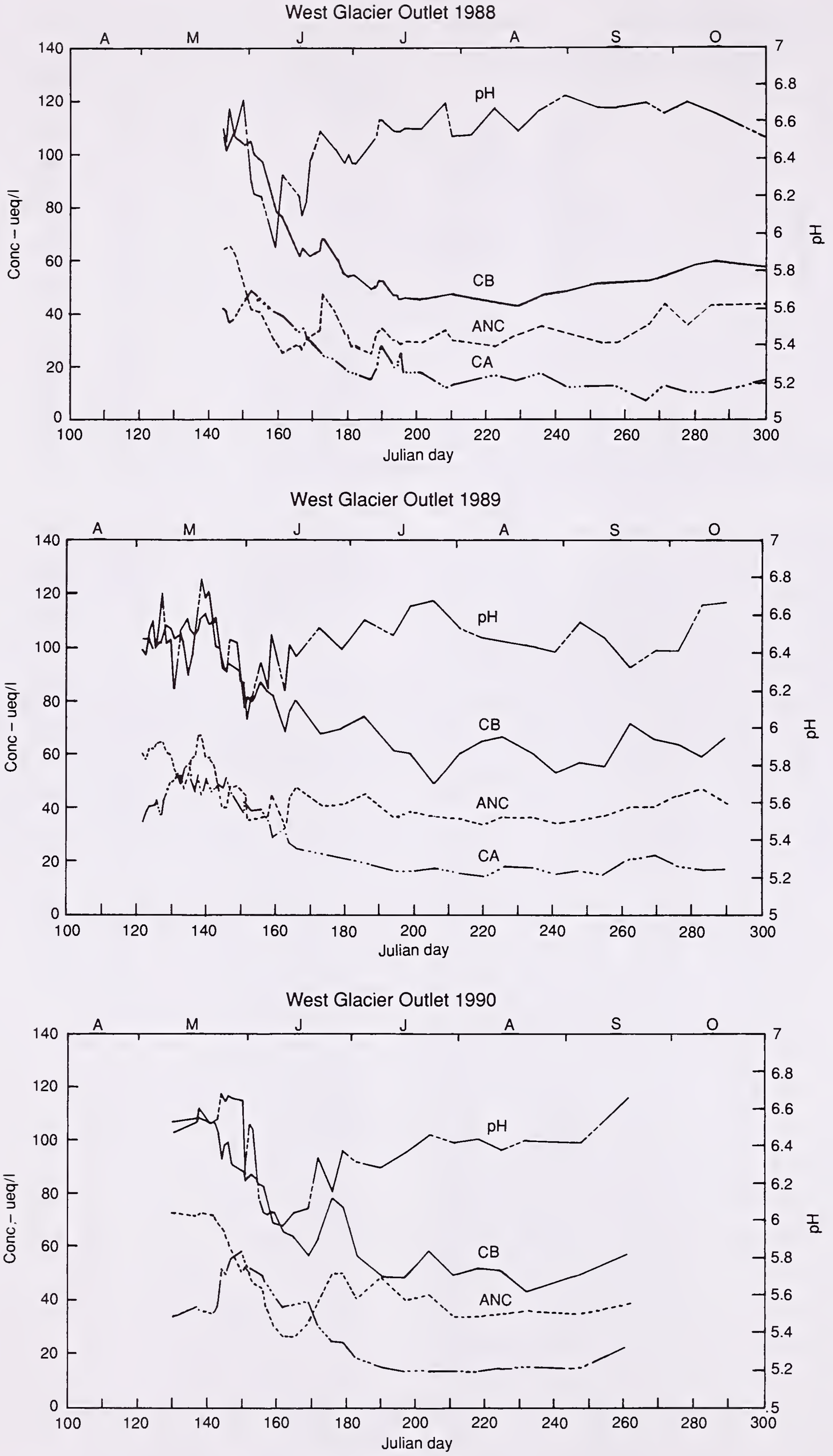

Figure 11. Sum of bases (C_B), sum of acids (C_A), ANC and pH by Julian day for West Glacier outlet.

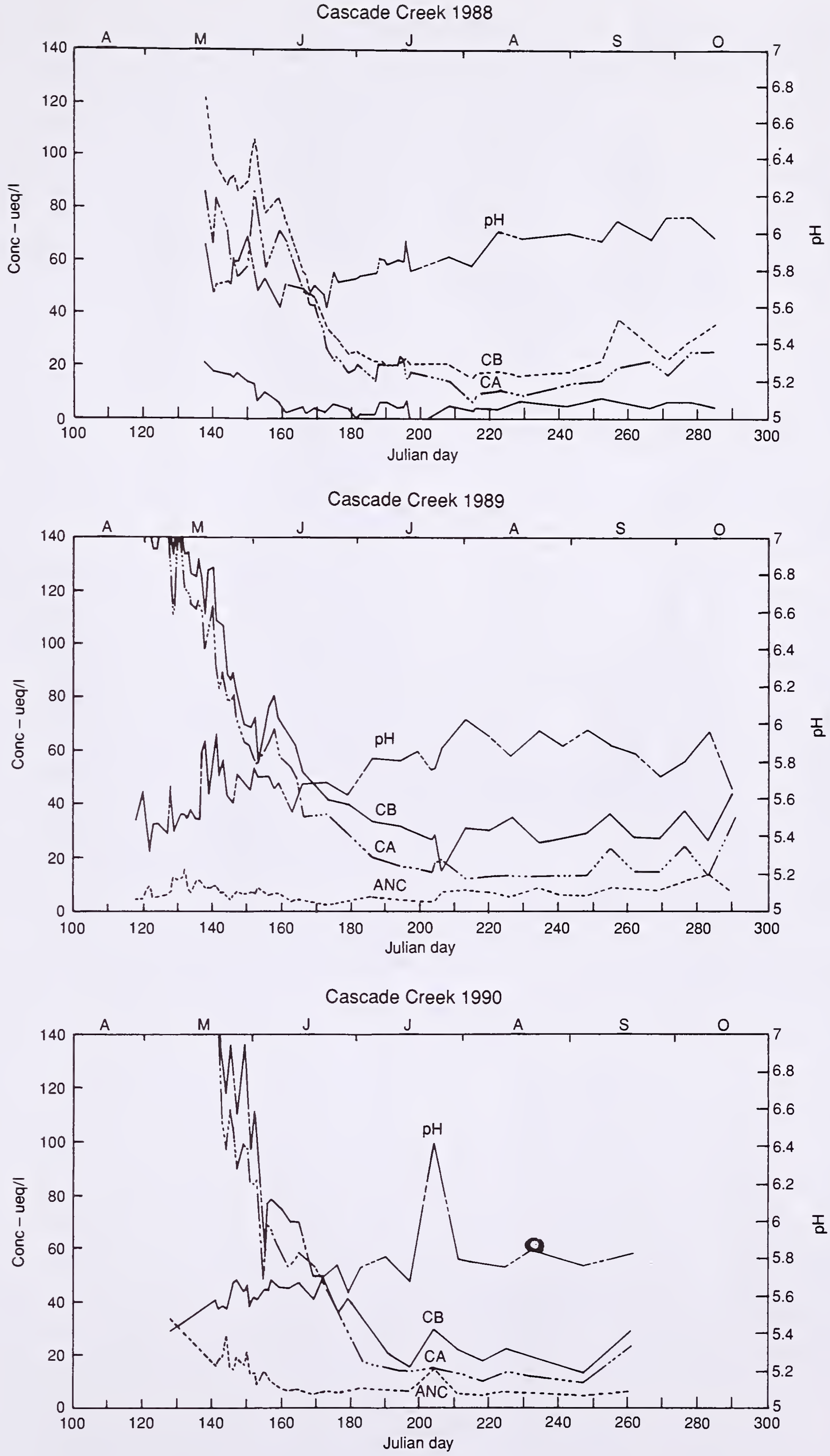

Figure 12. Sum of bases (C_B), sum of acids (C_A), ANC and pH by Julian day for Cascade Creek.

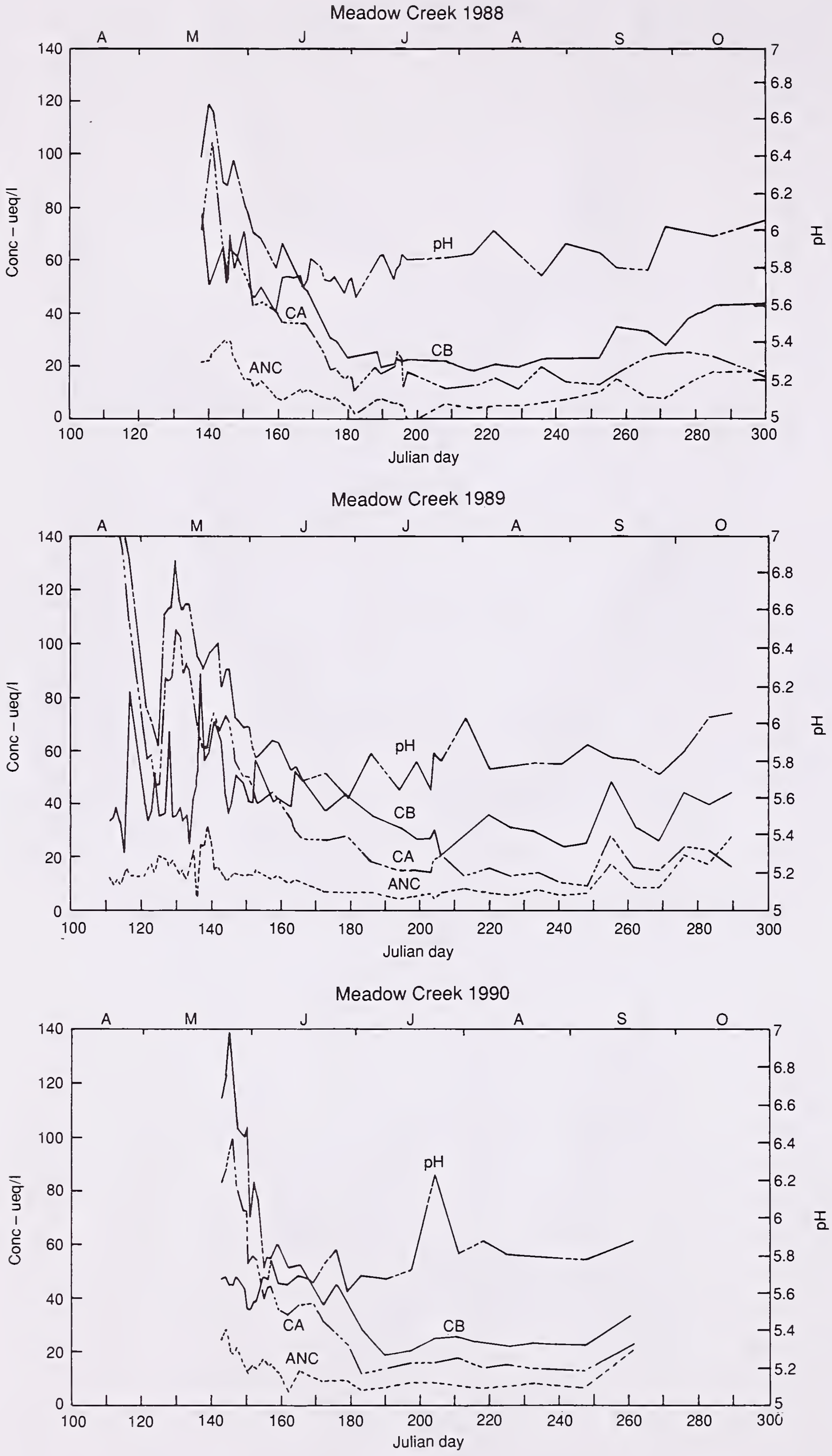

Figure 13. Sum of bases (C_B), sum of acids (C_A), ANC and pH by Julian day for Meadow Creek.

terms of overall lake status probably is not warranted. In 1990 at EGO the bases (C_B) drop off slowly in the early season (about day 150-170) while the acids (C_A) are maintained at a low level, resulting in a drop in ANC over this period. The cause of this temporary drop in ANC is not completely clear but it is most likely due to dilution of high ANC waters that have collected over the winter, while the late season recovery reflects the influx of high ANC waters from the soil and groundwater.

West Glacier outlet (fig. 11) also exhibits high early levels with a marked decrease in mid-season. The high early values for C_A and C_B are again likely due to a combination of influx from the ground water during the winter and high concentrations in the early melt water. High early ANC values are at least in part due to in-lake processes over the winter (Vertucci 1991). In 1988 the bases (C_B) drop more rapidly than do the acids (C_A) resulting in marked decrease in pH and ANC just prior to day 160. These data have been interpreted as supporting a small pulse of episodic acidification in West Glacier Lake. Details are available elsewhere (Vertucci 1988a ,1988b, 1990; Musselman et al. 1990) and will not be discussed here. The late-season rise in ANC is less noticeable than in East Glacier, as low-concentration streamflow from the high snow fields supplements the higher concentration ground water inflows. The 1990 data also show a drop in ANC about day 160. This drop is caused by a faster decline in C_B than in C_A but it is difficult to determine whether it is simply due to dilution or whether differential elution of acids and bases plays a significant role. In all three years there is an increase in ANC and pH at about day 170, which would appear to result from an influx of soil water and groundwater.

The high concentrations during the early snowmelt are very evident in the concentration patterns in Cascade and Meadow Creeks as shown in figures 12 and 13. The question arises as to whether these high early concentrations reflect the early elution of solutes during the snowmelt, or whether "piston flow" is displacing high-concentration water from the soil and rock interstices. There is a small increase in bases and ANC when compared to precipitation input, indicating that some bases are furnished by weathering and/or soil exchange. Concentrations of Ca and Si in Cascade Creek are available for 1988 and 1989, and are shown in figure 14, along with Si/Ca ratios. Silica values do tend to be high in the spring, drop off during the peak flow times, and recover in mid and late summer. This suggests that at least some of the water may come from the soil and rock pores. However, this seasonal pattern is not nearly as marked for Si as it is for Ca, so that Si/Ca (mol/mol) ratios in the spring are between 0.5 and 1.0, increasing to about 2.5 over the course of the season. The fact that the Si/Ca ratios are lowest during the period of highest solute concentrations suggests that most of the high concentration of solutes during the early season is due to the differential release of solutes from the snowpack during melting.

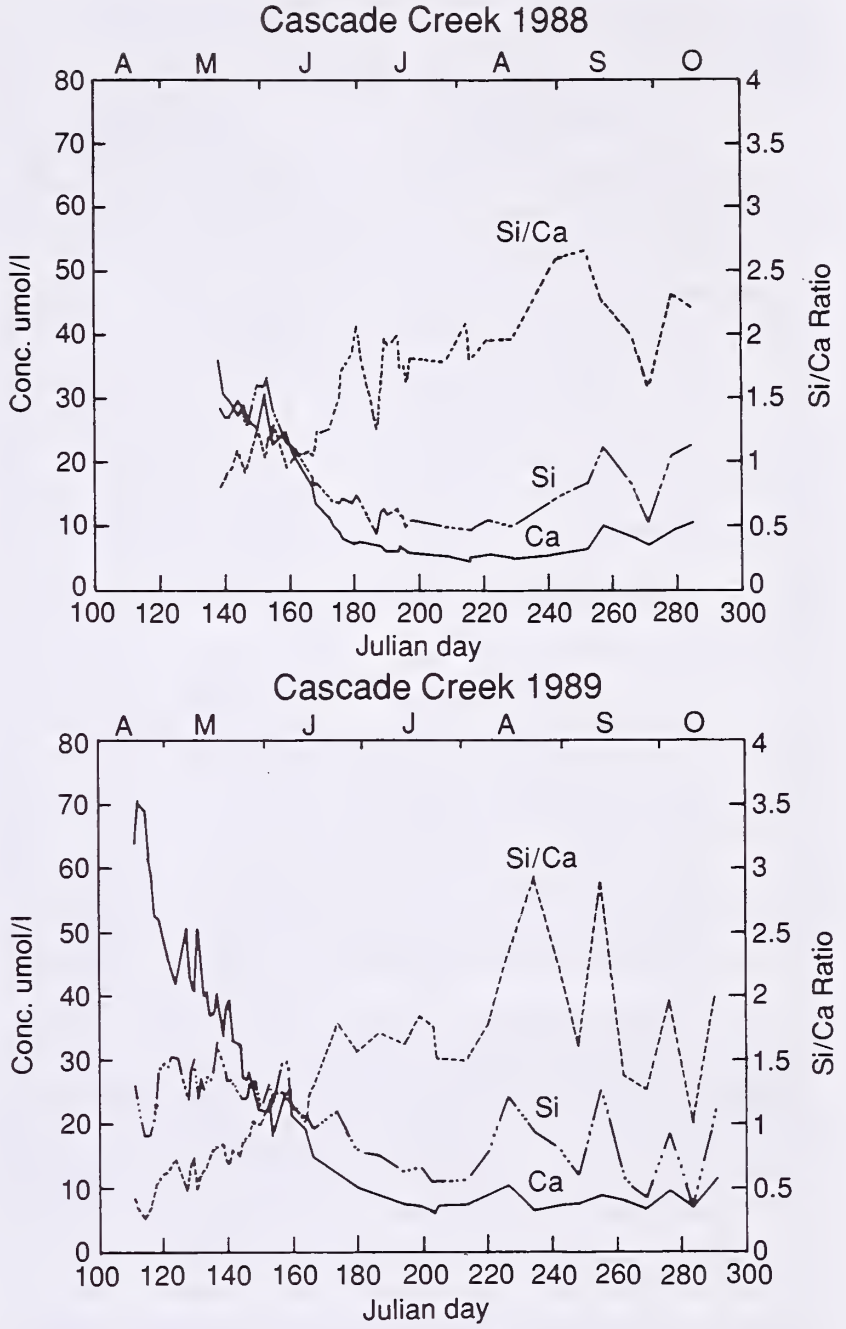

Figure 14. Concentration of Ca and Si (umol/l) and Si/Ca ratio in Cascade Creek in 1989 and 1990.

The concentration of both bases and acids is high early on and drops off as early melting proceeds. However, there is little evidence in these data for a substantial difference in the melting of the acids (C_A) and bases (C_B). As there are relatively large altitude differences (ca 200 m) on these watersheds, differences in melting due to elevation may mask any such differential release of acids and bases. Even so, it is clear that small increases in the acidity of the snowpack could result in marked acidification of the early melt water, unless it were completely offset by an increase in the rate of weathering of base cations.

Chemical Fluxes

Summaries of the three-year mean chemical fluxes are shown in table 5. Data for the individual years are

Table 5.—Input and output summaries for East and West Glacier catchments. Values are three-year means. Positive differences indicate net retention while negative values indicate net loss.

	Snow Pit Input				NADP Input			
	Input	Output	Diff	S.E. Diff	Input	Output	Diff	S.E. Diff
	meq/m^2				meq/m^2			
East Glacier								
H	4.3	0.1	4.2	0.31	4.3	0.1	4.2	0.31
Ca	10.0	31.0	-21.0	1.04	9.9	31.0	-21.1	1.04
Mg	2.4	11.8	-9.4	0.88	2.3	11.8	-9.5	0.89
Na	2.5	7.2	-4.6	0.21	8.5	7.2	1.4	0.25
K	1.8	2.0	-0.2	0.13	0.4	2.0	-1.6	0.19
NH_4	4.3	0.2	4.0	0.34	6.8	0.2	6.6	0.53
Cl	2.7	2.0	0.7	0.45	4.0	2.0	2.0	0.36
SO_4	10.3	11.2	-1.0	0.06	15.9	11.2	4.7	0.46
NO_3	10.8	0.4	10.4	0.82	10.8	0.4	10.4	0.82
ANC	-2.9	33.6	-36.5	2.36	-2.8	33.6	-36.5	2.36
West Glacier								
H	8.0	0.3	7.7	0.75	8.0	0.3	7.7	0.75
Ca	18.7	59.8	-41.1	2.29	18.5	59.8	-41.3	2.28
Mg	4.4	23.9	-19.5	1.01	4.3	23.9	-19.6	1.01
Na	4.7	14.0	-9.3	0.98	16.0	14.0	2.0	1.98
K	3.3	5.5	-2.2	1.10	0.8	5.5	-4.7	0.90
NH_4	8.0	0.9	7.1	0.81	12.7	0.9	11.9	1.23
Cl	5.1	4.9	0.2	0.19	7.4	4.9	2.5	0.38
SO_4	19.3	27.3	-8.1	2.01	29.9	27.3	2.6	2.89
NO_3	20.1	8.0	12.3	3.27	20.3	8.0	12.3	3.18
ANC	-5.4	61.2	-66.6	3.23	-5.3	61.2	-66.5	3.24

included in the Appendix (tables A17 and A18). Yearly inputs are based on the precipitation amounts measured for that year, but input concentrations are averaged over years (table 1) prior to use in the calculations. This procedure was adopted because the variation in precipitation chemistry measurements within years is greater than the variation among years, and the best estimates are probably those that contain as many observations as possible. Yearly outputs are based on measurements of both flow and concentration made in that year. Values reported in table 5 for inputs, outputs, and fluxes are simple means of the three yearly values.

As no completely satisfactory basis could be established for choosing between snow pit and NADP input data, table 5 includes calculations based on both sets. We must also recognize that the only dry deposition included in the input fluxes is that which accumulates in the snowpack (snow pit data only), so the input may be underestimated. This limitation is not as serious here as in many systems, as much of the catchments is bare rock. Based on the soil maps of Hopper and Walthall (1987) we have estimated that only 39% of the West Glacier catchment is vegetated, much of which is tundra or krummholtz that is covered by snow much of the year. These areas have much less surface area for collection of dry deposition than do the coniferous forests. Nonetheless, this limitation must be recognized.

Base Cations.—There is substantial agreement between the fluxes of Ca, Mg, and K as calculated with the two sets of input data. However, using the snow pit input data gives a net Na removal of 4.6 and 9.3 meq/m^2 for East and West Glacier, respectively, while calculations based on NADP data give a respective net accumulation of 1.4 and 2.0 meq/m^2. Total annual base cation (not including NH_4) removal from the West Glacier catchment is 72.2 meq/m^2 using snow pit input and 63.6 meq/m^2 using NADP data. The difference between the two values is almost entirely due to differences in the Na input values. We are unable to resolve this discrepancy at the present time, but a small net removal of Na is more likely than a net retention. Both values are substantially above the 44.4 meq/m^2 value estimated by Rochette et al. (1988).

Base cation removal (not including NH_4) from the East Glacier catchment is estimated as 35.2 meq/m^2 using snow pit input data and 30.8 meq/m^2 using NADP inputs, with the difference again being largely due to Na. The lower flux from the East Glacier catchment is associated with lower precipitation inputs, i.e. a 2-year mean of 1.06 m at East Glacier as compared to 1.99 m at West Glacier, suggesting that base cation removal is nearly proportional to precipitation amount. This proportionality suggests that caution should be exercised in the use of cation export values to compare sensitivity of different catchments to acidic deposition (Rochette et al. 1988). On this basis East Glacier would be more sensitive than West Glacier to an increase in deposition acidity. However, East Glacier ANC's are higher than those in West Glacier, and the analysis below suggests that West Glacier would be somewhat more sensitive than East Glacier to an increase in precipitation acidity. Baron (1991b) reported a net annual cation export of 51.9 meq/m^2 for the Loch Vale catchment, or about midway between that of East and West Glacier Lakes. However, the molar ratio of Mg to Ca was about 3.8, compared to 2.4 for GLEES. Caine and Thurman (1990) report a rate of about 100 meq/m^2 at Green Lakes.

The NH_4 deposition in the East Glacier catchment is estimated as 4.3 meq/m^2 (0.60 kg N/ha) from the snow pit data and 6.8 (0.95 kg N/ha) using NADP values. Deposition is higher at West Glacier due to the higher rainfall, estimated at 8.0 meq/m^2 (1.1 kg N/ha) using the snow pits and 12.7 meq/m^2 (1.78 kg N/ha) using NADP. Virtually all of this is retained in both the East and West Glacier catchments. The low NH_4 levels in Cascade and Meadow Creeks suggests that most is retained by the terrestrial or wetland components and does not actually reach the lakes.

Acid Forming Anions.—The most important discrepancy between the two sets of input data is in the SO_4 levels, which in turn is reflected in the fluxes. Using the snow pit data for West Glacier results in an estimated net annual removal of 8.1 meq/m^2 or about 1.3 kg S/ha. The NADP data estimates a net retention of 2.6 meq/m^2 or 0.42 kg S/ha. The corresponding values for East

Glacier are a removal of 1.0 meq/m^2 (0.16 kg S/ha) using snow pit data or a retention of 4.7 meq/m^2 (0.75 kg S/ha). Either net removal or accumulation is possible. There is some evidence of a small amount of pyrite in the catchments (James Drever, Univ. of Wyoming, personal communication), which would provide a source of sulfur. On the other hand, sulfur might be retained by either the biota or soil adsorption. While this cannot be resolved at present, fortunately the amounts are small in either case and the effect on simulations of the effect of acidic deposition should be moderate at most.

There are also some differences in the two data sets as regards Cl. The snow pit data would suggest that the input and output of Cl is approximately in balance, with less than 1.0 meq/m^2 net retention in either catchment. The NADP values result in an estimate of about 2-3 meq/m^2 Cl retained annually. Again, the authors favor the snow pit data which indicate virtually no retention. While the snow pit data, seems more reliable for Na and Cl, it does not necessarily follow that it is more reliable in the case of SO_4.

Substantial amounts of NO_3 are deposited. Both sets of input data estimate an input of about 11 meq/m^2 (1.5 kg N/ha) in the East Glacier catchment and 20 meq/m^2 (2.8 kg N/ha) at West Glacier. Virtually no NO_3 is discharged from East Glacier, but West Glacier Lake discharges more than one-third (8.0 meq/m^2) of the NO_3 input.

Acidity and ANC.—While H^+ ion values are included in the tables these will not be discussed. In these waters, which are at present never more than slightly acidic (pH < 5.7), ANC is a better indicator of the acid-base status. We have used the Henriksen model (Henriksen 1979, 1980) as modified by Brakke et al. (1990) to estimate the change in precipitation acidity that would be required to acidify East and West Glacier Lakes, and Cascade and Meadow Creeks. In this case the end point is defined as an annual volume weighted mean ANC of zero. This modified form of the Henriksen model uses an "F" factor, which may be defined as the fraction of increased acidity that is neutralized by an increase in release of base cations from the catchment, either by accelerated weathering or soil exchange. Unfortunately, there is no really satisfactory method of predicting this value. Brakke et al. (1990) pointed out that lakes in catchments that are well supplied with exchangeable and/or weatherable bases will naturally have high ANC. Such catchments are well supplied with bases so that virtually all acidic deposition will be neutralized in the catchment (the F value will be 1.0). They then proposed a relationship by which the F value may be estimated from lake ANC.

$$F = \sin 90(BC^*/S),$$

where BC^* is the concentration of non-marine base cations and S is the ANC at which F = 1.0. S is expected to be in the range of 200-400 ueq/l. Using this relationship we have calculated F for S values of 200, 300, and 400 ueq/l (table 6). These range from 0.302 to 0.575 for East Glacier and 0.256 to 0.494 for West Glacier. Wright (1983) estimated a value of 0.4 for North American lakes in sensitive areas. Based on these F values, acidification of East Glacier Lake would require an increased rainfall acidity of 45-75 ueq/l or a precipitation pH of about 4.11 to 4.33. Acidification of West Glacier would require increased precipitation acidity of 41-61 ueq/l, or a precipitation pH of 4.20-4.35. These values are similar to current or recent precipitation acidity in the Adirondack Mountains, where the more sensitive lakes have become acidified (Linthurst et al. 1986; Asbury et al. 1989). Our conclusion would be that, while these systems must be considered moderately sensitive, they are perhaps less so than would be inferred from the earlier work of Rochette et al. (1988).

Cascade and Meadow Creeks are much more sensitive than are the lakes. Mean ANC values are very low, currently 5.9 ueq/l for Cascade and 8.8 ueq/l for Meadow Creek. Increased precipitation acidity of only about 10 ueq/l would be sufficient to reduce annual ANC values to zero. This corresponds to a final precipitation pH of about 4.9. Clearly, these systems must be classified as extremely sensitive.

Table 6.—Changes in deposition and precipitation acidity required to acidify GLEES catchments to an annual volume weighted mean ANC of zero assuming various values of S, the ANC at which the Henriksen F factor would be 1.0 (Brakke et al. 1989). Acidification assumed to be due to H_2SO_4.

	Precip mm	S (ueq/l) 200	300	400
East Glacier	1060			
F Value		0.575	0.397	0.302
Change in				
SO4 dep (meq/m^2)		79	56	48
SO4 conc (ueq/l)		75	53	45
Final precip pH		4.11	4.26	4.32
West Glacier	1991			
F Value		0.494	0.338	0.256
Change in				
SO4 dep (meq/m^2)		121	92	82
SO4 conc (ueq/l)		61	46	41
Final precip pH		4.20	4.31	4.35
Cascade Creek	2570			
F Value		0.287	0.193	0.145
Change in				
SO4 dep (meq/m^2)		17	15	14
SO4 conc (ueq/l)		7	6	6
Final precip pH		5.02	5.05	5.07
Meadow Creek	2080			
F Value		0.299	0.201	0.151
Change in				
SO4 dep (meq/m^2)		20	17	16
SO4 conc (ueq/l)		9	8	8
Final precip pH		4.91	4.95	4.97

* *Cascade and Meadow Creek precipitation calculated from discharge assuming 50 cm ET.*

The previous analysis focuses on annual mean effects of increased deposition. While a precipitation pH of < 4.3 would probably be required to reduce annual average ANC of these lakes to less than zero, given the high degree of differential elution during the melting process (Bales et al. 1990; Rochette et al. 1988) increases in acidic deposition would undoubtedly be reflected in large seasonal effects. At present these seasonal effects are reflected in the measured concentration patterns as shown in figures 10-13. However, at present the snow pack is nearly neutral or only very slightly acidic. If acidic deposition were increased it is likely that the early water that is concentrated by differential elution would be highly acidic as well. These seasonal effects would probably be much more marked in West Glacier Lake than in East Glacier due to both the lower initial ANC and the fact that annual discharge is about 21 times lake volume at West Glacier and less than 5 times lake volume at East Glacier. Major acidic events would likely be even more pronounced in the tributaries than in the lakes.

Given likely current sources of precipitation acidity, the question arises as to what the effects would be if the precipitation were enriched with nitric acid rather than sulfuric acid. As most NO_3 currently entering the Cascade and Meadow Creek subcatchments is discharged to West Glacier Lake, presumably most of the increase in NO_3 would also be passed on. Therefore, the most likely scenario for these tributary streams is that the effect on stream ANC would be similar with precipitation enriched by either sulfuric or nitric acid.

The effect of nitric acid on the acid-base status of East and West Glacier Lakes is more difficult to predict. We would expect that biological immobilization would attenuate at least part of the acidifying effect of nitric acid inputs. Currently the net immobilization in the West Glacier system is about two-thirds of the NO_3 input. There is no way to predict to what extent this fraction would hold for increased NO_3. The fact that a significant amount is currently being discharged may indicate that the lake productivity is limited by factors other than nitrogen, and/or the relatively short residence time does not allow for complete immobilization. In either case the system likely would not have the ability to absorb substantial increases, so that decreased ANC would be expected, particularly during snowmelt.

In the East Glacier catchment, almost all NO_3 inputs are currently being immobilized. Given the hydrology of the catchment, there is a good deal more opportunity for the terrestrial component of the ecosystem to utilize incoming N before it reaches the lake. To what extent increases in NO_3 can be absorbed cannot really be predicted. In either catchment, it is very likely that if NO_3 inputs were to increase, substantial changes would take place in the species composition and productivity of both the aquatic and terrestrial systems.

Summary

Current annual volume-weighted mean acid neutralizing capacities are approximately 50 ueq/l at East Glacier and 39 ueq/l at West Glacier. Using the modified Henriksen model the estimated increase in precipitation acidity required to acidify the outflow to an annual volume weighted mean ANC of zero is in the range of 45-75 ueq/l for East Glacier and 41-61 ueq/l for West Glacier. Using these criteria, final precipitation acidity of about 4.1 to 4.3 would be required to acidify the outflow of these catchments. However, due to the differential elution of contaminants from the snowpack, episodic acidification and severe biological effects would be expected at deposition levels well below those required to reduce mean annual ANC values to zero.

The West Glacier tributary streams are much more sensitive. Current annual ANC's are only 6 ueq/l for Cascade Creek and 9 ueq/l for Meadow Creek. The mean annual ANC in these systems would reach zero if precipitation acidity were increased by only 10 ueq/l, corresponding to a final precipitation pH of about 4.8-4.9. Again, episodic acidification would be a major factor in these streams if deposition acidity were to increase. The expected pattern would be for the streams to be highly acidic early in the season, shifting to near neutrality as snowmelt progresses.

There are discrepancies between the chemical inputs calculated using snow pit data as compared to NADP data, particularly for Na, Cl, and SO_4. The input-output analysis would suggest that the snow pit data are more nearly correct, but it is not possible to definitively resolve the differences using currently available data.

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APPENDIX A

Table A-1. Summary of deposition and volume weighted mean precipitation concentrations by water year using NADP data from the Wyoming Snowy Range station.

A. SUMMARY BY WATER YEAR (Oct-Sept) meq/m^2

	Ca	Mg	K	Na	NH4	NO3	Cl	SO4	H	Cond Sx100/cm	ppt*
1986/87	8.65	1.89	0.50	6.22	4.40	9.49	3.46	11.61	5.98	6.08	93.46
1987/88	9.39	2.15	0.45	5.95	3.23	7.35	3.40	14.27	5.24	6.30	104.65
1988/89	9.84	2.41	0.34	10.42	8.92	12.60	4.26	18.16	4.52	8.19	108.89
1989/90	9.01	2.16	0.29	9.33	8.73	10.90	3.73	15.86	1.87	6.52	91.03
Mean	9.22	2.15	0.39	7.98	6.32	10.09	3.71	14.97	4.40	6.77	99.51

B. VOLUME WEIGHTED MEAN CONCENTRATIONS ueq/l

	Ca	Mg	K	Na	NH4	NO3	Cl	SO4	H	Cond Sx100/cm	C_B-C_A
1986/87	9.25	2.02	0.53	6.65	4.71	10.16	3.71	12.42	6.40	6.51	-3.11
1987/88	8.97	2.05	0.43	5.69	3.09	7.02	3.25	13.64	5.01	6.02	-3.69
1988/89	9.03	2.22	0.31	9.57	8.20	11.57	3.91	16.67	4.15	7.52	-2.83
1989/90	9.90	2.37	0.32	10.25	9.59	11.98	4.10	17.42	2.05	7.17	-1.07
Mean***	9.29	2.16	0.40	8.04	6.40	10.18	3.74	15.04	4.40	6.80	-2.68
Std Err	0.21	0.08	0.05	1.11	1.51	1.12	0.18	1.20	0.91	0.33	0.56

* *1988/89 precipitation does not include Dec (16.26 cm) as no chemical analyses are available.*

* *C-A values include NH4.*

*** *Simple means over four years.*

Table A-2. Three-year summary of chemical concentrations from snow pits.

								UEQ/L				
LOCATION	JULIAN DAY	CM H2O	H	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
Snow Pits 1988 (Bales et al. 1990)				7.1	1.7	2.6	1.7		2.4	8.8	7.9	
Snow Pits 1989												
B	83			9.61	2.41	2.75	0.89	2.28	3.38	9.37	9.68	
C	115			8.56	1.95	1.85	1.54	4.07	1.88	9.75	11.21	
E	132			7.87	2.11	5.72	1.49	3.84	2.88	7.68	11.56	
G	137			8.22	1.70	1.23	1.44	2.27	3.35	6.89	10.92	
Mean - 1989				8.57	2.04	2.89	1.34	3.12	2.87	8.42	10.84	
Standard Error				0.38	0.15	1.00	0.15	0.49	0.35	0.68	0.41	
Snow Pits 1990												
East - Deep	138	34.8	2.76	10.71	2.74	2.58	0.70	4.48	1.28	7.78	6.17	6.39
East - Shallow	138	72.6	7.14	7.74	2.32	1.89	0.67	2.47	1.72	7.26	9.07	-5.82
Meadow Cr - De	138	109.2	2.66	12.92	3.71	2.78	0.94	2.52	3.12	6.66	9.81	7.67
Meadow Cr - Sh	138	71.7	2.80	8.37	2.80	2.60	0.72	3.60	2.13	5.64	6.60	1.01
Norbert - Deep	100	57.0	3.17	16.07	3.79	5.46	1.62	5.05	3.71	9.70	11.52	1.35
Norbert - Shal	100	24.2	5.99	9.66	2.65	2.62	1.07	2.55	2.38	6.76	9.38	-4.99
Norbert - Deep	138	114.6	2.82	15.47	4.04	3.42	0.94	3.81	1.73	8.40	9.95	2.29
Mean - 1990		69.2	3.91	11.56	3.15	3.05	0.95	3.50	2.29	7.46	8.93	1.13
Standard Error		12.9	0.70	1.26	0.26	0.43	0.12	0.39	0.32	0.50	0.72	1.94
THREE YEAR MEANS				9.08	2.30	2.85	1.33	3.31	2.52	8.23	9.22	
Standard Error				1.31	0.44	0.13	0.22	0.18	0.40	0.86		

Notes: 1989 Pit means are simple means of all observations from the pit.
1990 Pit means are volume weighted.
Year means are simple means over pits.

Table A-3 . Mean chemical composition by years for for East Glacier outlet (EGO), West Glacier outlet (WGO), Cascade Creek (CSC), and Meadow Creek (MDW).

	EGO			WGO			CSC			MDW		
	1988	**1989**	**1990**	**1988**	**1989**	**1990**	**1988**	**1989**	**1990**	**1988**	**1989**	**1990**
Ions	ueq/l			ueq/l			ueq/l			ueq/l		
H+ (Calc)	0.12	0.11	0.10	0.16	0.13	0.13	1.00	0.78	0.70	0.63	0.58	0.54
Ca	45.81	48.28	45.13	35.67	41.10	36.47	19.45	23.59	21.09	21.82	23.08	20.80
Mg	18.16	17.05	17.44	14.56	15.55	15.04	6.98	7.65	8.04	7.90	7.51	7.93
Na	10.61	11.23	10.36	7.83	10.42	8.47	4.86	7.45	4.96	5.07	7.81	5.71
K	3.24	3.24	2.42	2.44	4.87	3.26	1.30	3.22	1.24	1.75	3.67	1.87
NH4	0.23	0.47	0.32	0.42	0.58	0.63	0.59	0.49	0.42	0.33	0.49	0.19
Sum(+)	78.18	80.38	75.78	61.09	72.66	64.00	34.18	43.18	36.45	37.51	43.13	37.04
Cl	4.37	1.86	2.32	3.31	3.38	2.60	3.14	2.65	1.99	3.28	2.64	2.07
SO4	16.99	17.42	16.00	16.55	18.01	17.10	13.01	14.41	13.82	13.02	13.43	12.69
NO3	0.41	0.58	0.84	4.06	3.71	7.03	9.09	12.82	11.41	8.41	10.33	10.05
[ANC]	46.10	51.32	53.75	33.97	41.58	40.30	4.42	6.20	7.07	7.93	8.82	9.42
Sum(-)	67.99	71.29	73.01	58.04	66.82	67.17	30.66	36.84	35.00	33.28	35.79	34.78
Anion deficit	10.19	9.09	2.77	3.04	5.84	-3.17	3.52	6.34	1.45	4.23	7.35	2.26
Other	mgm/l			mgm/l			mgm/l			mgm/l		
SiO2	1.42	1.54		1.25	1.07		0.88	1.03	0.012	0.76	0.92	
P	0.008	0.007	0.009	0.011	0.004	0.013	0.009		0.012		0.005	0.011
Al	0.046	0.037		0.025	0.033		0.031	0.050		0.035	0.04	
DIC	0.53	0.66			0.48			0.12			0.24	
DOC	1.82	2.66			1.26			0.90			1.54	
Charge (ueq/mgm DOC)	5.60	3.42			4.63			7.06			4.78	

Table A-4. Volume weighted mean chemical concentrations for East Glacier outlet in 1988.

EAST GLACIER OUTPUT 1988 SUMMARY - TOTAL OUTPUT

	FLOW	KG					KEQ									
MONTH	**M^3**	**SiO2**	**P**	**Al**	**DIC**	**DOC**	**H+**	**CA**	**MG**	**NA**	**K**	**NH4**	**CL**	**SO4**	**NO3**	**[ANC]**
April																
May	2526	5.06	0.02	0.12	NA	NA	0.001	0.164	0.063	0.038	0.015	0.003	0.015	0.059	0.013	0.146
June	172161	241.18	1.32	8.49	20.78	70.97	0.074	8.044	3.183	1.838	0.562	0.038	0.678	2.996	0.061	8.035
July	35870	52.41	0.38	1.19	17.80	61.76	0.010	1.439	0.580	0.359	0.105	0.008	0.228	0.523	0.013	1.524
Aug	660	1.04	0.01	0.00	0.28	0.53	0.000	0.028	0.011	0.007	0.002	0.001	0.003	0.010	0.001	0.032
Annual	211217	299.69	1.72	9.80	38.86	133.26	0.085	9.675	3.837	2.242	0.685	0.050	0.923	3.588	0.087	9.737

DIC and DOC data start 23 June (day 175)

EAST GLACIER OUTPUT 1988 SUMMARY - CONCENTRATION

	FLOW	MG/L					UEQ/L									
MONTH	**M^3**	**SiO2**	**P**	**AL**	**DIC**	**DOC**	**H+**	**CA**	**MG**	**NA**	**K**	**NH4**	**CL**	**SO4**	**NO3**	**[ANC]**
April																
May	2526	2.00	0.01	0.05	NA	NA	0.34	64.88	24.78	15.17	6.04	1.03	5.82	23.25	5.08	57.73
June	172161	1.40	0.01	0.05	0.57	1.93	0.43	46.72	18.49	10.68	3.27	0.22	3.94	17.40	0.36	46.67
July	35870	1.46	0.01	0.03	0.50	1.72	0.28	40.12	16.16	10.00	2.93	0.23	6.34	14.58	0.36	42.49
Aug	660	1.58	0.01	0.00	0.43	0.81	0.16	43.17	16.92	10.11	2.53	0.77	4.91	15.62	0.87	48.72
Annual	211217	1.42	0.01	0.05	0.53	1.82	0.40	45.81	18.16	10.61	3.24	0.23	4.37	16.99	0.41	46.10

Table A-5. Volume weighted mean chemical concentrations for East Glacier outlet in 1989.

EAST GLACIER OUTLET 1989 SUMMARY - TOTAL

	FLOW	KG					KEQ									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April	0															
May	39141	51.95	0.105	0.884	34.0	116.2	0.012	2.247	0.762	0.479	0.105	0.022	0.069	0.781	0.044	2.385
June	95886	146.54	0.951	4.945	61.2	252.0	0.036	4.337	1.539	1.017	0.311	0.036	0.183	1.608	0.029	4.508
July	25716	45.98	0.010	0.149	12.3	58.3	0.007	1.146	0.434	0.299	0.103	0.017	0.048	0.414	0.018	1.321
Aug	4128	8.66	0.015	0.162	1.6	11.4	0.001	0.230	0.076	0.056	0.015	0.003	0.006	0.070	0.003	0.247
Sept	181	0.39	0.002	0.011	0.1	0.4	0.000	0.010	0.003	0.002	0.001	0.000	0.000	0.003	0.002	0.009
Annual	165051	253.53	1.08	6.15	109.2	438.2	0.06	7.97	2.81	1.85	0.54	0.08	0.31	2.88	0.10	8.47

EAST GLACIER OUTLET 1989 SUMMARY - CONCENTRATION

	FLOW	MG/L					UEQ/L									
MONTH	M^3	SiO2	P	AL	DIC	DOC	H	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April	0															
May	39141	1.33	0.003	0.023	0.87	2.97	0.30	57.41	19.48	12.23	2.69	0.56	1.77	19.95	1.11	60.95
June	95886	1.53	0.010	0.052	0.64	2.63	0.38	45.23	16.05	10.61	3.24	0.38	1.91	16.77	0.30	47.01
July	25716	1.79	0.000	0.006	0.48	2.27	0.29	44.56	16.88	11.61	3.99	0.64	1.87	16.09	0.70	51.35
Aug	4128	2.10	0.004	0.039	0.39	2.75	0.20	55.70	18.40	13.58	3.64	0.61	1.53	16.86	0.75	59.92
Sept	181	2.16	0.009	0.063	0.54	2.07	0.28	52.89	17.77	13.48	6.52	0.33	2.28	19.28	12.64	51.40
Annual	165051	1.54	0.007	0.037	0.66	2.66	0.34	48.28	17.05	11.23	3.24	0.47	1.86	17.42	0.58	51.32

Table A-6. Volume weighted mean chemical concentrations for East Glacier outlet in 1990.

EAST GLACIER OUTLET 1990 SUMMARY - TOTAL

	FLOW	KG					KEQ									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H+	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April	0															
May	12678	NA	0.07	NA	NA	NA	0.005	0.831	0.332	0.166	0.043	0.012	0.035	0.254	0.043	1.03
June	140238	NA	1.14	NA	NA	NA	0.067	6.439	2.457	1.431	0.352	0.042	0.355	2.314	0.097	7.44
July	40294	NA	0.49	NA	NA	NA	0.015	1.414	0.581	0.408	0.078	0.008	0.068	0.532	0.021	1.89
Aug	5969	NA	0.02	NA	NA	NA	0.002	0.306	0.104	0.058	0.010	0.001	0.003	0.087	0.006	0.35
Sept	0															
Oct	0															
Annual	199179	NA	1.7	NA	NA	NA	0.089	8.989	3.474	2.064	0.482	0.064	0.462	3.187	0.167	10.71

EAST GLACIER OUTLET 1990 SUMMARY - CONCENTRATION

	FLOW	MG/L					UEQ/L									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H+	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April	0															
May	12678	NA	0.005	NA	NA	NA	0.426	65.57	26.17	13.10	3.39	0.96	2.78	20.01	3.41	81.00
June	140238	NA	0.008	NA	NA	NA	0.479	45.91	17.52	10.21	2.51	0.30	2.53	16.50	0.69	53.07
July	40294	NA	0.012	NA	NA	NA	0.382	35.08	14.42	10.13	1.93	0.19	1.68	13.21	0.52	46.93
Aug	5969	NA	0.003	NA	NA	NA	0.253	51.25	17.50	9.75	1.61	0.22	0.52	14.49	1.06	57.99
Sept	0															
Oct	0															
Annual	199179	NA	0.009	NA	NA	NA	0.449	45.13	17.44	10.36	2.42	0.32	2.32	16.00	0.84	53.75

Table A-7. Volume weighted mean chemical concentrations for West Glacier outlet in 1988.

WEST GLACIER OUTLET 1988 SUMMARY - TOTAL

		KG					KEQ									
MONTH	**M^3**	**SiO2**	**P**	**AL**	**DIC**	**DOC**	**H+**	**CA**	**MG**	**NA**	**K**	**NH4.**	**CL**	**SO4**	**NO3**	**[ANC]**
May	61648	125.29	0.608	0.764	NA	NA	0.017	3.776	1.582	0.774	0.281	0.038	0.266	1.696	0.671	3.400
June	324207	441.01	2.473	12.272	NA	NA	0.173	13.134	5.254	2.807	0.880	0.090	0.984	6.345	2.464	10.877
July	246153	247.20	2.731	5.624	NA	NA	0.071	6.915	2.908	1.625	0.416	0.067	1.138	3.167	0.076	7.300
Aug	100076	95.05	1.469	0.495	NA	NA	0.025	2.636	1.067	0.585	0.207	0.050	0.158	1.374	0.028	3.092
Sept	41352	52.69	0.730	0.207	NA	NA	0.008	1.189	0.482	0.280	0.102	0.064	0.058	0.423	0.001	1.409
Oct	26671	36.66	0.516	0.392	NA	NA	0.006	0.895	0.362	0.195	0.066	0.031	0.042	0.245	0.015	1.084
Nov	2031	2.73	0.028	0.024	NA	NA	0.001	0.068	0.028	0.014	0.005	0.000	0.005	0.027	0.000	0.087
Annual	802137	1000.6	8.556	19.778	NA	NA	0.301	28.613	11.682	6.280	1.956	0.341	2.651	13.276	3.254	27.249

WEST GLACIER OUTLET 1988 SUMMARY - CONCENTRATION

		MG/L					UEQ/L									
MONTH	**M^3**	**SiO2**	**P**	**AL**	**DIC**	**DOC**	**H+**	**CA**	**MG**	**NA**	**K**	**NH4**	**CL**	**SO4**	**NO3**	**[ANC]**
May	61648	2.03	0.010	0.012	NA	NA	0.27	61.25	25.66	12.56	4.55	0.62	4.32	27.51	10.88	55.16
June	324207	1.36	0.008	0.038	NA	NA	0.53	40.51	16.21	8.66	2.71	0.28	3.03	19.57	7.60	33.55
July	246153	1.00	0.011	0.023	NA	NA	0.29	28.09	11.81	6.60	1.69	0.27	4.62	12.87	0.31	29.66
Aug	100076	0.95	0.015	0.005	NA	NA	0.25	26.34	10.66	5.85	2.07	0.50	1.58	13.73	0.28	30.90
Sept	41352	1.27	0.018	0.005	NA	NA	0.20	28.75	11.65	6.77	2.47	1.55	1.40	10.23	0.02	34.06
Oct	26671	1.37	0.019	0.015	NA	NA	0.24	33.56	13.56	7.32	2.49	1.17	1.58	9.18	0.56	40.66
Nov	2031	1.34	0.014	0.012	NA	NA	0.34	33.28	13.74	6.74	2.43	0.17	2.62	13.33	0.00	42.90
Annual	802137	1.25	0.011	0.025	NA	NA	0.37	35.67	14.56	7.83	2.44	0.42	3.31	16.55	4.06	33.97

Table A-8. Volume weighted mean chemical concentrations for West Glacier outlet in 1989.

WEST GLACIER OUTLET 1989 SUMMARY - TOTAL

		KG					KEQ									
MONTH	**FLOW M^3**	**SiO2**	**P**	**Al**	**DIC**	**DOC**	**H+**	**CA**	**MG**	**NA**	**K**	**NH4**	**CL**	**SO4**	**NO3**	**[ANC]**
May	129867	257.6	0.62	4.94	106.2	223.9	0.050	7.699	2.937	1.656	0.636	0.074	0.577	3.626	1.795	6.78
June	296583	398.3	1.44	14.21	153.7	402.3	0.124	13.043	4.951	2.781	1.294	0.107	0.979	5.725	1.410	12.14
July	226077	194.5	0.19	2.61	83.0	273.5	0.060	7.924	2.978	2.186	1.132	0.110	0.599	3.382	0.012	9.00
Aug	116552	46.2	0.73	4.90	34.8	78.9	0.039	3.902	1.364	1.282	0.584	0.094	0.356	1.536	0.000	4.16
Sept	60797	17.1	0.47	1.89	22.6	60.6	0.022	1.848	0.710	0.739	0.411	0.056	0.302	0.821	0.000	2.33
Oct	36281	14.2	0.00	0.00	17.8	52.1	0.010	1.181	0.532	0.385	0.160	0.066	0.118	0.511	0.000	1.60
Annual	866156	927.9	3.5	28.5	418.1	1091.3	0.305	35.597	13.472	9.029	4.218	0.507	2.931	15.602	3.218	36.01

WEST GLACIER OUTLET 1989 SUMMARY - CONCENTRATION

		MG/L					UEQ/L									
MONTH	**FLOW M^3**	**SiO2**	**P**	**Al**	**DIC**	**DOC**	**H+**	**CA**	**MG**	**NA**	**K**	**NH4**	**CL**	**SO4**	**NO3**	**[ANC]**
May	129867	1.98	0.005	0.038	0.82	1.72	0.384	59.29	22.62	12.75	4.89	0.57	4.44	27.92	13.82	52.20
June	296583	1.34	0.005	0.048	0.52	1.36	0.418	43.98	16.69	9.38	4.36	0.36	3.30	19.30	4.76	40.92
July	226077	0.86	0.001	0.012	0.37	1.21	0.267	35.05	13.17	9.67	5.01	0.49	2.65	14.96	0.05	39.83
Aug	116552	0.40	0.006	0.042	0.30	0.68	0.338	33.48	11.70	11.00	5.01	0.80	3.05	13.18	0.00	35.73
Sept	60797	0.28	0.008	0.031	0.37	1.00	0.361	30.39	11.67	12.15	6.77	0.93	4.97	13.51	0.00	38.31
Oct	36281	0.39	0.000	0.000	0.49	1.44	0.262	32.55	14.67	10.62	4.41	1.81	3.26	14.09	0.00	44.17
Annual	866156	1.07	0.004	0.033	0.48	1.26	0.352	41.10	15.55	10.42	4.87	0.58	3.38	18.01	3.71	41.58

Table A-9. Volume weighted mean chemical concentrations for West Glacier outlet in 1990.

WEST GLACIER OUTLET 1990 SUMMARY - TOTAL

	FLOW	KG					KEQ									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H+	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April	0															
May	28974	NA	0.24	NA	NA	NA	0.010	1.817	0.824	0.372	0.140	0.044	0.118	0.728	0.330	2.02
June	385128	NA	4.81	NA	NA	NA	0.297	15.600	6.897	3.700	1.584	0.425	1.386	8.617	5.711	14.09
July	349558	NA	5.19	NA	NA	NA	0.167	12.082	4.535	2.833	1.099	0.128	0.674	4.821	0.791	15.81
Aug	142216	NA	1.09	NA	NA	NA	0.054	4.044	1.676	0.961	0.290	0.042	0.207	1.798	0.000	4.98
Sept	90158	NA	1.30	NA	NA	NA	0.029	2.779	1.144	0.606	0.169	0.007	0.185	1.194	0.197	3.28
Oct	29273	36.2	0.53	6.12	NA	NA	0.007	1.066	0.342	0.210	0.061	0.005	0.096	0.380	0.178	1.13
Annual	1025307	NA	13.2	NA	NA	NA	0.564	37.388	15.419	8.682	3.341	0.651	2.665	17.537	7.207	41.32

WEST GLACIER OUTLET 1990 SUMMARY - CONCENTRATION

	FLOW	MG/L					UEQ/L									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H+	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April	0															
May	28974	NA	0.008	NA	NA	NA	0.351	62.72	28.43	12.83	4.83	1.50	4.09	25.12	11.39	69.66
June	385128	NA	0.012	NA	NA	NA	0.770	40.51	17.91	9.61	4.11	1.10	3.60	22.37	14.83	36.60
July	349558	NA	0.015	NA	NA	NA	0.479	34.57	12.97	8.10	3.14	0.37	1.93	13.79	2.26	45.23
Aug	142216	NA	0.008	NA	NA	NA	0.381	28.43	11.79	6.76	2.04	0.29	1.45	12.64	0.00	35.03
Sept	90158	NA	0.014	NA	NA	NA	0.323	30.82	12.69	6.72	1.87	0.08	2.05	13.24	2.19	36.41
Oct	29273	1.24	0.018	0.209	NA	NA	0.222	36.41	11.68	7.18	2.07	0.17	3.27	12.99	6.08	38.70
Annual	1025307	NA	0.013	NA	NA	NA	0.550	36.47	15.04	8.47	3.26	0.63	2.60	17.10	7.03	40.30

Table A-10. Volume weighted mean chemical concentrations for Cascade Creek in 1988.

CASCADE CREEK OUTPUT 1988 SUMMARY - TOTAL

	FLOW	KG					KEQ									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April																
May	8044	14.23	0.07	0.68	NA	NA	0.011	0.432	0.159	0.095	0.038	0.008	0.053	0.268	0.179	0.122
June	62849	65.48	0.47	2.21	NA	NA	0.126	1.735	0.617	0.460	0.114	0.058	0.200	1.340	0.919	0.253
July	53723	34.49	0.52	0.71	NA	NA	0.080	0.656	0.237	0.170	0.049	0.019	0.272	0.352	0.262	0.136
Aug	35540	23.26	0.22	1.35	4.62	56.87	0.040	0.369	0.127	0.080	0.015	0.013	0.018	0.206	0.110	0.175
Sept	14646	14.24	0.17	0.54	NA	NA	0.015	0.205	0.078	0.048	0.010	0.006	0.019	0.117	0.098	0.086
Oct	5844	7.76	0.13	0.09	NA	NA	0.006	0.116	0.043	0.025	0.008	0.003	0.007	0.066	0.075	0.026
Annual	180647	159.47	1.58	5.58	NA	NA	0.278	3.514	1.261	0.877	0.234	0.107	0.568	2.349	1.643	0.798

CASCADE CREEK OUTPUT 1988 SUMMARY - CONCENTRATION

	FLOW	MG/L					UEQ/L									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April																
May	8044	1.77	0.009	0.085	NA	NA	1.39	53.75	19.80	11.79	4.75	1.00	6.61	33.36	22.25	15.20
June	62849	1.04	0.007	0.035	NA	NA	2.00	27.61	9.82	7.31	1.81	0.92	3.17	21.32	14.62	4.02
July	53723	0.64	0.010	0.013	NA	NA	1.48	12.20	4.41	3.16	0.92	0.35	5.06	6.55	4.87	2.54
Aug	35540	0.65	0.006	0.038	0.13	1.60	1.13	10.39	3.57	2.26	0.41	0.37	0.50	5.81	3.10	4.92
Sept	14646	0.97	0.012	0.037	NA	NA	1.03	14.00	5.30	3.26	0.69	0.38	1.28	7.97	6.69	5.84
Oct	5844	1.33	0.021	0.015	NA	NA	1.01	19.90	7.36	4.28	1.45	0.54	1.20	11.38	12.77	4.53
Annual	180647	0.88	0.009	0.031	NA	NA	1.54	19.45	6.98	4.86	1.30	0.59	3.14	13.01	9.09	4.42

Table A-11. Volume weighted mean chemical concentrations for Cascade Creek in 1989.

CASCADE CREEK OUTPUT 1989 SUMMARY - TOTAL

	FLOW	KG					KEQ									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April	693	0.97	0.00	0.03	0.52	1.37	0.002	0.081	0.028	0.020	0.006	0.003	0.010	0.061	0.064	0.005
May	13203	20.49	0.05	0.54	4.50	23.41	0.032	0.869	0.287	0.179	0.057	0.021	0.097	0.595	0.561	0.107
June	43726	55.94	0.23	2.30	7.66	54.61	0.098	1.386	0.454	0.366	0.132	0.015	0.168	0.942	0.785	0.200
July	58054	46.18	0.25	2.83	3.78	49.38	0.086	0.820	0.286	0.372	0.197	0.027	0.105	0.508	0.435	0.309
Aug	36286	38.02	0.23	2.30	2.00	13.04	0.043	0.595	0.156	0.230	0.096	0.009	0.045	0.246	0.185	0.267
Sept	16431	12.77	NA	0.66	1.19	9.86	0.024	0.251	0.081	0.094	0.054	0.007	0.024	0.102	0.136	0.129
Oct	4647	3.84	NA	0.03	0.38	3.58	0.007	0.079	0.031	0.029	0.016	0.003	0.009	0.038	0.051	0.056
Annual	173038	178.20	NA	8.70	20.03	155.26	0.291	4.082	1.323	1.289	0.558	0.085	0.458	2.493	2.217	1.072

CASCADE CREEK OUTPUT 1989 SUMMARY - CONCENTRATION

	FLOW	MG/L					UEQ/L									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April	693	1.39	0.00	0.04	0.75	1.98	3.04	116.71	40.84	28.20	9.32	4.27	13.89	88.55	92.62	6.73
May	13203	1.55	0.00	0.04	0.34	1.77	2.43	65.83	21.77	13.59	4.31	1.59	7.33	45.10	42.51	8.11
June	43726	1.28	0.01	0.05	0.18	1.25	2.24	31.70	10.39	8.36	3.03	0.34	3.85	21.55	17.96	4.57
July	58054	0.80	0.00	0.05	0.07	0.85	1.48	14.12	4.93	6.41	3.39	0.47	1.81	8.76	7.50	5.32
Aug	36286	1.05	0.01	0.06	0.06	0.36	1.18	16.40	4.29	6.35	2.64	0.26	1.24	6.77	5.10	7.35
Sept	16431	0.78	NA	0.04	0.07	0.60	1.43	15.30	4.93	5.70	3.29	0.42	1.44	6.18	8.25	7.86
Oct	4647	0.83	NA	0.01	0.08	0.77	1.46	16.97	6.57	6.18	3.35	0.55	2.03	8.17	10.96	12.02
Annual	173038	1.03	NA	0.05	0.12	0.90	1.68	23.59	7.65	7.45	3.22	0.49	2.65	14.41	12.82	6.20

Table A-12. Volume weighted mean chemical concentrations for Cascade Creek in 1990.

CASCADE CREEK OUTPUT 1990 SUMMARY - TOTAL

	FLOW	KG					KEQ									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H+	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April	0															
May	5775	NA	0.04	NA	1.51	15.47	0.014	0.406	0.155	0.080	0.030	0.010	0.045	0.263	0.243	0.102
June	63939	NA	0.60	NA	NA	NA	0.140	2.197	0.819	0.500	0.158	0.030	0.243	1.557	1.346	0.437
July	65592	NA	0.87	NA	NA	NA	0.097	0.895	0.353	0.272	0.060	0.029	0.061	0.540	0.382	0.526
Aug	44659	NA	0.55	NA	NA	NA	0.072	0.511	0.204	0.118	0.008	0.017	0.039	0.317	0.171	0.243
Sept	28463	NA	0.44	NA	NA	NA	0.046	0.390	0.148	0.068	0.004	0.000	0.028	0.214	0.233	0.166
Oct	2112	2.72	0.04	0.48	NA	NA	0.003	0.042	0.014	0.007	0.000	0.001	0.003	0.020	0.026	0.014
Annual	210540	NA	2.55	NA	NA	NA	0.372	4.441	1.693	1.045	0.261	0.088	0.420	2.911	2.402	1.489

CASCADE CREEK OUTPUT 1990 SUMMARY - CONCENTRATION

	FLOW	MG/L					UEQ/L									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H+	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April	0															
May	5775	NA	0.01	NA	0.26	2.68	2.45	70.34	26.89	13.82	5.26	1.78	7.84	45.56	42.05	17.70
June	63939	NA	0.01	NA	NA	NA	2.18	34.36	12.81	7.81	2.47	0.47	3.80	24.35	21.05	6.83
July	65592	NA	0.01	NA	NA	NA	1.49	13.65	5.39	4.15	0.92	0.45	0.94	8.23	5.83	8.02
Aug	44659	NA	0.01	NA	NA	NA	1.60	11.44	4.57	2.64	0.18	0.38	0.88	7.09	3.83	5.45
Sept	28463	NA	0.02	NA	NA	NA	1.60	13.69	5.18	2.40	0.14	0.02	0.98	7.51	8.18	5.84
Oct	2112	1.29	0.02	0.23	NA	NA	1.49	19.98	6.53	3.26	0.08	0.55	1.49	9.68	12.48	6.60
Annual	210540	NA	0.01	NA	NA	NA	1.76	21.09	8.04	4.96	1.24	0.42	1.99	13.82	11.41	7.07

Table A-13. Volume weighted mean chemical concentrations for Meadow Creek in 1988.

MEADOW CREEK OUTPUT 1988 SUMMARY - TOTAL

	FLOW			KG								KEQ				
MONTH	**M^3**	**SiO2**	**P**	**Al**	**DIC**	**DOC**	**H**	**CA**	**MG**	**NA**	**K**	**NH4**	**CL**	**SO4**	**NO3**	**[ANC]**
April																
May	10845	13.92	0.08	0.68	NA	NA	0.015	0.568	0.211	0.129	0.058	0.007	0.079	0.353	0.229	0.232
June	53105	39.91	NA	2.21	NA	NA	0.101	1.424	0.525	0.324	0.115	0.017	0.144	0.920	0.523	0.460
July	39203	19.79	0.39	0.61	NA	NA	0.059	0.521	0.179	0.123	0.035	0.009	0.184	0.226	0.200	0.161
Aug	21148	14.87	0.18	0.83	NA	NA	0.027	0.255	0.087	0.055	0.018	0.007	0.020	0.146	0.128	0.106
Sept	8662	10.88	0.11	0.34	NA	NA	0.012	0.131	0.049	0.040	0.006	0.004	0.012	0.088	0.040	0.082
Oct	1817	2.99	0.03	0.04	NA	NA	0.002	0.042	0.016	0.013	0.003	0.001	0.003	0.023	0.014	0.028
Annual	134780	102.37	NA	4.71	NA	NA	0.216	2.941	1.065	0.684	0.236	0.045	0.442	1.755	1.134	1.069

MEADOW CREEK OUTPUT 1988 SUMMARY - CONCENTRATION

	FLOW			MG/L								UEQ/L				
MONTH	**M^3**	**SiO2**	**P**	**Al**	**DIC**	**DOC**	**H**	**CA**	**MG**	**NA**	**K**	**NH4**	**CL**	**SO4**	**NO3**	**[ANC]**
April																
May	10845	1.28	0.007	0.062	NA	NA	1.36	52.41	19.41	11.87	5.39	0.60	7.28	32.54	21.15	21.43
June	53105	0.75	NA	0.042	NA	NA	1.90	26.81	9.88	6.10	2.17	0.32	2.72	17.32	9.85	8.66
July	39203	0.50	0.010	0.016	NA	NA	1.51	13.28	4.55	3.13	0.90	0.23	4.70	5.76	5.10	4.10
Aug	21148	0.70	0.009	0.039	NA	NA	1.29	12.06	4.10	2.62	0.84	0.34	0.92	6.90	6.03	5.01
Sept	8662	1.26	0.012	0.039	NA	NA	1.34	15.15	5.68	4.61	0.73	0.43	1.34	10.14	4.58	9.45
Oct	1817	1.65	0.019	0.022	NA	NA	1.01	23.07	8.53	7.09	1.76	0.51	1.68	12.58	7.85	15.49
Annual	134780	0.76	NA	0.035	NA	NA	1.60	21.82	7.90	5.07	1.75	0.33	3.28	13.02	8.41	7.93

Table A-14. Volume weighted mean chemical concentrations for Meadow Creek in 1989.

MEADOW CREEK 1989 OUTPUT SUMMARY - TOTAL

	FLOW			KG								KEQ				
MONTH	**M^3**	**SiO2**	**P**	**Al**	**DIC**	**DOC**	**H**	**CA**	**MG**	**NA**	**K**	**NH4**	**CL**	**SO4**	**NO3**	**[ANC]**
April	1157	1.6	0.000	0.069	0.81	2.3	0.003	0.093	0.034	0.024	0.009	0.000	0.012	0.062	0.070	0.014
May	10548	14.1	0.058	0.513	6.85	20.8	0.025	0.561	0.190	0.131	0.049	0.009	0.067	0.366	0.297	0.161
June	33697	31.7	0.195	1.974	10.79	46.7	0.073	0.952	0.318	0.268	0.113	0.016	0.116	0.558	0.382	0.327
July	36996	22.8	0.089	0.167	5.38	85.4	0.062	0.533	0.180	0.234	0.156	0.020	0.061	0.301	0.274	0.231
Aug	21638	21.8	0.098	1.324	2.18	13.0	0.033	0.346	0.087	0.153	0.060	0.007	0.029	0.159	0.110	0.152
Sept	9239	10.5	0.077	0.236	0.82	7.6	0.014	0.133	0.042	0.071	0.030	0.004	0.015	0.077	0.045	0.086
Oct	2290	3.9		0.048	0.41	1.7	0.002	0.049	0.018	0.023	0.008	0.001	0.005	0.030	0.015	0.048
Total	115565	106.3	0.517	4.330	27.25	177.6	0.212	2.667	0.868	0.903	0.424	0.056	0.305	1.552	1.193	1.019

MEADOW CREEK 1989 OUTPUT SUMMARY - CONCENTRATION

	FLOW			MG/L								UEQ/L				
MONTH	**M^3**	**SiO2**	**P**	**Al**	**DIC**	**DOC**	**H**	**CA**	**MG**	**NA**	**K**	**NH4**	**CL**	**SO4**	**NO3**	**[ANC]**
April	1157	1.37	0.000	0.06	0.70	1.98	2.48	80.52	29.42	20.72	7.48	0.37	10.15	53.49	60.29	12.11
May	10548	1.34	0.005	0.05	0.65	1.98	2.36	53.17	18.01	12.43	4.65	0.85	6.34	34.69	28.19	15.29
June	33697	0.94	0.006	0.06	0.32	1.39	2.17	28.26	9.44	7.95	3.35	0.46	3.43	16.56	11.35	9.72
July	36996	0.62	0.002	0.00	0.15	2.31	1.67	14.40	4.85	6.31	4.22	0.53	1.66	8.13	7.41	6.24
Aug	21638	1.01	0.005	0.06	0.10	0.60	1.52	16.01	4.00	7.05	2.75	0.33	1.34	7.35	5.08	7.04
Sept	9239	1.13	0.008	0.03	0.09	0.82	1.53	14.39	4.60	7.69	3.23	0.38	1.62	8.28	4.84	9.26
Oct	2290	1.72	0.000	0.02	0.18	0.75	1.06	21.20	7.76	9.84	3.39	0.39	2.22	12.94	6.59	20.87
Annual	115565	0.92	0.005	0.04	0.24	1.54	1.83	23.08	7.51	7.81	3.67	0.49	2.64	13.43	10.33	8.82

Table A-15. Volume weighted mean chemical concentrations for Meadow Creek in 1990.

MEADOW CREEK OUTPUT 1990 SUMMARY - TOTAL

	FLOW	KG					KEQ									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April	0															
May	4252	NA	0.04	NA	2.51	8.05	0.010	0.265	0.092	0.052	0.022	0.005	0.028	0.151	0.146	0.075
June	45826	NA	0.42	NA	NA	NA	0.094	1.301	0.475	0.300	0.136	0.011	0.137	0.758	0.654	0.472
July	37083	NA	0.51	NA	NA	NA	0.064	0.430	0.200	0.164	0.041	0.002	0.037	0.285	0.210	0.265
Aug	16228	NA	0.16	NA	NA	NA	0.025	0.205	0.075	0.076	0.009	0.003	0.013	0.144	0.077	0.119
Sept	9531	NA	0.15	NA	NA	NA	0.014	0.150	0.055	0.051	0.003	0.001	0.017	0.095	0.051	0.123
Oct	848	1.78	0.02	0.19	NA	NA	0.001	0.016	0.006	0.007	0.001	0.000	0.003	0.011	0.005	0.018
Annual	113768	NA	1.30	NA	NA	NA	0.209	2.367	0.902	0.650	0.212	0.021	0.236	1.443	1.143	1.072

MEADOW CREEK OUTPUT 1990 SUMMARY - CONCENTRATION

	FLOW	MG/L					UEQ/L									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
April	0															
May	4252	NA	0.01	NA	0.59	1.89	2.47	62.28	21.57	12.30	5.16	1.09	6.55	35.50	34.23	17.68
June	45826	NA	0.01	NA	NA	NA	2.05	28.40	10.36	6.54	2.97	0.23	3.00	16.54	14.28	10.29
July	37083	NA	0.01	NA	NA	NA	1.73	11.59	5.39	4.42	1.11	0.06	1.01	7.69	5.65	7.14
Aug	16228	NA	0.01	NA	NA	NA	1.51	12.64	4.60	4.68	0.56	0.18	0.80	8.85	4.77	7.35
Sept	9531	NA	0.02	NA	NA	NA	1.50	15.74	5.79	5.35	0.34	0.08	1.83	9.96	5.34	12.95
Oct	848	2.10	0.02	0.22	NA	NA	1.31	18.50	6.61	8.00	0.79	0.55	3.44	12.99	6.39	21.00
Annual	113768	NA	0.01	NA	NA	NA	1.83	20.80	7.93	5.71	1.87	0.19	2.07	12.69	10.05	9.42

Table A-16. Three-year volume weighted mean concentrations by month.

	FLOW	MG/L					UEQ/L									
MONTH	M^3	SiO2	P	Al	DIC	DOC	H	CA	MG	NA	K	NH4	CL	SO4	NO3	[ANC]
EAST GLACIER OUTLET																
May	18115	1.37	0.003	0.024	0.82	2.79	0.33	59.66	21.28	12.57	3.01	0.68	2.19	20.11	1.83	65.48
June	136095	1.45	0.008	0.050	0.59	2.18	0.43	46.09	17.58	10.50	3.00	0.29	2.98	16.94	0.46	48.95
July	33960	1.60	0.008	0.022	0.49	1.95	0.32	39.25	15.65	10.46	2.80	0.32	3.37	14.42	0.50	46.48
Aug	3586	2.03	0.011	0.034	0.40	2.48	0.23	52.46	17.81	11.24	2.44	0.40	1.17	15.47	0.93	58.16
Sept	60	2.16	0.004	0.063	0.54	2.07	0.28	52.89	17.77	13.48	6.52	0.33	2.28	19.28	12.64	51.40
WEST GLACIER OUTLET																
April																
May	73496	2.00	0.007	0.030	0.82	1.72	0.35	60.29	24.23	12.71	4.79	0.70	4.36	27.44	12.68	55.32
June	335306	1.35	0.009	0.043	0.52	1.36	0.59	41.53	17.00	9.23	3.74	0.62	3.33	20.56	9.53	36.89
July	273929	0.94	0.010	0.017	0.37	1.21	0.36	32.76	12.68	8.08	3.22	0.37	2.93	13.84	1.07	39.08
Aug	119615	0.65	0.009	0.025	0.30	0.68	0.33	29.49	11.44	7.88	3.01	0.52	2.01	13.12	0.08	34.10
Sept	64102	0.68	0.013	0.020	0.37	1.00	0.31	30.24	12.15	8.45	3.55	0.66	2.83	12.68	1.03	36.51
Oct	30741	1.38	0.011	0.103	0.49	1.44	0.24	34.07	13.40	8.57	3.11	1.10	2.78	12.32	2.09	41.42
Nov	677	1.34	0.014	0.012			0.34	33.28	13.74	6.74	2.43	0.17	2.62	13.33	0.00	42.90
CASCADE CREEK																
April	231	1.39		0.043	0.75	1.98	3.04	116.71	40.84	28.20	9.32	4.27	13.89	88.55	92.62	6.73
May	9007	1.63	0.006	0.058	0.32	2.05	2.13	63.20	22.28	13.10	4.64	1.45	7.23	41.70	36.38	12.27
June	56838	1.14	0.008	0.042	0.18	1.25	2.13	31.19	11.09	7.77	2.37	0.60	3.58	22.51	17.89	5.21
July	59123	0.72	0.009	0.032	0.07	0.85	1.48	13.36	4.94	4.59	1.73	0.43	2.47	7.89	6.09	5.48
Aug	38828	0.85	0.009	0.051	0.18	0.97	1.33	12.67	4.18	3.68	1.02	0.34	0.88	6.60	4.00	5.88
Sept	19847	0.87	0.014	0.039	0.07	0.60	1.42	14.21	5.14	3.52	1.15	0.22	1.18	7.25	7.83	6.40
Oct	4201	1.14	0.021	0.048	0.08	0.77	1.25	18.83	6.93	4.81	1.92	0.54	1.55	9.91	12.06	7.64
MEADOW CREEK																
April	386	1.37		0.060	0.70	1.98	2.48	80.52	29.42	20.72	7.48	0.37	10.15	53.49	60.29	12.11
May	8548	1.31	0.012	0.056	0.63	1.95	1.95	54.36	19.19	12.18	5.05	0.78	6.77	33.92	26.22	18.29
June	44209	0.82	0.005	0.048	0.32	1.39	2.02	27.73	9.93	6.72	2.75	0.33	3.00	16.85	11.76	9.49
July	37761	0.56	0.009	0.010	0.15	2.31	1.64	13.09	4.93	4.59	2.05	0.27	2.50	7.17	6.04	5.79
Aug	19671	0.86	0.007	0.050	0.10	0.60	1.43	13.67	4.20	4.81	1.46	0.29	1.04	7.60	5.33	6.40
Sept	9144	1.19	0.012	0.032	0.09	0.82	1.46	15.10	5.36	5.90	1.44	0.29	1.60	9.45	4.93	10.60
Oct	1652	1.76	0.019	0.067	0.18	0.75	1.09	21.42	7.84	8.52	2.35	0.46	2.23	12.82	7.02	18.92

Table A-17. Input and output summaries for East Glacier catchment. H+ calculated from ANC.

	Snow Pit Input				NADP Input			
	Input	Output	Diff	Ratio	Input	Output	Diff	Ratio
	meq/m^2				meq/m^2			
EGO 1988								
H+	4.9	0.1	4.8	56.34	4.8	0.1	4.8	56.02
Ca	11.3	33.8	-22.4	0.34	11.2	33.8	-22.6	0.33
Mg	2.7	13.4	-10.7	0.20	2.6	13.4	-10.8	0.19
Na	2.9	7.8	-5.0	0.37	9.7	7.8	1.9	1.24
K	2.0	2.4	-0.4	0.84	0.5	2.4	-1.9	0.20
NH4	4.8	0.2	4.7	28.01	7.7	0.2	7.5	44.59
Cl	3.1	3.2	-0.1	0.96	4.5	3.2	1.3	1.40
SO4	11.7	12.5	-0.9	0.93	18.1	12.5	5.6	1.45
NO3	12.2	0.3	11.9	40.15	12.3	0.3	12.0	40.23
ANC	-3.3	34.0	-37.2	-0.10	-3.2	34.0	-37.2	-0.09
EGO 1989								
H+	3.8	0.1	3.7	62.44	3.8	0.1	3.7	62.09
Ca	8.8	27.8	-19.0	0.32	8.7	27.8	-19.1	0.31
Mg	2.1	9.8	-7.7	0.21	2.0	9.8	-7.8	0.21
Na	2.2	6.5	-4.2	0.35	7.5	6.5	1.1	1.17
K	1.6	1.9	-0.3	0.83	0.4	1.9	-1.5	0.20
NH4	3.8	0.3	3.5	14.00	6.0	0.3	5.7	22.29
Cl	2.4	1.1	1.3	2.24	3.5	1.1	2.4	3.28
SO4	9.1	10.0	-1.0	0.90	14.1	10.0	4.1	1.41
NO3	9.5	0.3	9.2	28.54	9.5	0.3	9.2	28.60
ANC	-2.5	29.6	-32.1	-0.09	-2.5	29.6	-32.1	-0.08
EGO 1990								
H+	4.2	0.1	4.1	59.96	4.2	0.1	4.1	59.63
Ca	9.8	31.4	-21.6	0.31	9.6	31.4	-21.7	0.31
Mg	2.3	12.1	-9.8	0.19	2.2	12.1	-9.9	0.18
Na	2.5	7.2	-4.7	0.34	8.3	7.2	1.1	1.16
K	1.7	1.7	0.0	1.02	0.4	1.7	-1.3	0.25
NH4	4.2	0.2	4.0	18.81	6.6	0.2	6.4	29.95
Cl	2.7	1.6	1.0	1.65	3.9	1.6	2.3	2.41
SO4	10.0	11.1	-1.1	0.90	15.6	11.1	4.5	1.40
NO3	10.5	0.6	10.0	18.08	10.6	0.6	10.0	18.12
ANC	-2.8	37.4	-40.2	-0.08	-2.8	37.4	-40.1	-0.07

Table A-18. Input and output summaries for West Glacier catchment. H+ calculated from ANC.

	Snow Pit Input				NADP Input			
	Input	Output	Diff	Ratio	Input	Output	Diff	Ratio
	meq/m^2				meq/m^2			
WGO 1988								
H+	9.5	0.3	9.2	36.10	9.4	0.3	9.2	35.89
Ca	22.0	59.0	-36.9	0.37	21.8	59.0	-37.2	0.37
Mg	5.2	24.1	-18.8	0.22	5.1	24.1	-19.0	0.21
Na	5.6	12.9	-7.4	0.43	18.9	12.9	5.9	1.46
K	3.9	4.0	-0.1	0.97	0.9	4.0	-3.1	0.23
NH4	9.4	0.7	8.7	13.58	15.0	0.7	14.3	21.62
Cl	6.0	5.5	0.5	1.10	8.8	5.5	3.3	1.60
SO4	22.7	27.4	-4.7	0.83	35.3	27.4	7.9	1.29
NO3	23.8	6.7	17.1	3.55	23.9	6.7	17.2	3.56
ANC	-6.3	56.2	-62.5	-0.11	-6.3	56.2	-62.4	-0.11
WGO 1989								
H+	7.4	0.5	6.9	14.07	7.4	0.5	6.9	13.99
Ca	17.3	58.7	-41.4	0.29	17.1	58.7	-41.6	0.29
Mg	4.1	22.2	-18.1	0.18	4.0	22.2	-18.2	0.18
Na	4.4	14.9	-10.5	0.29	14.8	14.9	-0.1	0.99
K	3.1	7.0	-3.9	0.44	0.7	7.0	-6.2	0.11
NH4	7.4	0.8	6.6	8.93	11.8	0.8	10.9	14.21
Cl	4.7	4.8	-0.1	0.98	6.9	4.8	2.1	1.42
SO4	17.8	25.7	-7.9	0.69	27.7	25.7	1.9	1.08
NO3	18.7	5.3	13.4	3.53	18.7	5.3	13.4	3.53
ANC	-5.0	59.4	-64.3	-0.08	-4.9	59.4	-64.3	-0.08
WGO 1990								
H+	7.2	0.2	7.0	31.89	7.2	0.2	7.0	31.72
Ca	16.8	61.7	-44.8	0.27	16.6	61.7	-45.0	0.27
Mg	4.0	25.4	-21.4	0.16	3.9	25.4	-21.6	0.15
Na	4.3	14.3	-10.1	0.30	14.4	14.3	0.1	1.00
K	3.0	5.5	-2.5	0.54	0.7	5.5	-4.8	0.13
NH4	7.2	1.1	6.1	6.70	11.4	1.1	10.4	10.67
Cl	4.6	4.4	0.2	1.04	6.7	4.4	2.3	1.52
SO4	17.3	28.9	-11.6	0.60	26.9	28.9	-2.0	0.93
NO3	18.2	11.9	6.3	1.53	18.2	11.9	6.3	1.53
ANC	-4.8	68.2	-73.0	-0.07	-4.8	68.2	-72.9	-0.07

Reuss, John O.; Vertucci, Frank A.; Musselman, Robert C.; Sommerfeld, Richard A. 1993. Biogeochemical fluxes in the Glacier Lakes catchments. Res. Pap. RM-314. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 27 p.

These lakes are moderately sensitive to acid deposition; acidification would require precipitation at least as acidic as that presently found in the more heavily impacted areas of eastern North America. Because most snowpack contaminants are released early in the melting process, seasonal acidification pulses would probably occur at much lower levels of acidic inputs.

Keywords: Acid precipitation, acid neutralizing capacity, sensitivity, snowmelt, acid pulse, GLEES

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Rocky Mountain Forest and Range Experiment Station

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