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SPATIAL AND TEMPORAL VARIATIONS OF BULK SNOW PROPERTIES IN AN ALPINE/SUBALPINE WATERSHED, ROCKY MOUNTAIN NATIONAL PARK

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ABSTRACT

Deposition of air pollutants to snowpacks is a concern to the health of aquatic and terrestrial ecosystems in Rocky Mountain National Park due to the possible acidic pulses of solutes during spring snowmelt. This study established spatial and temporal patterns and variations in snow chemical concentrations related to snow distribution and spring melt patterns in the high elevation alpine/subalpine Loch Vale watershed (LVWS), and sought to determine if the snow chemistry reflects the observed differences in stream chemistry between Icy Brook and Andrews Creek.

A snow survey conducted in 1996 sampled thirteen sites selected to represent the variability in slope, aspect, and elevation in the LVWS. Bulk snow chemistry samples and snow depth and snow water equivalence (SWE) measurements were taken during four sampling periods from April through June. The elution of ions from the snowpack did not follow the same pattern throughout the watershed. Snow depth, aspect, and location within the watershed accounts for some of the observed differences in stream chemistry.

INTRODUCTION

There is growing evidence that the LVWS, located in Rocky Mountain National Park, is leaking nitrogen into headwater streams (Baron and Campbell, 1997), (Figure 1). The concern is that increasing nitrogen deposition could increase the risk of acidification of stream waters during spring melt (Denning et al., 1991; Williams and Melack, 1991; Campbell et al., 1995) and cause sudden changes in stream and lake water quality (Johannessen and Henriksen, 1978). Previous studies in the LVWS indicate a difference in stream chemistry with Andrews Creek having a higher volume weighted mean concentration of nitrate (NO_3^-) than Icy Brook (Campbell et al., 1995; Baron and Campbell, 1997). What role snow chemistry contributes to the observed differences in stream chemistry was not known.

The questions addressed in this study were; 1) do the SWE distributions, chemical concentrations, and chemical loading follow the same trends or patterns for each sampling period from April to June?; 2) are the spatial and temporal variations greater between sample sites than within sample sites?; and 3) is the snow chemistry the same throughout the watershed, or does the snow chemistry reflect the observed differences in stream chemistry between Icy Brook and Andrews Creek?

Site description

The LVWS is located along the continental divide approximately 80 km northwest of Denver, Colorado (Figure 1). The 6.60 km^2 northeast facing glacial watershed ranges in elevation from 3050 m to 4026 m (Baron and Mast, 1991). The watershed can be divided into three natural subbasins: the Lower Loch, which is predominately sub-alpine forest; Sky Pond, which is an open U-shaped northeast facing cirque; and Andrews Creek, which runs east-west and is slightly V-shaped.

METHODS

Thirteen sampling sites, selected to represent the diverse spatial variability of slope, aspect, and elevation found in the LVWS, were sampled during the first and last sampling periods, April 9-10 and June 11-18, respectively. Each site was a 50 m by 50 m square with 25 m increments between sampling points. Due to physical constraints, the

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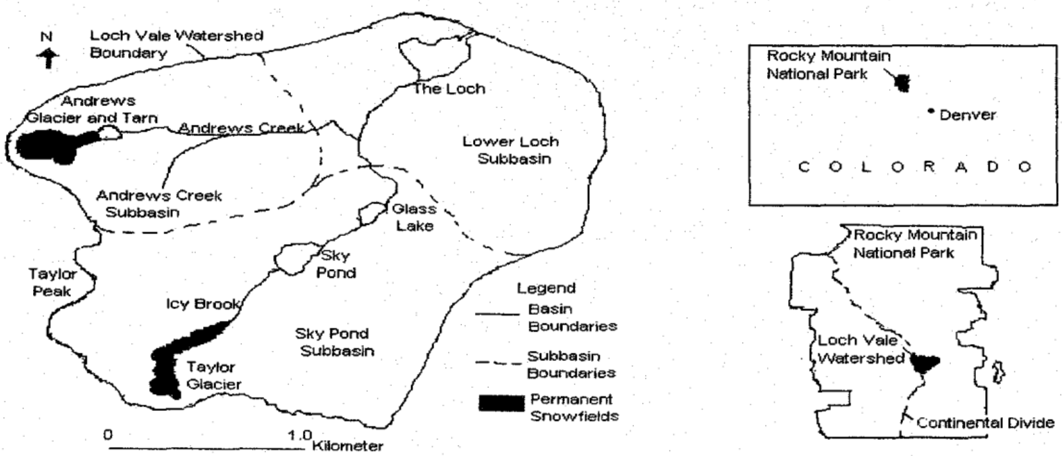

Figure 1: Location of the Loch Vale Watershed in Rocky Mountain National Park with Andrews Creek, Sky Pond, and the Lower Loch Subbasins (after Campbell et al., 1995).

middle two sampling periods, April 23-24 and May 21-22, had samples collected at four and six sites, respectively.

Nine snow depth measurements and three SWE measurements taken were at each site using a depth probe and federal sampler, respectively, except for one site during the April 9-10 sampling period when only one depth and density measurement was taken due to physical constraints. An average snow density was calculated from the federal sampler measurements and used to determine SWE for the additional six snow depth measurements at each site. A total of 110 snow density data values and 316 snow depth and SWE values were used for the entire project.

At least one bulk snow chemistry sample was collected at every site surveyed using the federal sampler that had been triple rinsed with snow to reduce contamination while sampling. The snow chemistry samples were analyzed using standard U.S. Geological Survey laboratory procedures and methods (Fishermann et al., 1997). A total of 55 snow chemistry samples were taken from all sampling sites for the entire project.

RESULTS AND DISCUSSION

Snow depth, density, and SWE

Descriptive statistics for depth, SWE, and density from the April 9 to June 18, 1996 sampling periods are shown in Table 1. ANOVA statistical analyses found statistically significant differences for snow depth and SWE between the three sites in Andrews Creek subbasin and the rest of the watershed for the April 9-10 sampling period ($F = 12.5$ $p = 0.0001$, and $F = 9.89$, $p = 0.0001$, respectively). The June 11-18 sampling period showed similar results for snow depth and SWE. Statistically significant differences were also found for snow depth and SWE between the Andrews Creek subbasin and the Sky Pond, $F = 47.68$, $p = 0.0001$, and the Lower Loch subbasins, $F = 49.21$, $p = 0.0001$, for all sampling periods.

Time series of snow depth and SWE for each site over the April 9-10, April 23-24, May 21-22, and June 11-18 sampling periods showed an overall decrease in snow depth and SWE at all sites. Snow density increased throughout the same time period. ANOVA statistics showed less difference within a site than between sites.

Snow chemistry

Descriptive statistics for pH, hydronium ion (H^+), calcium (Ca^{+2}), ammonium (NH_4^+), sulfate (SO_4^{-2}), and nitrate (NO_3^-) from the April 9-10 and June 11-18, 1996 sampling periods are in Table 1. Chemical concentrations overall reflected a decreasing trend. The snow chemistry on a concentration basis varied and was statistically different at some sites for SO_4^{-2} concentrations during the first-three sampling periods; for Ca^{+2} concentrations at five out of six sites during May; and for NO_3^- concentrations at two sites during the June sampling period (Figure 2). Isolated snow storms throughout the study accounted for the increase of SO_4^{-2} and NO_3^- at some of the sites. Statistical tests run on chemical load and mass for the April 9-10 sampling period resulted in statistically significant differences for H^+, Ca^{+2}, NH_4^+, NO_3^-, and SO_4^{-2} between Andrews Creek subbasin and the other subbasins.

Difference in stream chemistry and ion elution between subbasins

In the LVWS, the effects of hydrologic flowpaths and differences in soils on stream NO_3^- are fairly well accepted as being the major determinants of stream chemistry (Denning et al., 1991; Campbell et al., 1995). Though clearly a component, snow chemistry in the LVWS is not the only, or the major determinant of stream chemistry. The observed difference in stream chemistry between Icy Brook and Andrews Creek related to snow chemistry found in this study was the large difference in snow depths and subsequent SWE between the different subbasins. On April 9-10, Andrews Creek subbasin had 46% and 40% more snow than Sky Pond or the Lower Loch, respectively, resulting in a longer snowmelt than the other subbasins. On April 9-10, Andrews Creek subbasin had 595 kg SO_4^{-2} and 1033 kg NO_3^- compared to 275 kg and 455 kg, respectively, for Sky Pond. Andrews Creek subbasin's snowpack still contained on a mass basis 71% more NO_3^- and 59% more SO_4^{-2} in June than the Sky Pond subbasin snowpack. The greater loading of SO_4^{-2} and NO_3^- in deposition in the Andrews Creek subbasin may influence the stream chemistry and does reflect the higher NO_3^- levels noted in Andrews Creek compared to Icy Brook 21 μeq/L and 18 μeq/L, respectively, for NO_3^-, and 23 μeq/L and 32 μeq/L, respectively, for SO_4^{-2}. Additionally, the heterogeneous snow distribution, which is largely affected by topography, wind redistribution, solar radiation, and surface roughness in alpine basins (Elder et al., 1991), influences snowmelt and was evident in the slower melting and subsequent release of ions at all of the north-facing sites regardless of subbasin.

CONCLUSIONS

The major points determined by this research project were; 1) the snow chemistry on a chemical load and mass basis was different throughout the LVWS during the winter of 1996; 2) there was more variability between sampling sites than within a site; 3) there was a subbasin difference in snow depth, SWE and chemical loading and mass; 4) the location, aspect, and snow depth influence snowmelt and the subsequent elution of solutes. North-facing sites melted slower and retained larger amounts of chemical mass regardless to subbasin; and 5) the greater depositional loading of NO_3^- in Andrews Creek subbasin's snowpack could account for some the observed higher concentrations of NO_3^- in Andrews Creek than Icy Brook.

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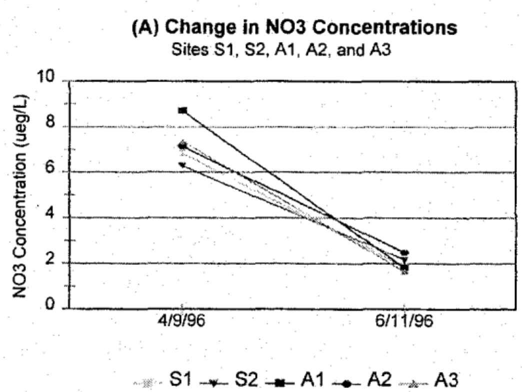
Table 1: Descriptive statistics for all sampling sites during the April 9-10 and June 11-18, 1996 sampling periods.

April Variables	N	Mean		June Variables	N	Mean
Depth (m)	109	2.86		Depth (m)	87	2.03
Density (kg/m^3)	39	421		Density (kg/m^3)	35	540
SWE (m)	109	1.22		SWE (m)	87	1.08
pH	21	5.46		pH	16	6.00
H (ueq/L)	21	3.6		H (ueq/L)	16	1.2
Ca (ueq/L)	21	7.0		Ca (ueq/L)	16	4.3
NH_4 (ueq/L)	21	4.4		NH_4 (ueq/L)	16	3.2
SO_4 (ueq/L)	21	5.8		SO_4 (ueq/L)	16	2.3
NO_3 (ueq/L)	21	7.4		NO_3 (ueq/L)	16	2.9



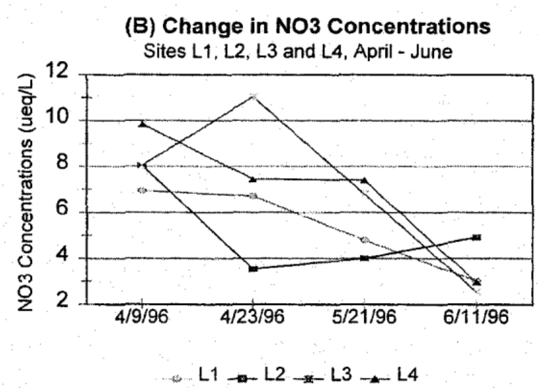


Figure 2: (A) Comparison of changes in NO_3 concentrations in the bulk snow chemistry samples for sites A1, A2, and A3 in the Andrews Creek subbasin, S1 and S2 in the Sky Pond subbasin, and (B) L1, L2, L3 and L4 in the Lower Loch subbasin during the April 9 to June 18 sampling periods. The Andrews Creek sites were only sampled twice due to physical constraints on the project. Sites L5-L8 are not shown, but had similar results to L1-L4.