ANNUAL HYDROCHEMICAL FLUXES FROM ALPINE-SUBALPINE CATCHMENTS IN THE SNOWY RANGE, WYOMING

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ABSTRACT

Annual hydrochemical fluxes were calculated from 1989 to 2004 for two alpine-subalpine catchments, West and East Glacier Lake Outlets in the Snowy Range, Wyoming. Mean annual atmospheric deposition inputs within Glacier Lake Ecosystem Experiments Sites (GLEES) were 3.50 kg ha^{-1} yr^{-1} and 2.27 kg ha^{-1} yr^{-1} for inorganic nitrogen (NO_3-N, HNO_3-N and NH_4-N) and sulfur (S), respectively. Dry deposition, as measured by CASTNET, accounts for less than 20% of total deposition for inorganic N and S. Lakes at GLEES are oligotrophic with a water quality specific conductance range of 5-15μS cm^{-1}. During the 1989 sampling period at West Glacier Lake, cations were in decreasing order of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, NH_4-N and anion were in decreasing order of Cl^{-}, SO_4-S, and NO_3-N. Chloride inputs were approximately equal to outputs suggesting proper accounting of precipitation and streamflow volumes. Hydrochemical outputs for major cations were greater than inputs and differences attributed to parent material and soil weathering. Inorganic N inputs are greater than outputs for annual hydrochemical fluxes from 1989-2004 suggest that GLEES catchments are accumulating N.

INTRODUCTION

Effects of anthropogenic inputs to ecosystems can be assessed using a mass balance approach for hydrochemical fluxes (Likens and Bormann, 1995). Hydrochemical fluxes quantify alteration of alpine-subalpine ecosystems to changes in atmospheric deposition inputs and streamflow chemistry outputs. For example, regional analyses have shown an increase of atmospheric deposition along the Central Rocky Mountains which has lead to nitrogen saturation within the alpine-subalpine long-term study sites of Niwot Ridge, Green Lake Valley, CO and Loch Vale, CO (Williams and Tonnessen, 2000; Burns, 2004). Long-term hydrochemistry data for alpine-subalpine catchments in Wyoming are limited and further study will allow the elucidation of hydrochemical changes. From 1989-2004 the objectives of this study were to 1) calculate chemical inputs from National Atmospheric Deposition Program (NADP) and Clean Air Status and Trends Network (CASTNET) and 2) calculate annual hydrochemical outputs from streamflow from West Glacier (WGO) and East Glacier Lakes Outlets (EGO) within Glacier Lake Ecosystem Experiments Sites (GLEES) and 3) calculate annual hydrochemical fluxes (inputs minus outputs).

STUDY SITE

GLEES is a long-term study site managed by the USDA Forest Service which monitors hydrology, meteorology, water chemistry, snow chemistry, wet and dry deposition, and snow cover in an alpine-subalpine area in the Snowy Range, WY approximately 55 km west of Laramie, WY (see Hultstrand et al., 2006 for a site map) (Musselman, 1994). GLEES mean annual precipitation is 120 cm approximately 75-85% falling as snow (Hultstrand et al., 2006). Streamflow has been measured at WGO and EGO since 1987 using Parshall flumes. The adjacent catchments are 28.7 ha and 60.7 ha, respectively, with a mean elevation of 3300 m. WGO catchment contains a permanent snowfield that feeds two streams, Cascade and Meadow Creeks, while EGO has no perennial flow. GLEES has a core Precambrian rock crossed with mafic intrusions and soils are minimally developed (Musselman, 1994).

METHODS

Wet (NADP) and dry atmospheric deposition (CASTNET) have been collected since 1986 and 1989, respectively (Musselman, 1994). Inputs were calculated weekly as the sum of wet and dry deposition using volume-weighted concentrations and weekly precipitation from NADP and fluxes from CASTNET. Streamflow

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chemistry including Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, NH_4^{+}, Cl^{-}, SO_4^{2-}, and NO_3^{-} have been measured since 1987. Acid neutralizing capacity, along with HCO_3^{-} has been measured in streamflow samples but is not a parameter in the NADP site and is not included in this presentation. Water quality sampling is conducted from the onset of snowmelt and into the summer months as there is no baseflow during the winter months. Sample frequency varied over the 16 year study period due site accessibility and varying budgets. Streamflow water chemistry samples were analyzed at the Rocky Mountain Research Station Biogeochemistry Lab in Fort Collins, CO using consistent laboratory protocols. A mass balance approach, inputs minus outputs, was used to determine hydrochemical fluxes.

RESULTS AND DISCUSSION

Inputs

From 1989-2004, annual mean inorganic nitrogen (N) and sulfur (S) inputs were 3.50 kg ha^{-1} yr^{-1} and 2.27 kg ha^{-1} yr^{-1}, respectively at GLEES. Dry deposition ranged from 0.5-1.0 kg N ha^{-1} yr^{-1} and 0.2-0.4 kg S ha^{-1} yr^{-1} and contributed 19% of total atmospheric N and 12% of atmospheric S. Central Rocky Mountain NADP inorganic N inputs for Niwot Ridge and Loch Vale averaged 6.69 and 3.04 kg ha^{-1} yr^{-1}, respectively (Table 1). In comparison, Loch Vale and GLEES have similar inorganic N inputs whereas Niwot Ridge had 52% higher inorganic N concentrations than GLEES. A 30-fold increase of inorganic N inputs from 1980's to pre-industrial levels was measured at Niwot Ridge (Williams and Tonnessen, 2000) and elevated N emission adjacent to Loch Vale was measured (Sullivan et al., 2005). Corresponding to the regional increased inorganic N inputs, Loch Vale and Niwot Ridge have shifted the ecosystem from N-limited to N-saturated (Williams and Tonnessen, 2000). S inputs to GLEES were approximately twice Loch Vale but 62% less than Niwot Ridge (Table 1). Though S has not been considered a limiting nutrient in other alpine-subalpine watershed, atmospheric S inputs can affect terrestrial and aquatic ecosystems (Likens and Bormann, 1995).

Table 1. Volume weighted mean inputs for 16 year (1989-2004) from NADP (kg ha^{-1} yr^{-1})

Catchment	GLEES, WY	Loch Vale, CO	Niwot Ridge, CO
Inorganic nitrogen (N)	3.50	3.04	6.69
Sulfur (S)	2.27	1.02	3.58

Outputs

Streamflow chemistry from WGO and EGO is slightly acidic (pH 6.5-6.7) and relatively dilute (specific conductance range is 5-15μS cm^{-1}) representing oligotrophic waters. Changes in constituent concentrations over time suggest preferential elution during snowmelt. Results are similar to an earlier study conducted by the USDA Forest Service (Reuss et al., 1995). Ca^{2+} concentrations decreased with discharge, while other cation concentrations remained low over the sampling period (Figure 1a), and both NO_3^{-} and SO_4^{2-} concentrations decreased with discharge (Figure 1b).

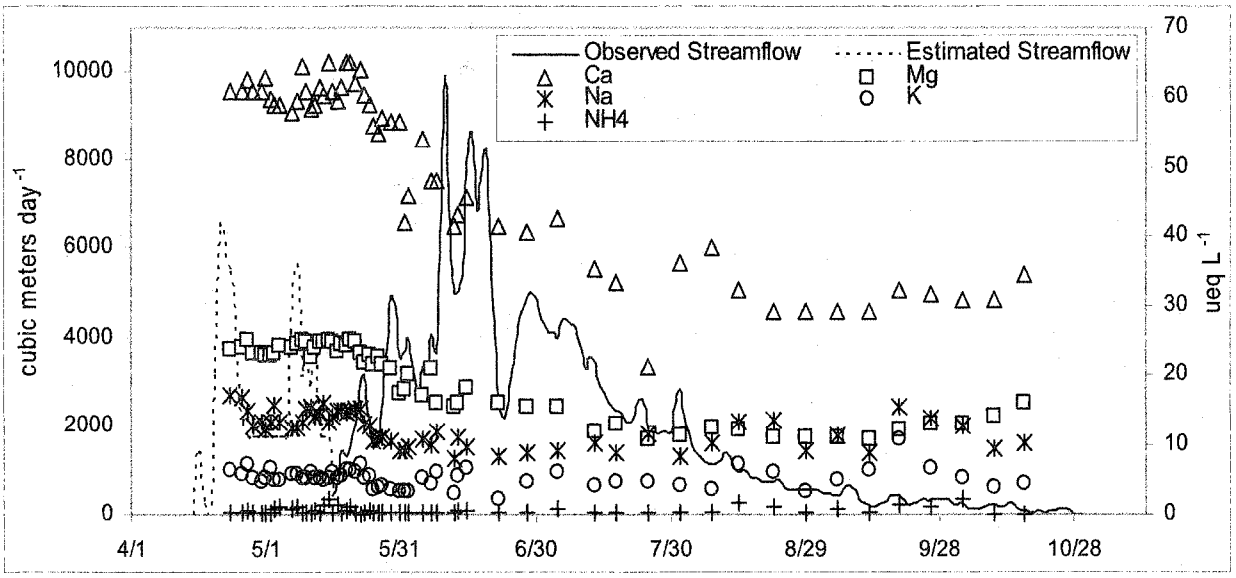

Figure 1a. WGO 1989 cation concentrations and daily stream flow overtime

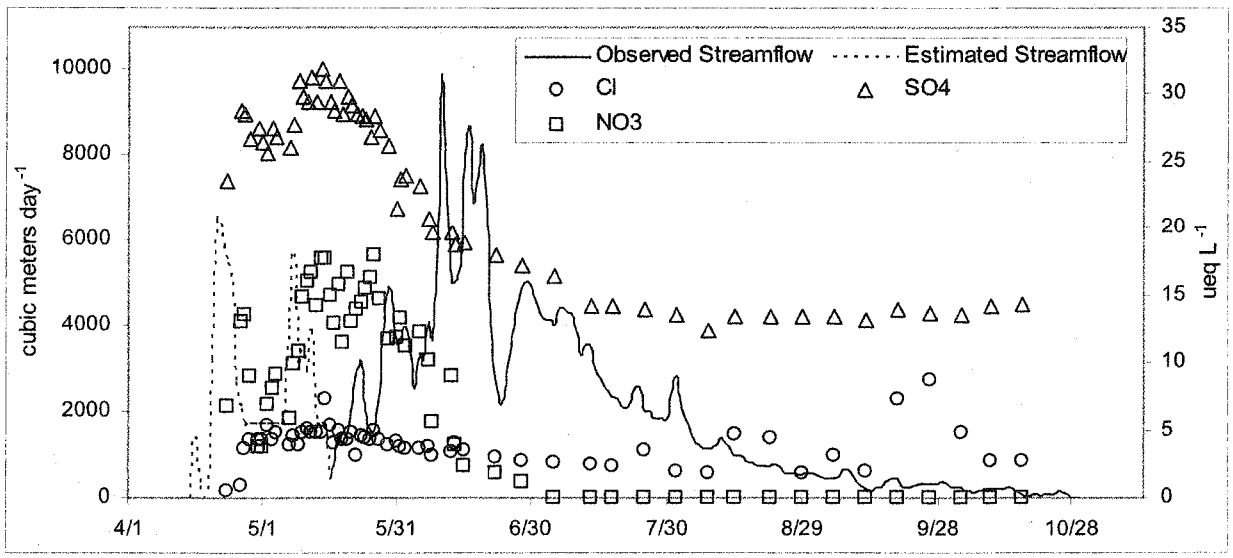

Figure 1b. WGO 1989 anion concentrations and daily streamflow overtime

Cation concentrations decreased in order of Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, and NH_4-N (Figure 1a). Anions in decreasing order were SO_4-S, NO_3-N, and Cl^{-} with concentrations of 7.6, 3.7 and 1.8μeq L^{-1} for WGO during the 1989 sampling period, respectively (Figure 1b). HCO_3^{-} is the dominate anion in streamflow (mean 43 μeq L^{-1}) with decreasing anion concentrations as SO_4-S, NO_3-N, and Cl^{-}. WGO outputs have a higher concentration then EGO for all constituents with the greatest differences noted for Ca^{2+}, SO_4-S, and inorganic N (Table 2).

Hydrochemical Fluxes

Hydrochemical fluxes were calculated as inputs minus outputs. The output of major cations was similar to Loch Vale (Sullivan et al., 2005). Ca^{2+} fluxes were approximately 3 to 5 times larger than Mg^{2+}, Na^{+}, and K^{+}. Cations may be controlled by the relative weathering rates of soil and bedrock material (Finley and Drever, 1997). Wind velocities vary considerably and significant differences in Ca^{2+} within the snowpack suggest eolian transport (Rohrbough et al., 2003). Major differences in hydrochemical fluxes between WGO and EGO are qualified by lithologies; however, wind blown material accumulates in a permanent snowfield in the WGO catchment acting as a reservoir for eolian material.

S outputs for WGO differ only slightly (0.1 kg ha^{-1} yr^{-1}) from inputs and EGO outputs differ more (0.7 kg ha^{-1} yr^{-1}) from inputs. Variability of SO_4^{2-} and NO_3^{-} concentrations within the snowpack has shown no significant differences within the GLEES catchments (Rohrbough et al., 2003). Hydrochemical fluxes from WGO and EGO differ suggesting additional undetermined processes within the catchments.

Inorganic N fluxes in the streamflow chemistry were less than the inputs from NADP and CASTNET (Table 2) with 3.7 and 2.8 kg ha^{-1} yr^{-1} mass balance for WGO and EGO, respectively. Net accumulation of inorganic N within GLEES differs from observations along the Colorado Front Range where inorganic N inputs approximate outputs leading to N-saturation within Niwot Ridge and Loch Vale, CO (Williams and Tonnessen, 2000; Burns, 2004). GLEES catchments inputs were slightly greater than Loch Vale, yet hydrochemical fluxes indicate that GLEES catchments are currently N-limited, inputs are greater than outputs.

Chloride inputs are approximately equal to the chloride outputs suggesting a proper accounting of both precipitation and streamflow volumes (Table 2). Differences in WGO and EGO fluxes over the period of record will be furthered investigated.

Table 2. Volume weighted mean hydrochemical fluxes over 16 year (1989-2004) (kg ha^{-1} yr^{-1})

Source		Ca	Mg	Na	K	NH_4-N	Cl	SO_4-S	NO_3-N	Inorg N
NADP + CASTNET	*Inputs*	2.5	0.3	1.0	0.2	1.3	1.1	2.3	2.2	4.2 *
WGO	*Outputs*	8.1	2.1	1.9	1.2	0.2	1.0	2.2	1.2	1.4†
	Flux	-5.6	-1.8	-0.9	-1.0	1.1	0.1	0.1	1.0	2.8
EGO	*Outputs*	6.0	1.5	1.6	0.8	0.1	0.8	1.6	0.4	0.5†
	Flux	-3.5	-1.2	-0.6	-0.6	1.2	0.3	0.7	1.8	3.7

* Input inorganic N= (NH_4-N+NO_3-N+HNO_3-N)

† Output inorganic N= (NH_4-N+NO_3-N)

CONCLUSIONS

Two alpine-subalpine catchments were characterized by hydrochemical fluxes from 1989-2004. Mean annual inorganic N and S inputs were 3.50 kg ha^{-1} yr^{-1} and 2.27 kg ha^{-1} yr^{-1} respectively. Atmospheric inputs in alpine-subalpine catchments primarily occur through wet deposition, with dry deposition of S and inorganic N only 12 and 19%, respectively, of the total inputs. Chemical concentrations outputs represent an oligotrophic ecosystem and show a preferential elution with snowmelt. Cations in decreasing order of concentration were Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, and NH_4- for WGO during the 1989 sampling period. Anions in decreasing order were HCO_3^{-}, SO_4-S, NO_3-N, and Cl^{-}. Hydrochemical fluxes suggest parent material and soil weathering as a source for major cations. The use of chloride as a conservative ion indicates confidence within the mass-balance analysis. Anion outputs of inorganic N and S were likely contributed by atmospheric sources, and net accumulation of inorganic N was noted within the GLEES catchments.

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