NUTRIENT RELATIONSHIPS IN TWO SMALL WEST VIRGINIA WATERSHEDS

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Abstract.--Precipitation inputs and hydrologic outputs of nutrients on two small watersheds in north-central West Virginia were studied for a one-year period. The contrasting watersheds had differing aspects, species compositions and biomass productivities.

The cations H, Ca, Mg, K, and Na were measured in both precipitation and stream water samples. The concentrations of these elements in precipitation samples varied sporadically with no apparent seasonal trends. Stream samples, however, showed seasonal trends for most elements. Calcium was more concentrated during the July low flow period, whereas other elements were less concentrated at this time.

Comparing the two watersheds revealed a higher output of all elements except hydrogen ion from the more productive site on the north-facing slope.

Keywords: Nutrient cycling, forest hydrology, Appalachian hardwoods.

INTRODUCTION

Nutrient cycling and biological and climatic conditions combine in the forest ecosystem to influence the vegetative growth which, in turn, affects the environment. At the West Virginia University Forest projects are underway to study various aspects of a forest ecosystem. The present study is designed to examine some of the nutrient and hydrologic characteristics of the system, including mineral export in streams and mineral content of soil water. This can be a crucial area of nutrient cycling because valuable nutrients, which may be in short supply, are lost to the system. Under certain conditions, leaching and stream loss of nutrients may exceed inputs from precipitation, weathering and vegetative decay. Various factors may influence loss of nutrients. These include slope, biomass, vegetative type, and soil type and depth, and the impact of forest harvesting practices may vary considerably, depending on these factors.

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This study has four objectives:

1) To sample dissolved minerals in streams of two watersheds.
2) To quantify the relationship between mineral export by the streams and the mineral content of the soil.
3) To sample soil water to determine if any differences in nutrient availability exist between watersheds.
4) To initiate development of a nutrient budget for Little Laurel Run watershed.

Study Area

The upper watershed of Little Laurel Run is located in the West Virginia University Forest which is part of Coopers Rock State Forest in Preston and Monongalia Counties, West Virginia. The watershed, containing 269 hectares, lies between latitudes 39°40' 30" N and 39°41' 30" N and longitudes 79°44' 47.1" W and 79°46'30" W. The elevation of the watershed varies from its lowest point of 561 meters above sea level, where Little Laurel Run and Little Laurel Creek converge, to 792 meters at the Sand Springs Fire Tower, see (Figure 1) (U.S. Geological Survey, 1960a and 1960b).

The climate of the area is temperate continental - warm summer (Trewartha, 1968). The average annual precipitation is 145 cm. The frost free season is approximately 139 days. Mean annual air temperature is 9.7° C, with the coolest month being February (-1.7° C) and the warmest month being August (20.2° C) (Lee and Hill 1975).

Soils on the watershed are described by the USDA Soil Conservation Service as Dekalb and Ernest. The Ernest series is an alluvial soil found mostly along the stream areas and is a moderately well-drained, stony slit loam. The DeKalb series covers the remainder of the watershed, along the mid- and upper slopes. They are generally shallow to moderately deep, well-drained soils of acid sandstone origin (Frank, 1981).

A 50-year old forest of Appalachian hardwoods covers the watershed. Cove hardwoods, predominatly yellow poplar, black cherry and northern red oak, constitute approximately 38% of the forest. The average oak site index is 24.7 meters. The remainder of the forest is upland oaks (northern red oak, scarlet oak, chestnut oak, black oak and white oak) with an average oak site index of 21.0 meters (Knight, 1980).

Two small watersheds containing perennial tributaries of the larger Little Laurel Run were chosen for this study. Watersheds with differing soil characteristics, especially in nutrient concentrations and soil properties (Frank 1981), were used in order to determine whether a correlation exists between soil nutrient status and stream output of nutrients.

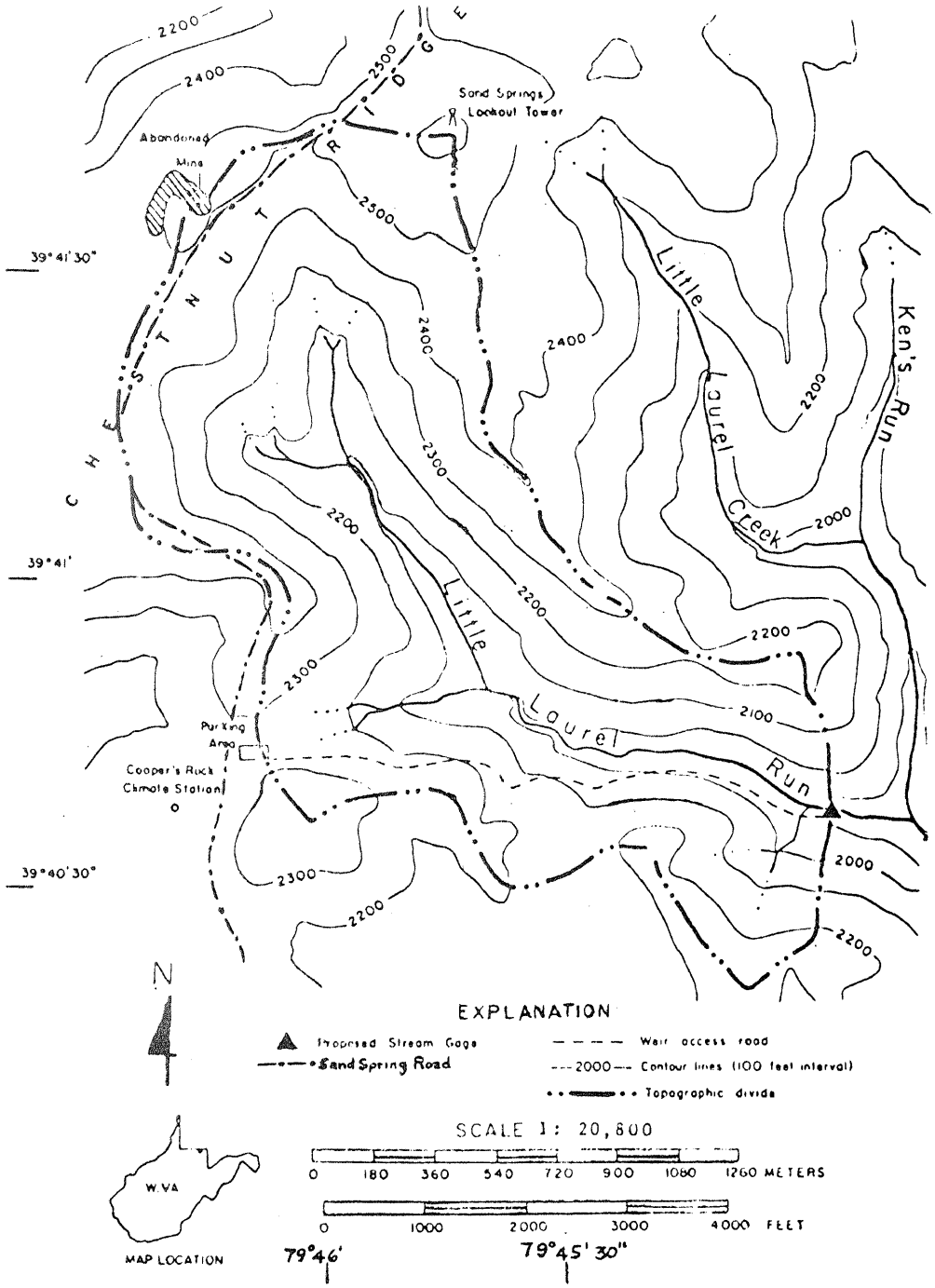

Figure 1.--Location of Little Laurel Run Watershed (U.S. Geological Survey, 1960a and 1960b).

Watershed I, which is 18.9 hectares, has northeast and southeast aspects. As seen in figure 2, yellow poplar and red maple have high importance values. The average slope is 17.5%, with a range of 12%-33% (Frank, 1981). The average biomass is 6,916 kg/ha. Watershed II is larger, 39.8 hectares. Aspects face southeast and southwest, with oak species being more dominant, Figure 2. The average slope is slightly greater at 18.8%, with a range of 2%-38% (Frank, 1981). The average biomass is much less - 5,300 kg/ha.

PROCEDURE

Field

Lysimeter (soil water) samples were taken weekly along with corresponding stream samples taken 1.5 m above the mouth of each watershed figure 3. The lysimeters were 1 m-long plastic tubes, 5 cm in diameter, and equipped with a porous ceramic cup at the bottom. Tubes were placed under vacuum after each sample removal. There were two separate periods of sampling: spring (May 22 through June 18) and summer (July 23 through September 10). Seasonal considerations were the basis for the sampling periods, as reported in other studies. At the Hubbard Brook Forest in New Hampshire it was found that ion concentrations in stream water are lower in summer, due to biologic utilization of nutrients during the growing season. Only 11% of the annual output of dissolved substances in stream water occurred in summer, compared to more than 55% in spring. Additionally, it was found that calcium and magnesium concentrations varied within a very narrow range although stream discharge fluctuates widely. Hydrogen and potassium were found to increase with increased discharge. Sodium was diluted during high stream flow (Likens et al., 1977). At Coweeta Hydrologic Laboratory a similar study had differing results. Calcium, sodium, potassium and magnesium showed definite seasonal trends: they peak in July, August or September and reach a minimum in winter. Also, these nutrients were poorly correlated with discharge. Losses were greatest in early spring and summer when biologic functions were active and streamflow was high; in winter when biologic activity was low and streamflow was high, losses were lower (Johnson and Swank, 1973).

Six lysimeter tubes were placed on each of the two small watersheds (Figure 3). Lysimeter sampling points were chosen using the following criteria:

1) The tube could be sunk to a depth of at least 24" and not exceeding 36", well below the major rooting zone of vegetation.
2) There was no vegetation (shrubs, trees) in the immediate area (within a four foot minimum radius).
3) The area was not a seasonal or storm related runoff point, in order that water collected will have had sufficient time

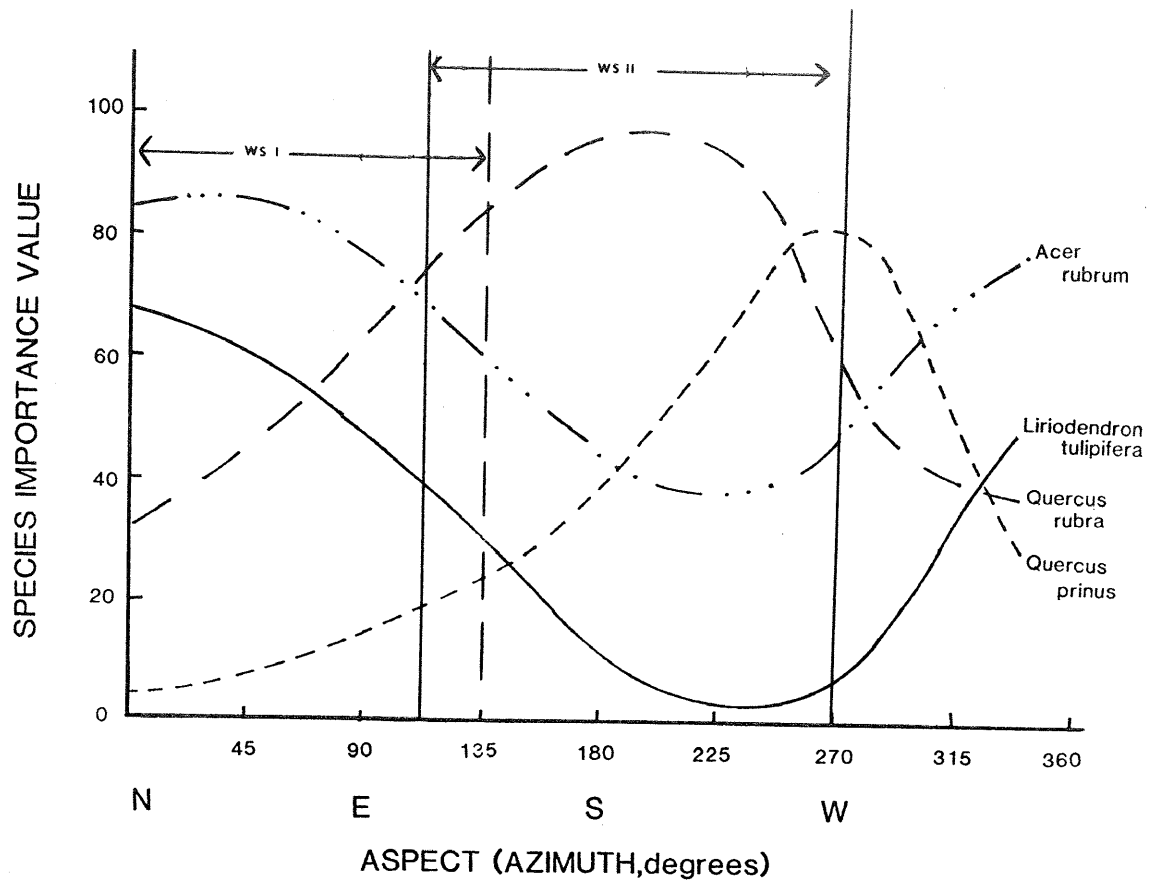

Figure 2.--Species importance values and primary aspects of the two small sample watersheds.

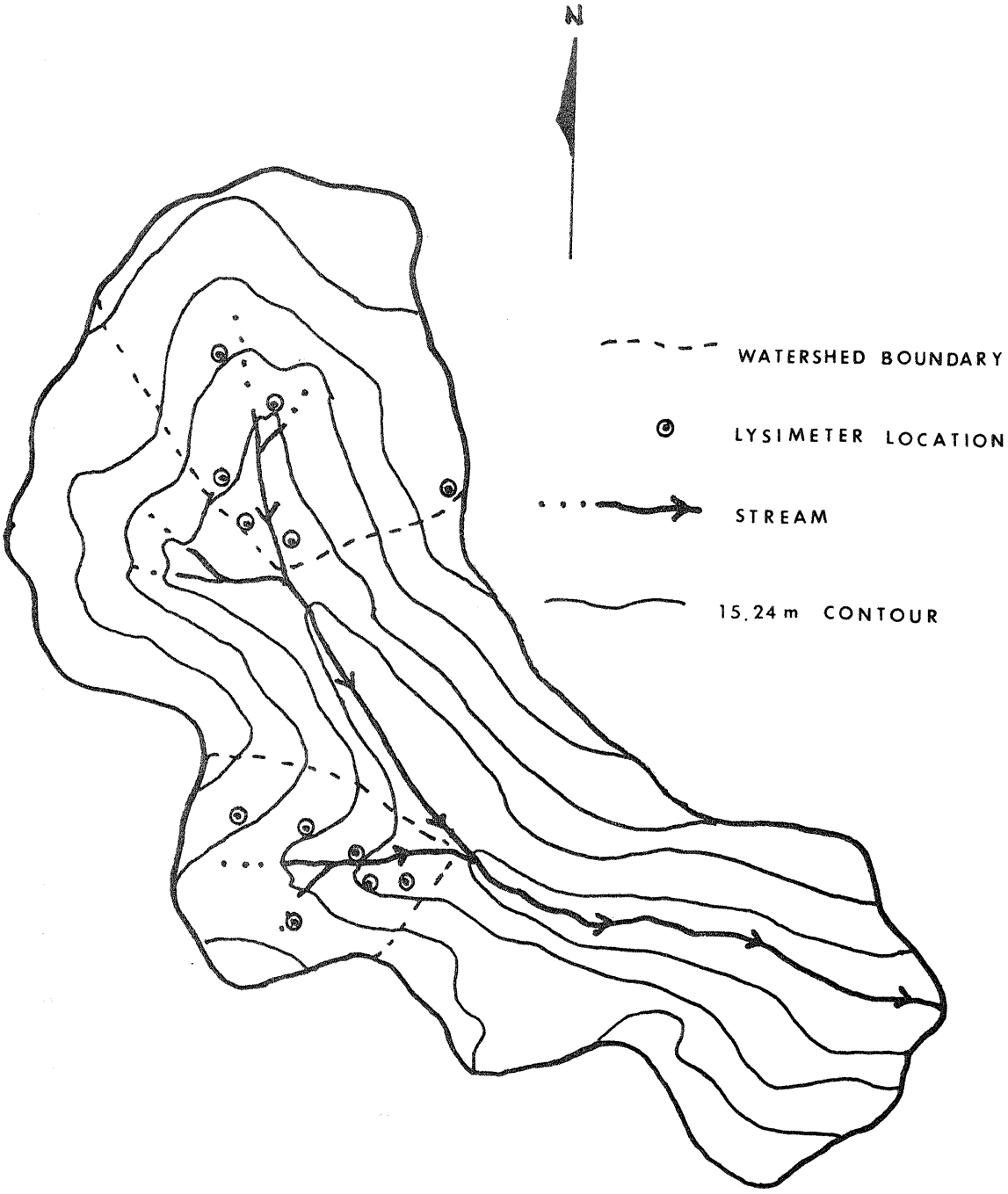

Figure 3.--Location of lysimeter tubes on the two small water watersheds.

to percolate through the soil.

4) All levels of the watershed would be represented (upper, mid- and lower slopes). Because of the time required to collect samples, two days were needed to sample all of the tubes. One set of tubes and the corresponding stream sample would be collected one day and the second set would be collected the following day. Any storm events between the two sampling times would have little or no effect on soil water tubes as after one week under vacuum the tubes would already be filled and no more water could be taken up. Only three storm events in June and July may have affected the stream samples.

Precipitation and stream samples for calculating the nutrient budget were collected weekly from May 1981 to May 1982. Precipitation samples were collected from a gauge placed in a nearby clearing and stream samples were collected from watersheds I and II, in a manner similar to studies performed by Johnson and Swank (1973) and Likens et al. (1967).

The rain water was collected in a device composed of a plastic cylinder and funnel sealed to a polyethylene sample bottle reservoir. A chemically inert netting was placed over the gauge when in use to exclude contaminants (leaves, seeds, insects, etc.) from entering the sample. This method of collection yielded bulk precipitation, i.e., a mixture of precipitation (snow, rain, hail, etc.) and dry chemical effluents, since the collector was continuously open (Whitehead and Feth, 1964). Evaporation was a concern during warm, sunny months of collection because it would have concentrated the sample solutions. However, Likens et al. (1967) found no significant evaporation from weekly collection devices similar to the ones used.

The sampling procedure involved the changing of sample bottles: resealing and securing the new bottle in place, protecting the collected sample with a tight fitting lid, and the transportation of samples to the laboratory for analysis. During warm months, the samples were placed on ice after collection to prevent any chemical degradation.

Snow was collected in a chemically inert pan, and the top layer was discarded to remove contaminants.

Streamflow was not directly measured in this study, but an estimate of monthly streamflow was obtained using a regression of precipitation to streamflow per unit area. This method, based on data from Parsons, WV is discussed in more detail later.

Laboratory

Within three to four hours after collection, pH readings were taken using half the sample collected. The remainder of the sample was frozen until chemical analysis could be done. All samples were analyzed within two weeks of collection. The samples were analyzed for calcium, potassium, magnesium and sodium

using atomic absorption spectrophotometry. Prior to chemical analysis the pH of the soil water samples was lowered (to between 2.8-3.0) because some of the samples had extremely high pH's due to excessively high potassium concentrations.

RESULTS AND DISCUSSION

Stream and Soil Water (Lysimeter) Comparisons

Prior to soil water and stream sampling, site related characteristics seemed to indicate a locational difference between the two watersheds in the soil nutrient concentrations (Frank, 1981). However, no statistically significant differences were found in average soil water nutrient concentrations (Ca, K, Mg, Na, H) between the two watersheds Table 1.

Soil water samples were collected for two separate periods of time. During the spring (May-June) sampling period there was a considerable amount of precipitation, approximately 27.4 cm. More than 2 cm of rain fell each week (except one) previous to collecting soil water samples. In the summer (July-September) sampling period half as much rain fell. Only 2 of the six weeks had rainfall over 2.5 cm; one week had no rain and the previous week had only 0.3 cm.

The differences between the two periods in rainfall and vegetative demand for moisture appears to have affected soil water nutrient concentrations Table 2. The cation most affected was Ca+ (Figure 4). During the three driest collection weeks concentrations rose 5-6 times above the previous concentration. Mg also rose, to peak at two times the previous level. (Figure 4) K was affected only slightly, with differing effects on both watersheds. (Figure 4). On watershed I concentrations were much lower in the first sampling week of summer than they had been during the spring. As soils became drier, however, concentrations rose slightly above previous levels. Concentrations on watershed II continued to drop toward summer, rising to reach spring levels in September, 3-4 weeks behind watershed I. Sodium levels decreased through the spring, and during the dry summer weeks were at their lowest points (Figure 4). As precipitation increased at the end of the sampling period Na concentrations rose to late spring levels. Hydrogen concentrations rose steadily as summer advanced, leveling off during the dry weeks (Figure 4).

The soil water nutrient concentrations reflect the relative ability of these cations to remain attached to soil particles (Henderson, 1978).

Stream water samples were collected in conjunction with soil water samples on both watersheds to detect any changes in nutrient concentrations occurring as moisture moved through the soil complex. Statistical comparison (using T-test at .025 level) between soil water and the corresponding stream had

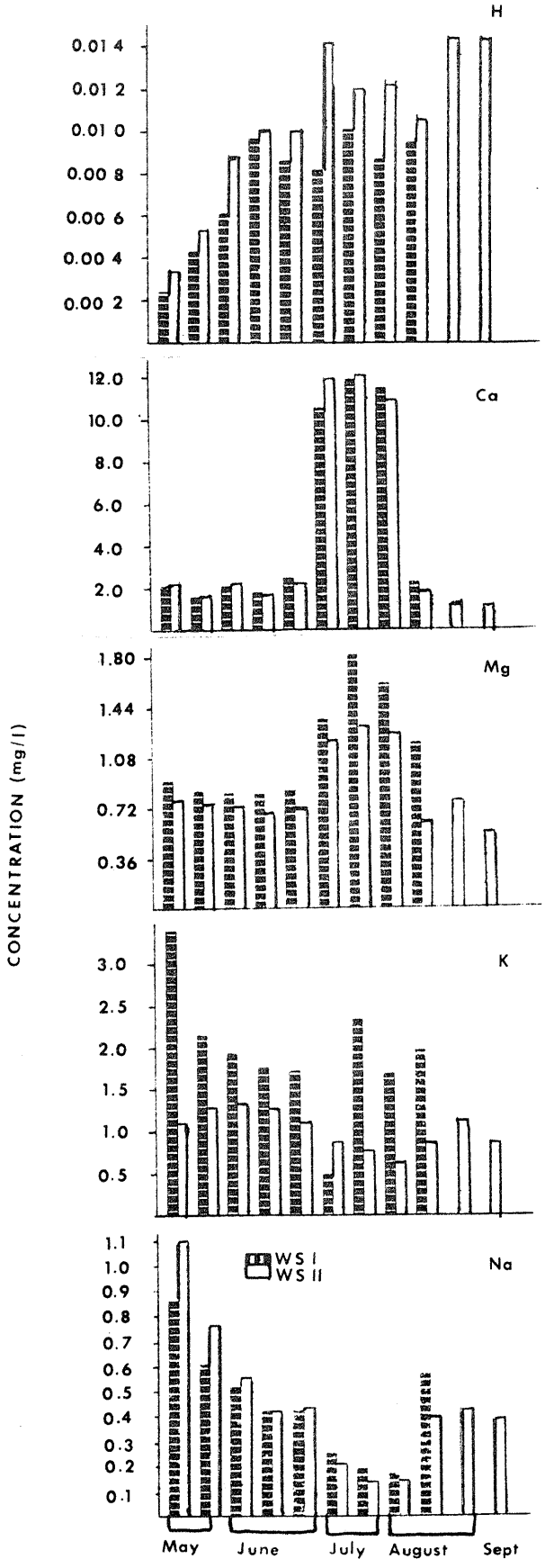

Figure 4.--Weekly averages of soil water nutrient concentrations.

Table 1.--Statistics for Soil Water.

(mg/l) Watershed I.

Cation	Mean	S. D.	Minimum Value	Maximum Value
Ca	5.20	4.94	0.22	14.82
Mg	1.13	0.72	0.35	3.97
K	2.06	3.19	0.18	15.30
Na	0.45	0.23	0.13	1.24
$H \times 10^{-2}$	0.80	0.60	0.00	2.13

Watershed II.

Cation	Mean	S. D.	Minimum Value	Maximum Value
Ca	4.40	4.45	0.65	13.71
Mg	0.84	0.34	0.23	0.4
K	0.99	0.71	0.12	3.11
Na	0.45	0.29	0.11	1.39
$H \times 10^{-2}$	1.09	0.51	0.20	2.50

Table 2.--Seasonal Means for Soil Water Nutrients.
mg/l

Loc.	Season	Ca	Mg	K	Na	$H \times 10^{-2}$	pH
W1	Spring	2.02	0.85	2.19	0.56	0.63	5.20
	Summer	8.16	1.40	1.60	0.30	1.04	4.98
W2	Spring	1.98	0.73	1.22	0.63	0.78	5.10
	Summer	7.00	0.98	0.81	0.26	1.29	4.89

similar results for both watersheds, the one exception being pH (H+ concentration). For both watersheds, Ca and Mg were more abundant in stream water than in soil water, and K and Na concentrations were greater in soil water. With pH, however, there were differences, such as:

Watershed I

Soil pH	A horizon-4.00; B horizon-4.19
Soil water	5.08
Stream pH	5.78

Watershed II

Soil pH	A horizon-3.75	B horizon-4.25
Soil water	4.98	
Stream pH	4.71	

As moisture moved through the soil into the deeper "B" horizon, pH rose by 1.0 unit on watershed I and 1.3 units on watershed II, equalizing soil water pH of both watersheds. Continued movement through the soil and into the stream resulted in a higher pH for watershed I but a lower pH for watershed II. Differences in underlying rock strata are most probably the cause. Watershed I has a higher incidence of limestone.

Precipitation and Stream Water Comparisons

Data were recorded to determine the relationship of monthly amounts of precipitation collected at the West Virginia University Forest and the number of storm events recorded (Figure 5). The greatest rainfall was recorded in June and September. The most intense storm months are those months that had the greatest amount of precipitation relative to the number of recorded storm events. The intense storm months are identified in order to explain any increases or decreases in cation concentrations recorded for precipitation (Figure 6) and streams(Figure 7). Johnson and Swank et al., (1973) found that seasonal variations in discharge concentrations due to seasonal precipitation inputs produced cation fluxes in stream concentrations.

Precipitation samples collected during June contained the greatest concentrations of Ca^{++} and Mg^{++}, including a slight increase for K^{+}. Magnesium peaked during September as did K^{+} and Na^{+}.

The ionic concentrations of streams during intense storm events in the growing season are also modified by increased nutrient additions of surface runoff and interflow (Timmons, Verry, Burwell, and Holt 1977), throughfall (Peterson, Rolfe, and Bazzaz 1979a), stemflow(Gersper and Holowaychuk 1971, Eaton, Likens and Bormann 1973), litterfall and decomposition (Gosz, Likens, and Bormann 1973, 1976, and Peterson, Rolfe, and Bazzaz 1979b).

Elemental analyses of precipitation and stream samples were recorded on a yearly graph to determine seasonal trends and to identify when the maximum and minimum values occur (Figures 6 and 7). In general, during the period of May 1981 to May 1982, no seasonal trends of precipitation cation concentrations are apparent (Figure 6). In fact, the precipitation concentrations of Ca^{++}, Mg^{++}, K^{+}, and Na^{+} collected on a weekly basis were highly variable as compared with corresponding stream data. Similar results were found by Swank and Henderson (1976),

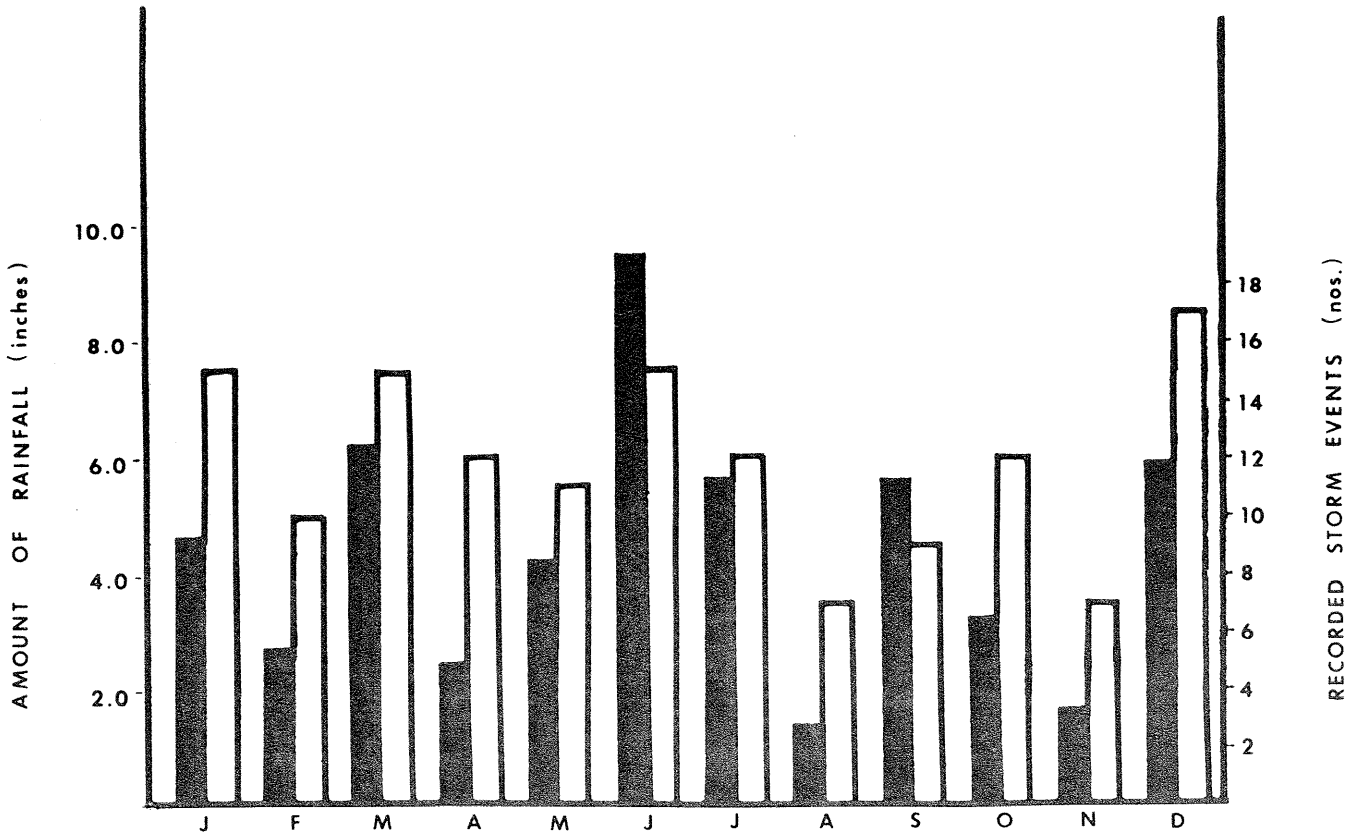

Figure 5--The relationship of monthly totals of preciptation collected at the West Virginia University Forest (black) and the number of storm events recorded (white), from May 1981 to May 1982.

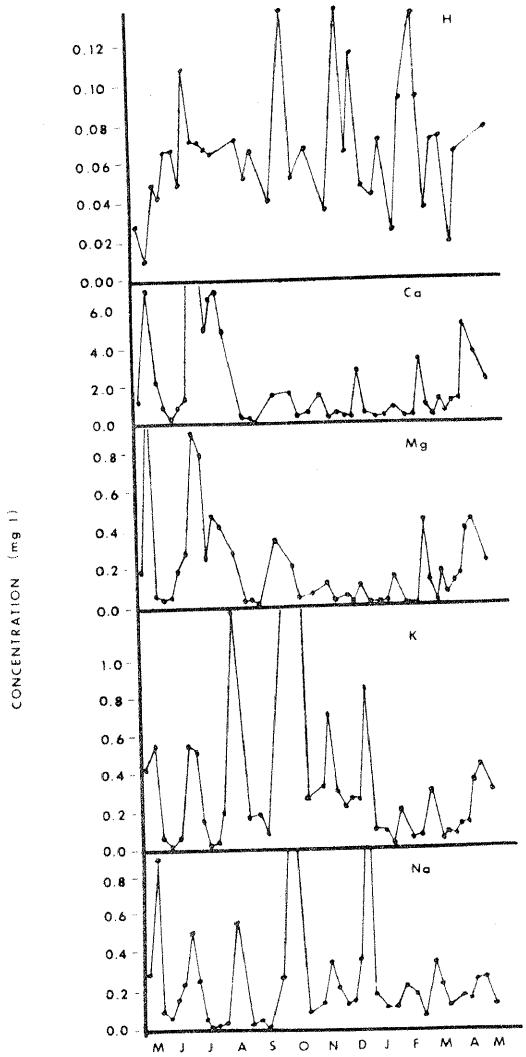

Figure 6.--Recorded weekly cation concentrations of H^+, Ca^{++}, Mg^{++}, K^+ and Na^+, of precipitation collected at the West Virginia University Forest, from May 1981 to May 1982.

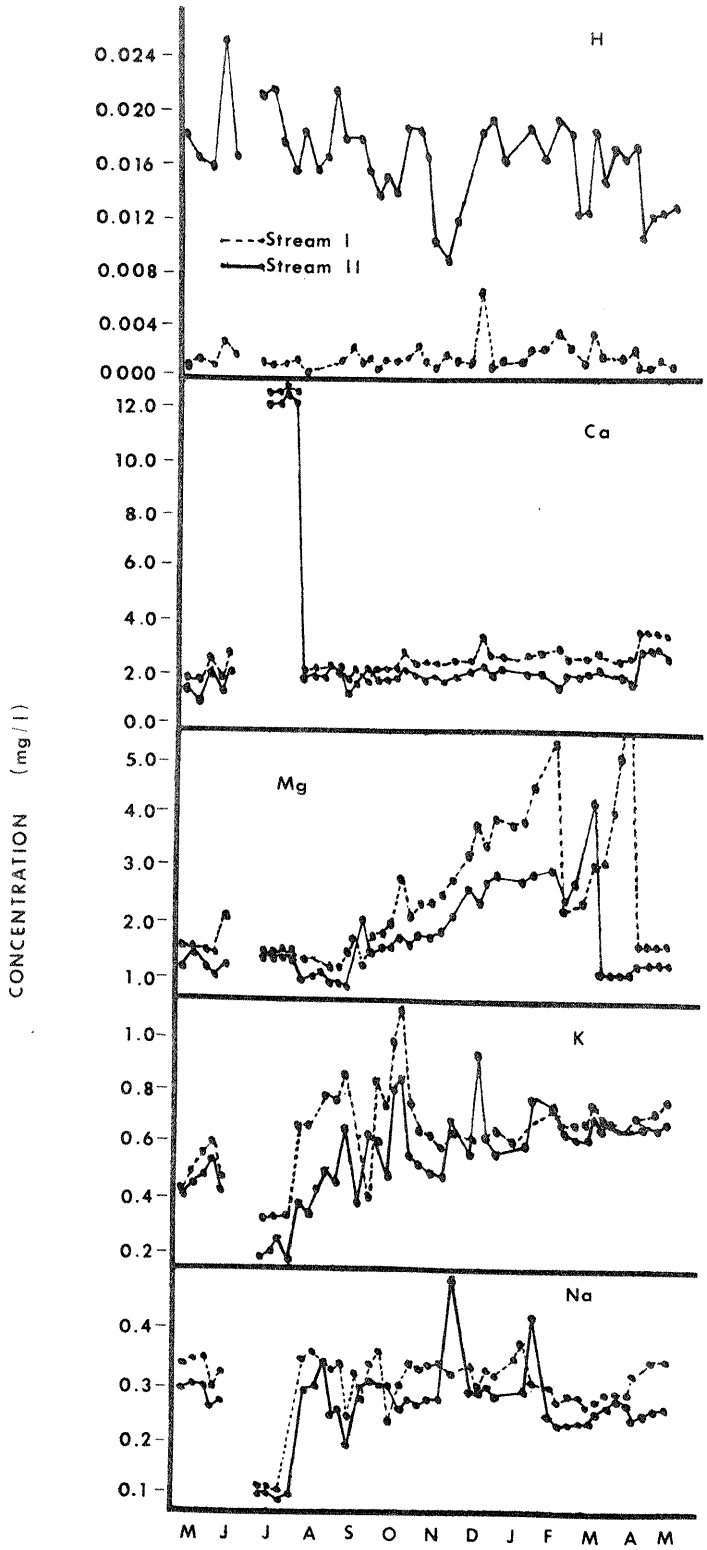

Figure 7.--Recorded weekly cation concentrations of H^+, Ca^{++}, Mg^{++}, K^+, and Na^+, in stream samples of two watersheds in the West Virginia University Forest, from May 1981 to May 1982.

Table 3.--The range and means of concentrations for precipitation collected at the West Virginia University Forest from May 1981 to May 1982.

	mg/l		
CATION	MINIMUM	MAXIMUM	MEAN
H	$0.116(10^{-2})$	$1.986(10^{-2})$	$0.713(10^{-2})$
Ca	0.123	14.320	2.248
Mg	0.005	1.198	0.208
K	0.013	1.766	0.316
Na	0.001	1.689	0.268

Table 4.--The range and weekly means of stream concentrations for two watersheds of West Virginia University Forest collected from May 1981 to May 1982.

	WS I mg/l		
CATION	MINIMUM	MAXIMUM	MEAN
H	$0.005(10^{-2})$	$0.068(10^{-2})$	$0.017(10^{-2})$
Ca	1.771	12.730	3.543
Mg	1.221	6.988	2.507
K	0.290	1.121	0.655
Na	0.106	0.388	0.302
	WS II mg/l		
CATION	MINIMUM	MAXIMUM	MEAN
H	$0.089(10^{-2})$	$0.336(10^{-2})$	$0.170(10^{-2})$
Ca	1.066	12.600	3.010
Mg	0.874	4.384	1.754
K	0.170	0.948	0.565
Na	0.088	0.509	0.269

Likens et al. (1967), and Johnson and Swank (1973) et al. (1969). Conversely, Henderson et al. (1978) found a seasonal trend in elemental concentration in precipitation. The range of cation concentrations and weekly means for the precipitation collected are given in Table 3.

Cation concentrations in streamflow do indicate some seasonal trends for the study year and the ranges and means for stream samples are given in Table 4.

The pH of both streams remained relatively constant throughout the study. There was a significant difference in H^+ concentrations between streams throughout the entire study year and no obvious seasonal trends for H^+ concentration are apparent. Bormann and Likens (1979) found H^+ concentrations of streams highly variable and subject to fluxes according to stream discharges.

Both streams reflected the large increases in Ca^{++} that occurred in precipitation at the end of June. However, the calcium concentration remained fairly constant, between 2.0 to 4.0 mg/l, for both streams throughout the remainder of the year.

The trend for Mg^{++} and K^+ begins with the minimum concentration in summer with a gradual buildup to a maximum concentration in mid-winter.

Sodium concentrations were lowest in mid-summer and varied sporadically thereafter reaching a peak in winter. The concentration differences may be partly explained by differences in biological activities as reported by Gosz, et al. (1976), Vitousek (1977), and Likens, et al. (1967). Johnson, et al. (1969) indicated that Na^+ concentration is dominated by streamflow volume i.e., high flows will dilute concentration, but this effect was not prominent in our study, since the lowest Na concentrations coincided with the low flow period of the streams.

An increase in the concentrations of K^+ and Na^+ begins with the onset of leaf senescence (late August/early September), reaching a maximum in autumn. These maximums of K^+ and Na^+ are maintained until the next growing season.

Statistical comparisons between stream concentrations for the various collection periods are given in Table 5. The differences detected could be due to a number of factors including differences in species composition, soils, geology and hydrologic flux of the two watersheds. Watershed I was mainly composed of yellow poplar and red maple while WS II was dominated by upland oaks. Henderson, et al. (1978) reported differences between species regarding nutrient uptake and differences in elevation or slope steepness caused significant differences in species composition and nutrient export as found by Vitousek (1977). Also, the geology of a watershed can contribute to the differences. Henderson et al.(1978) found watersheds to vary in cationic concentration primarily due to geologic differences rather than due to biologic processes. And Vitousek (1977) indicated that rock weathering was more important in contributing cation concentration than the precipitation inputs.

To compare the seasonal trends in total nutrient output of the watersheds, weighted averages of cation concentrations on a monthly basis were estimated. These averages were calculated for each watershed by using a computed discharge rate based on the size of the watershed monthly precipitation and the average cationic concentration of the stream (Figure 8). Streamflow and

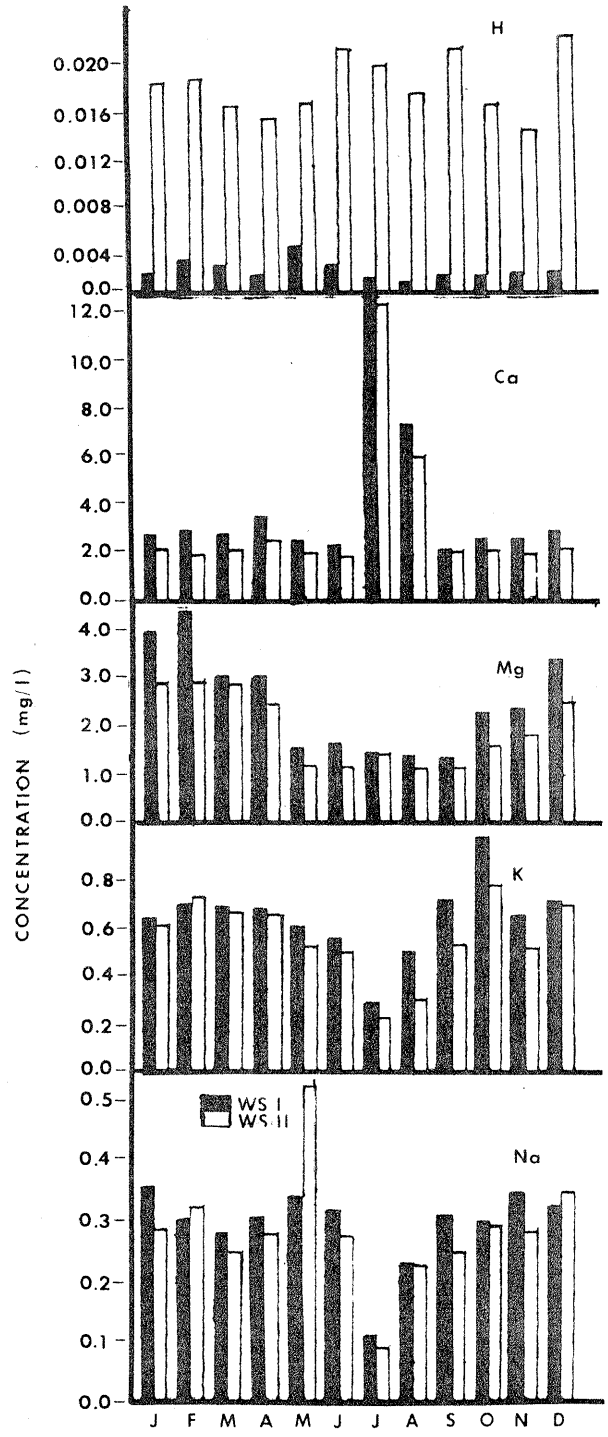

Figure 8.--Weighted monthly average concentrations for H^+, Ca^{++}, Mg^{++}, K^+, and Na^+, in the stream samples of two watersheds in the West Virginia University Forest, from May 1981 to May 1982.

Table 5.--Seasonal analysis of variance of H^+, Ca^{++}, Mg^{++}, K^+, and Na^+ for two watersheds of the West Virginia University Forest, from May 1981 to May 1982.

CATION	SPRING PR > F	SUMMER PR > F	AUTUMN PR > F	WINTER PR > F
H	0.0001*	0.0001*	0.0001*	0.0001*
Ca	0.0176*	0.7371	0.0044*	0.0001*
Mg	0.0689	0.0063*	0.0410*	0.0030*
K	0.4126	0.0661	0.0143*	0.8886
Na	0.0004*	0.7124	0.0076*	0.8744

*Significant difference between watersheds at the 5% level.

precipitation data from gauged watersheds in Parsons, West Virginia were used to develop a regression which we used to compute our monthly estimates.

The highest cation outputs per unit area were consistently found in WS I, the smaller watershed, except for the H^+ concentration which was 10 times less. The reason for the large difference in hydrogen ion output is not readily apparent, but it may be related to geologic differences between the sites. Geologic differences could affect buffering capacity of the soils or could relate to the exposure of acid-producing strata. The same general seasonal trends occurred for both watersheds.

Nutrient Budget

A nutrient budget of dissolved cations for the two forested watersheds of the West Virginia University Forest was determined from the "difference between the meteorologic input per hectare and the geologic output per hectare" (Bormann and Likens, 1967).

The Likens, et al. (1967) procedure for calculating the nutrient inputs and outputs was used. The cationic input is the product of the dissolved cation concentration (mg/l) in the precipitation and the volume of precipitation as liquid (liters). The cationic output is the product of the volume (liters) of water leaving the watershed and its cation concentration (mg/l). The difference between the calculated inputs and outputs is recorded as a net gain or loss to the watershed Table 6.

In spite of the tenfold difference in H^+ between the watersheds, both reflect a large net gain in H^+ concentration for the study year. A net gain was also determined for Na^+ in both instances.

Table 6.--The nutrient budgets of H^+, Ca^{++}, Mg^{++}, K^+, and Na^+ for two forested watersheds of the West Virginia University Forest

CATION	INPUT (Kg/ha/yr)	OUTPUT (Kg/ha/yr)	NET (GAIN/LOSS) (Kg/ha/yr)
		WS I	
H	75.68	1.22	+ 74.46
Ca	205.24	212.90	- 7.66
Mg	18.17	195.83	-177.66
K	23.96	44.46	- 20.50
Na	22.33	21.08	+ 1.25
		WS II	
H	75.68	10.01	+ 65.67
Ca	205.24	147.58	+ 57.66
Mg	18.17	123.34	-105.17
K	23.96	36.10	- 12.14
Na	22.33	16.50	+ 5.83

Large net losses in Mg^{++} concentrations were found for both watersheds along with appreciable losses of K^+.

Calcium showed a net loss for WS I and a net gain for WS II. This large variation could be due mainly to the presence of limestone in WS II. Again, geologic processes, such as rock weathering could contribute more to the cation inputs than precipitation or biologic inputs (Henderson, et al. 1978, Vitousek 1977). However, no attempt was made in this study to estimate the amount of inputs from these sources.

Conclusions

Preliminary nutrient data were recorded on two forested watersheds at West Virginia University Forest. The two watersheds were choosen for their differences in soil characteristics, such as nutrient concentrations and soil properties.

Seasonal trends for stream nutrient outputs were found for both watersheds. Seasonal nutrients inputs from precipitation were highly variable and no seasonal trends were apparent.

Although not statistically significant, differences in concentrations of cations were detected between the two watersheds studied. Generally, the watershed with the more fertile soils and higher woody biomass also had the greatest concentration of elements in the water. Many factors could contribute to the watershed nutrient differences such as: soil characteristics, species

composition, slope and aspect, amount of precipitation, and geologic chemistry.

These data from one year are far from conclusive but do give an indication of nutrient relationships in Appalachian hardwoods ecosystems. Further study will continue and hopefully will help guide forest management planning to prevent site depletion while maximizing productivity.

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