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Nutrient Transport in Surface Runoff and Interflow from an Aspen-Birch Forest[1]

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ABSTRACT

Nutrients transported in surface runoff and interflow from an undisturbed aspen-birch (*Populus tremuloides* Michx., and *Betula papyrifera* Marsh.) forest (6.48 ha) in northern Minnesota were measured for 3 years. Surface runoff from snowmelt accounted for 97% of the average annual surface runoff and for 57% of the average annual water loss. Slope aspect influenced the amount, rate, and time of snowmelt runoff. In surface runoff, organic nitrogen (N) comprised 80% of the total N load, and organic (+ hydrolyzable) phosphorus (P) comprised 45% of the total P load. The quantities of cations in surface runoff were in the order of calcium (Ca) > potassium (K) > magnesium (Mg) > sodium (Na). More than 96% of all the nutrients in surface runoff were transported by snowmelt. The annual volumes of interflow varied only slightly during the 3 years. Compared with surface runoff, the amounts of all the nutrients (except Na) and their weighted concentrations decreased in interflow. These nutrient losses from the ecosystem can accumulate in surface waters.

Additional Index Words: nitrogen, phosphorus, potassium, calcium, magnesium, sodium, COD, snowmelt.

The increased accumulation of nutrients in many lakes in the north central United States has caused concern that water quality is deteriorating at an accelerating rate. Nutrient loads from contributing watersheds are influenced by many factors and can change when the watersheds are altered by natural and/or manmade disturbances. Nutrient losses for undisturbed and disturbed forest ecosystems have been reported for other areas, but no data have been reported for the western Great Lakes area.

Nutrient losses in streamflow from an undisturbed northern hardwood forest ecosystem in New Hampshire have been reported (Bormann et al., 1968; Bormann and Likens, 1970). After clear-cutting and repeated herbicide control of regeneration, net losses of NO_3-N, K, Ca, Al, Mg, and Na were, respectively, 67, 21, 10, 9, 7, and 3 times greater than those in the undisturbed system (Likens et al., 1969; Bormann and Likens, 1970). In Michigan, the effects of clear-cutting on nutrient losses were evaluated in three 60-year-old aspen stands located on good, intermediate, and poor soils (Richardson and Lund, 1975). For the first year, they found little evidence of increased nutrient losses in soil leachate (except Ca and Mg) as a consequence of clear-cutting.

Changes in water chemistry caused by the thinning, clear-cutting, and conversion to pine and grass on southern mixed-hardwood watersheds have been reported by Douglas and Swank (1975). In four contrasting ecosystems they found relatively minor changes in mean annual cation and anion concentrations, and concluded that the increased loss of nutrients from the watersheds would not create pollution problems. Recently, Leak and Martin (1975) reported a good relationship between streamwater NO_3 during spring and summer and stand age, or age since disturbance for northern hardwoods in the northeast.

In Ohio, Taylor et al. (1971) compared water and nutrient losses from a deciduous hardwood and pine watershed with those from an adjacent farmland watershed. During a 3-year period, they found significantly higher nutrient losses but only slightly greater water loss from farmland. In eastern Ontario, Schindler and Nighswander (1970) used long-term hydrologic data to determine annual nutrient loading for Clear Lake from the 125-ha upland forest watershed. The per hectare losses of inorganic N, total P, K, Na, Ca, and Mg from this watershed ranged from 23 to 81% of the respective annual losses reported for the New Hampshire watershed.

Many lakes have watersheds comprised of agricultural or forested land, alone or in combination. Nutrient losses in surface runoff from agricultural plots in Minnesota have been reported (Timmons et al., 1973; Burwell et al., 1975), but more information is needed to evaluate the nutrient contribution from forests to lakes and streamflow. Since northern Minnesota has a large area covered with mixed aspen and white birch, a study was initiated to (i) determine annual nutrient loads transported by surface runoff and interflow from an aspen-white birch forest, and (ii) to evaluate the quantities of nutrients in surface runoff transported by snowmelt and rainfall.

EXPERIMENTAL PROCEDURE

Runoff plots were installed to collect surface runoff and interflow during 1971 through 1973 from upland forest slopes in Watershed 2 (WS-2), Marcell Experimental Forest, Itasca County, Minnesota (ca. 47°32'N; 93°28'W). This watershed covers 9.72 ha consisting of a 6.48-ha upland forest with a mature, well-stocked sawlog stand of aspen (*Populus tremuloides* Michx.) and birch (*Betula papyrifera* Marsh.), and a 3.24-ha bog with a well-stocked pole stand of black spruce (*Picea mariana* Mill. B.S.P.). The upland forest has 3.00 ha with northerly aspect and 3.48 ha with southerly aspect (30.6 and 35.9%, respectively, of the total watershed area).

One surface and one subsurface plot were installed on each slope aspect. Surface runoff from the upland forest soil (Warba series) flows through the surface organic (O) horizon instead of over the forest floor. The surface runoff plot on the northerly aspect was 1.83 m wide and 23.16 m long (0.004 ha) and was located on a 22% slope; the plot on the southerly aspect was 1.83 m wide and 18.29 m long (0.003 ha) and was located on a 26% slope. Each surface runoff plot extended from the base of the slope near the bog to the top of the slope. With some variation, the equipment used to collect and measure surface runoff was similar to that described by Mutchler (1963). The metal water collection tanks were coated with a chemically inert paint to prevent P adsorption on the galvanized surface (Latterell et al., 1974). Sampling of snowmelt runoff was facilitated by heating each collection tank shelter 0.5 to 3.3C when necessary.

Interflow in the upland forest soil moves along the upper boundary of the slowly permeable B2t horizon to the bog water table. To collect this interflow, a 1.82-m stainless steel wellpoint was placed horizontally at the junction of the A22 and B2t horizons and connected to a collection tank with PVC pipe (Fig. 1). The forest litter and soil horizons to about the 33-cm depth (to the

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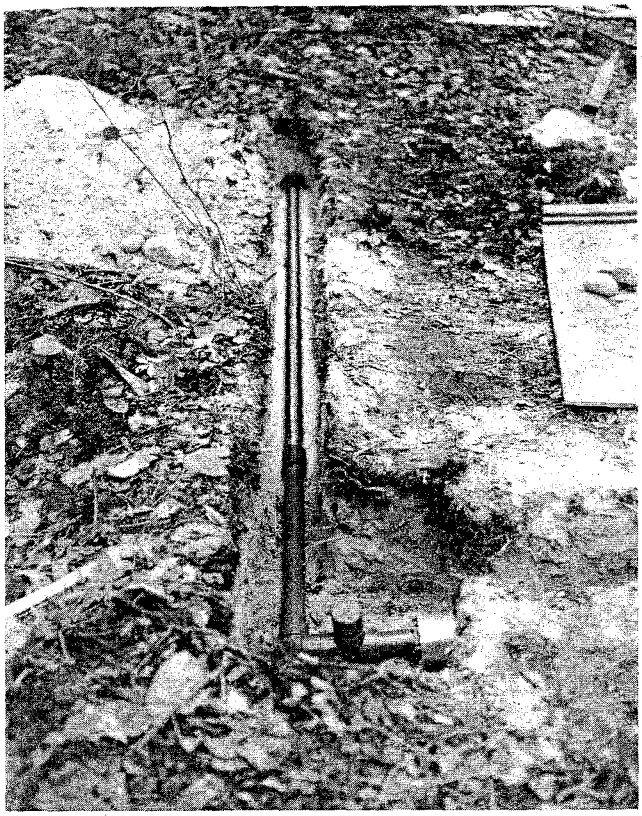

Fig. 1—Installation of stainless steel wellpoint at the junction of the A22 and B2t horizons to collect interflow, which comes from the left.

B2t horizon) were replaced to their original depths after the wellpoint was installed in a 13-cm wide trench. While refilling the trench a thin stainless steel sheet was placed over the wellpoint at about 5 cm below the mineral soil surface to help prevent downward movement of surface runoff at the interflow collection point. Runoff samples for nutrient analyses were collected after each runoff event. During snowmelt and prolonged rainfall, samples were collected daily or more often. The samples were collected in 1-liter polyethylene containers when runoff was measured, and were refrigerated at 2 to 3C until analyzed.

Unfiltered portions of each sample were analyzed for Kjeldahl N, total P, and chemical oxygen demand (COD). Filtered portions (0.45 μm) were analyzed for NH_4-N, $(NO_2 + NO_3)$-N, ortho-P, K, Na, Ca, and Mg. Kjeldahl N was determined with a macro-Kjeldahl method (U. S. Environmental Protection Agency, 1974) in which the sample was digested with concentrated H_2SO_4 and one Kel-Pak,[3] distilled into H_3BO_3, and titrated with standard H_2SO_4. Total P was measured with a spectrophotometer after digestion with concentrated $HClO_4$ and HNO_3, and color development with combined reagent (U. S. Environmental Protection Agency, 1974). Chemical oxygen demand was determined by oxidation with $K_2Cr_2O_7$ in 50% (vol/vol) H_2SO_4 solution at reflux temperature (U. S. Environmental Protection Agency, 1974). During 1971 and 1972, NH_4-N and $(NO_2 + NO_3)$-N were measured with the steam distillation method (Bremner, 1965). During 1973, NH_4-N and $(NO_2 + NO_3)$-N were measured with a Technicon Auto-Analyzer II[3] (after verifying the different methods agreed) using Technicon's NH_3 in water and wastewater, and NO_2 and NO_3 in water and wastewater methods, respectively. Ortho-P was measured with a spectrophotometer after color development using combined reagent. Concentrations of K, Na, Ca, and Mg were determined by atomic absorption spectroscopy (Issac and Kerber, 1971). Organic N was determined by subtracting NH_4-N from Kjeldahl N, and organic P (including hydrolyzable) was determined by subtracting ortho-P from total P.

Nutrient losses in surface runoff from each slope aspect were determined for each sampling interval or runoff event as the product of water loss quantities and their respective nutrient concentrations. Seasonal nutrient losses were determined as the accumulated sum of nutrients in snowmelt runoff or rainfall runoff. The respective water and nutrient losses from the northerly and southerly aspects were combined to obtain total losses from the upland aspen area, and then divided by 6.48 to determine per hectare values.

Interflow from the upland forest was estimated by a total watershed hydrograph separation technique. An analysis of total watershed hydrographs showed that logs of the recession leg slope were significantly higher ($\alpha = 0.001$) during July and August than at other times. July and August recession legs represent flow periods from the bog only because the runoff plots did not collect flow during this period. July and August hydrographs for 10 years (1961-1970) for WS-2 were used to calculate an average recession leg for the flow originating in the bog from precipitation and included both high and low flow data. An annual bog-water-only hydrograph was then constructed using the average bog recession leg and measured rising legs from the total hydrograph. Interflow from the upland was estimated as the difference between the total watershed hydrograph and the bog-water-only hydrograph. We interpret the difference in hydrographs as interflow because upland surface flow always occurred before watershed flow, and the bog-water-only hydrograph was not subtracted from the total watershed hydrograph until after the initial snowmelt rise in early April (streamflow always ceased during winter). Nutrient losses in interflow were determined as the product of the average concentration for two consecutive samplings and the quantity of interflow between the two samplings. When interflow samples were obtained from both northerly and southerly aspects simultaneously, the nutrient concentrations were averaged to determine interflow nutrient losses; otherwise, the concentrations from each aspect were used separately. Weighted concentrations were calculated by converting the kg of nutrients/ha per cm of water loss to ppm.

RESULTS AND DISCUSSION

Annual surface runoff from WS-2 upland during the 3 years ranged from 5.10 to 12.52 cm, and interflow ranged from 5.66 to 5.82 cm (Table 1). Snowmelt accounted for 93 to 100% of the total annual surface runoff, and for 46 to 68% of the total annual water loss from the aspen-birch forest. After snowmelt surface runoff ceased, measurable ($>$0.013 cm) surface runoff events caused by rainfall contributed negligible amounts of water to the total annual water loss. These measurable runoff events occurred only after heavy rainfalls and/or during several consecutive days of rainfall.

Since 1961, when hydrologic and climatic measurements for WS-2 started, annual precipitation has ranged from 59.39 to 88.49 cm, and averaged 77.09 cm. During the 3 years of nutrient sampling, annual precipitation averaged 79.03 cm. In early March each year, just before the spring thaw, average depth and water content of the snowpack were uniform for both slope aspects of the aspen-birch forest; the amount of snowmelt surface runoff was related to the snowpack water content (Table 1). Slope aspect influenced the amount of snowmelt surface runoff (Table 1) as well as the time and rate. Snowmelt from the southerly aspect began earlier, ran off at a faster rate, and contributed more water to surface runoff than the snowpack on the northerly aspect. Although the effect of slope aspect on interflow wasn't delineated by the

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[3] Trade names are used here solely to provide specific information. Mention of a trade name does not constitute a guarantee or warranty and does not signify that the product is approved to the exclusion of other comparable products.

Table 1—Surface and interflow water losses from the aspen-birch forest and precipitation received during 1971-1973

Annual precipitation			Snowfall before spring thaw	Early March snowpack†		Surface runoff						Interflow	Total water loss
						From snowmelt			From rainfall				
Snow	Rain	Total		N aspect	S aspect	N aspect	S aspect	WS-2	N aspect	S aspect	WS-2		
cm													
1971													
18.29	63.81	82.10	20.90‡	15.75	16.26	4.88	19.10	12.52	0	0	0	5.82	18.34
1972													
20.04	59.44	79.48	16.94§	10.67	10.92	0.01	11.99	6.45	0	0.86	0.46	5.72	12.63
1973													
7.19	68.32	75.51	9.52¶	5.59	4.57	0.18	9.02	4.94	0	0.28	0.16	5.66	10.76

† Average H_2O content for 10 sampling sites during the first week in March.

‡ Snowfall as water from 10 Nov. 1970 to 4 Apr. 1971.

§ Snowfall as water from 19 Nov. 1971 to 13 Apr. 1972.

¶ Snowfall as water from 7 Nov. 1972 to 28 Mar. 1973.

method used to determine interflow volumes, more interflow was consistently collected from the northerly aspect than the southerly aspect during snowmelt.

Nutrient losses in surface runoff from the aspen-birch forest are given in Table 2. Annual total N losses ranged from 1.13 to 2.12 kg/ha with 74 to 87% as organic N. More NH_4-N than (NO_2 + NO_3)-N (hereafter shown as NO_3-N) was transported in surface runoff but only for 2 of the 3 years. The amounts of inorganic N(NH_4-N + NO_3-N) were low compared to the organic N and ranged from 0.19 to 0.55 kg/ha during the 3 years. Total P losses ranged from 0.13 to 0.30 kg/ha (Table 2), with more soluble inorganic P (ortho-P) than organic P transported in surface runoff during 2 of the 3 years. However, based on the overall average, the ortho-P and organic P were almost equal. Average annual Ca losses were about 3 and 20 times greater than the respective total N and P losses, and annual K losses were about 2 and 13 times greater, respectively. Generally, losses of cations in surface runoff were in the order of Ca > K > Mg > Na, which reflected the concentrations of these cations in yellowing aspen leaves just beginning to fall from the tree (Verry and Timmons, 1976). During the next spring thaw, these leaves would be subject to leaching by snowmelt runoff.

Nutrients in interflow are also presented in Table 2. Since the method used to determine interflow precludes separating precisely the interflow nutrients transported by snow and rain, the losses are given on an annual basis. As in surface runoff, organic N comprised the greatest portion of the annual total N loss in interflow (88 to 91%), but averaged 0.67 kg/ha per year < did organic N in surface runoff. For 2 of the 3 years, NH_4-N losses were

Table 2—Average nutrient losses measured in surface runoff, interflow, and total water loss from the aspen-birch forest

	Runoff	N				P			K	Na	Ca	Mg	COD
		NH_4	NO_3	Organic	Total	Ortho	Organic	Total					
	cm	kg/ha											
Surface runoff													
1971													
Snowmelt	12.52	0.09	0.10	1.22	1.41	0.04	0.09	0.13	2.08	0.63	4.98	1.54	65.95
Rainfall	0	0	0	0	0	0	0	0	0	0	0	0	0
Annual†	12.52	0.09	0.10	1.22	1.41	0.04	0.09	0.13	2.08	0.63	4.98	1.54	65.95
1972													
Snowmelt	6.45	0.38	0.17	1.51	2.06	0.17	0.12	0.29	2.20	0.54	4.17	1.12	72.45
Rainfall	0.46	<0.01	0	0.06	0.07	<0.01	<0.01	0.01	0.16	0.01	0.17	0.04	2.59
Annual	6.91	0.38	0.17	1.57	2.12	0.18	0.13	0.30	2.36	0.55	4.34	1.17	75.05
1973													
Snowmelt	4.94	0.10	0.07	0.92	1.10	0.15	0.08	0.23	4.18	0.12	3.64	0.94	41.04
Rainfall	0.16	<0.01	0.01	0.02	0.03	0	0	<0.01	0.18	0	0.10	0.03	0.83
Annual	5.10	0.11	0.08	0.94	1.13	0.15	0.08	0.23	4.36	0.12	3.74	0.97	41.88
Average													
Snowmelt	7.97	0.19	0.11	1.22	1.52	0.12	0.10	0.22	2.82	0.43	4.26	1.20	59.82
Rainfall	0.21	0	0	0.03	0.04	0	0	<0.01	0.11	0	0.09	0.02	1.14
Annual	8.18	0.19	0.12	1.25	1.56	0.12	0.10	0.22	2.93	0.43	4.35	1.22	60.96
Interflow													
1971‡	5.82	0.04	0.04	0.59	0.67	<0.01	0.03	0.04	0.36	0.62	2.02	0.68	29.29
1972	5.72	0.06	0.01	0.70	0.77	0.01	0.04	0.05	0.42	0.72	2.23	0.69	40.36
1973	5.66	0.05	<0.01	0.46	0.52	<0.01	0.03	0.03	0.34	0.79	2.31	0.74	28.32
Average	5.74	0.05	0.02	0.58	0.65	<0.01	0.03	0.04	0.37	0.71	2.18	0.70	32.65
Total water loss													
Avg. annual	13.92	0.24	0.14	1.83	2.21	0.13	0.13	0.26	3.30	1.14	6.53	1.92	93.61

† Annual losses may not be the exact sum of snowmelt losses and rainfall losses due to rounding off.

‡ Computation of interflow volumes did not allow separation of snowmelt and rainfall components.

greater than NO_3-N losses. The amounts of inorganic N(NH_4-N + NO_3-N) in interflow were 42, 13, and 26% of the amounts in surface runoff for 1971, 1972, and 1973, respectively.

Average annual total P loss in interflow was only 18% of the annual total P loss in surface runoff (Table 2). The decrease of ortho- and organic P loads in interflow as compared with surface runoff, and the change of the ortho/organic P ratio, indicated that P (especially ortho-P) leached from the most recent forest litter was utilized and/or immobilized in the partially decomposed organic horizons and/or mineral soil. Except for Na, the cations in interflow also decreased. Average annual K, Ca, and Mg losses in interflow were 13, 50, and 57% of their respective annual losses in surface water. Although the average annual interflow was about 70% of the average annual surface runoff, the annual Na loss in interflow was nearly twice that for surface runoff.

The average annual loss of that portion of the organic matter oxidized by a strong oxidant (COD) in surface runoff was about twice the loss in interflow. During the 3 years, the average COD concentration was 78 mg/liter with an overall range of 23 to 250 mg/liter. In west central Minnesota, the COD concentration of Eagle Lake outlet averaged 26 mg/liter and the drainage water from its 3,645-ha agricultural watershed ranged from 2 to 47 mg/liter with an average of 22 mg/liter (unpublished data). Both surface runoff and interflow from the aspen-birch forest contained greater COD concentrations than did water from an agricultural watershed.

Except for Na, 64 to 92% of the total annual nutrient losses from the aspen-birch forest occurred in surface runoff, while only 59% of the total water loss was surface runoff. When surface runoff from snowmelt passes through the organic horizon, there appears to be a net leaching effect for all nutrients except NH_4-N and NO_3-N since nutrient loads in the snowpack are low.[4] With 97% of the annual surface runoff from snowmelt, most surface runoff occurs at temperatures very near freezing and apparently passes through the forest floor with little opportunity for immobilization and/or utilization.

Nutrient inputs from precipitation and aspen throughfall are important sources contributing nutrients to the forest floor. Except for NH_4-N and NO_3-N, the quantities of nutrients contributed annually by precipitation were increased by aspen throughfall.[4] However, the annual nutrient losses in surface runoff plus interflow showed reductions of about 2 to 12 times the amount contributed by aspen throughfall (except for Na), so the forest floor and mineral soil plus all the biological processes appear to be acting annually as nutrient sinks.

Average annual inorganic N loss from the aspen-birch forest was 21, 30, and 37%, respectively, compared to the losses reported for New Hampshire (Bormann et al., 1968), eastern Ontario (Schindler and Nighswander, 1970), and Ohio (Taylor et al., 1971). However, total P loss from the aspen-birch forest was about 3 times greater than total P loss from the climax hardwoods in eastern Ontario and about 5 times greater than the deciduous hardwood and pine in Ohio.

Table 3—Weighted nutrient concentrations for surface runoff, interflow, and total water loss from the aspen-birch forest

	N				P							
	NH_4	NO_3	Organic	Total	Ortho	Organic	Total	K	Na	Ca	Mg	COD
	ppm											
					Surface runoff							
					1971							
Snowmelt	0.07	0.08	0.97	1.12	0.03	0.07	0.10	1.66	0.50	3.97	1.23	52.7
Rainfall	--	--	--	--	--	--	--	--	--	--	--	--
Annual	0.07	0.08	0.97	1.12	0.03	0.07	0.10	1.66	0.50	3.97	1.23	52.7
					1972							
Snowmelt	0.58	0.27	2.33	3.18	0.26	0.19	0.45	3.42	0.83	6.46	1.74	112.2
Rainfall	0.16	0.10	1.40	1.67	0.14	0.14	0.28	3.42	0.20	3.66	0.94	55.7
Annual	0.55	0.26	2.27	3.08	0.25	0.19	0.44	3.42	0.79	6.28	1.68	108.5
					1973							
Snowmelt	0.20	0.15	1.87	2.22	0.30	0.15	0.45	8.46	0.23	7.36	1.91	83.0
Rainfall	0.41	0.33	1.26	2.00	0.22	0.14	0.36	11.49	0.22	6.53	1.71	52.5
Annual	0.20	0.15	1.85	2.21	0.30	0.15	0.45	8.56	0.23	7.34	1.90	82.1
					Average							
Snowmelt	0.29	0.16	1.72	2.18	0.20	0.14	0.33	4.51	0.52	5.93	1.63	82.6
Rainfall	0.28	0.22	1.33	1.83	0.18	0.14	0.32	7.46	0.21	5.10	1.32	54.1
Annual	0.28	0.16	1.70	2.14	0.19	0.14	0.33	4.54	0.51	5.86	1.61	81.1
					Interflow							
1971†	0.07	0.07	1.01	1.16	0.01	0.06	0.07	0.62	1.07	3.46	1.16	50.3
1972	0.11	0.02	1.23	1.35	0.02	0.07	0.09	0.73	1.26	3.89	1.21	70.5
1973	0.10	0.01	0.81	0.92	0.01	0.05	0.06	0.60	1.40	4.07	1.31	50.0
Average	0.09	0.04	1.02	1.14	0.01	0.06	0.07	0.65	1.24	3.81	1.22	56.9
					Total water loss							
Average annual	0.19	0.10	1.36	1.65	0.11	0.10	0.20	2.63	0.85	4.88	1.42	69.5

† Computation of interflow volumes did not allow separation of snowmelt and rainfall components.

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[4] Personal communication from E. S. Verry, North Central Forest Experiment Station, U. S. Forest Service, Grand Rapids, Minn.

Losses of Na, Ca, and Mg (average annual) from the aspen-birch forest and eastern Ontario hardwoods were about equal but were less than respective losses from the New Hampshire sugar maple-beech-yellow birch forest (Bormann and Likens, 1970). Except for the Ohio watershed, average annual K loss from the aspen-birch forest was greatest. Average annual nutrient losses in interflow from the aspen-birch forest were only 3 to 38% of the nutrient losses measured in soil leachate under aspen in Michigan (Richardson and Lund, 1975). For two soils with aspen-birch cover from northern Minnesota, estimated annual percolation losses of P, K, and Ca from soil columns (Severson et al., 1975) were about the same as respective losses in interflow from WS-2.

Weighted concentrations provide a basis to compare nutrients in surface runoff and interflow and to assess the interyear variation for each. Except for Na, the average annual weighted concentrations for all the other nutrients were highest in surface runoff (Table 3). For both surface runoff and interflow, the NH_4-N to NO_3-N ratios were about 2:1. The ratio of inorganic N to organic N increased from about 1:4 in surface runoff to 1:8 in interflow, so the inorganic N forms in interflow were utilized and/or immobilized before they were collected at the slope bottom. The average weighted ortho-P concentration decreased nearly 20-fold from surface runoff to interflow, whereas the organic P decreased about 2-fold. Weighted concentrations of K, Ca, Mg, and COD in interflow were 14, 65, 76, and 70% of their respective values in surface runoff. The data indicate that interyear variations for average annual weighted concentrations were less in interflow than in surface runoff.

These data present nutrient losses from an undisturbed aspen-birch ecosystem and will provide a base for comparing water quality changes when disturbances occur. Nutrient loads from similar upland areas to surface waters can also be estimated by using average weighted concentrations (Table 3) and water losses. Site variation must be considered in estimating nutrient losses. For three soils under aspen in northern Minnesota, Alban (1974), in a soil sampling study, reported that the average coefficients of variation for N, P, K, Ca, and Mg ranged from 14 to 17, 13 to 31, and 21 to 24 for the forest floor, surface soil (0-25 cm), and subsoil (25-102 cm), respectively. Annual nutrient losses estimated from the total average annual weighted concentrations (surface runoff and interflow combined) should give reasonable loss values providing the percent interflow is about the same and the annual water loss is known. Finally, the separation of surface runoff and interflow enable a finer breakdown of output components considered in the interpretation of nutrient cycling studies.

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