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25. Stream Chemistry Responses to Disturbance

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The vegetation on 12 watersheds at Coweeta has been altered by experimentation
ing the past 50 years. Disturbances include light selection cutting and logging, clear
ting without roads and no products removed, clearcutting with various method
commercial logging, agricultural cropping, conversion of mixed hardwoods to w
pine, and conversion of hardwoods to grass accompanied by applications of lime,
tilizer, and subsequent herbicide application. Also, hardwoods on two of the con
watersheds have been partially defoliated by insects during the spring for var
periods of time. Two stream-gaging sites are on fourth-order streams and these la
drainages contain a combination of undisturbed and treated watersheds. A brief s
mary of each vegetation type represented during the period of stream chemistry rec
is given in Table 25.1. (see Chapter 1 for details of treatments).

In this chapter the objectives are (1) to characterize the chemistry of streams drai
the variety of disturbed watersheds at Coweeta in terms of mean annual inorga
nutrient concentrations; (2) to compare long-term net nutrient budgets of selected
turbances with their controls; (3) to describe changes in stream chemistry in respo
to commercial clearcutting and succession; and (4) to examine stream chemi
responses to natural disturbances.

Mean Annual Solute Concentrations

In most cases the initiation of stream chemistry studies postdate watershed treatme
Results therefore represent conditions at varying time periods since disturbance. M
annual nutrient concentrations of streams have been divided into two groups; those

Table 25.1. Summary of Treatments for Coweeta Watersheds, Vegetation Types, and Yea
Stream Chemistry Records

Watershed No.	Area (ha)	Vegetation Type Corresponding to Period of Stream Chemistry
1	16.2	White pine at ages 15 and 16 years and at 24 a 25 years
3	9.3	Yellow poplar, white pine and coppice mixture age 20 and 30 years
6	8.9	Grass-to-forest succession at age 2 through 15 years
7	58.7	Mature hardwoods for 4 years and coppice regrowth at ages 1 through 7 years
13	16.2	Coppice at ages 7 and 8 years; 16 and 17 years
8, 9, 16	759.6, 723.6 and 381.6 respectively	Mixture of mature hardwoods and variety of altered vegetation. WS 8 for 1972 through pre WS 9 and 16 1972–73 and 1980–81.
17	13.4	White pine at ages 13 through 25 years
19	28.3	Mature mixed hardwoods, 24 years and 34 yea after understory cut
22	24.3	50 percent mature hardwoods; 50 percent copp at age 18 and 28 years
27	38.8	Mixed hardwoods, period from 1972 through 1
28	144.1	Coppice regrowth, poplar cove and mature har woods, 9 & 10 years after harvest
36	48.6	Mixed hardwoods, period from 1972–1983
37	43.7	Coppice at ages 9 and 10 years, 19 years
40	20.2	Mostly mature hardwoods, 18 and 28 years aft selection cutting
41	28.7	Mostly mature hardwoods, 18 and 28 years aft selection cutting

which associated discharge records are available and streams where flow meas ments were discontinued in the past. The first group represents flow volume weig means and the latter are simple arithmetic averages.

The long-term mean flows and flow weighted chemical concentrations of tre watersheds indicate several interesting patterns (Table 25.2). On watersheds wher hardwood vegetation was most recently clearcut (7, 13, 28, 37), NO_3-N concentrat 7 to 20 years after treatment range from 0.02 to 0.18 mg L^{-1}, which substant exceed concentrations for control watersheds. Catchments converted from hardw to white pine (1, 17) also exhibit elevated NO_3-N concentrations more than 25 y after treatment. On WS 40, the light selection cut, NO_3-N levels are equivalent to trol streams. The highest NO_3-N concentrations (0.67 mg L^{-1}) observed in the Cow Basin occur on WS 6, the most severely disturbed watershed. With regard to o solutes, concentrations of Cl, Ca, and Mg are elevated on WS 6 in comparison t other streams, partly in response to previous lime and fertilizer applications. Con trations of NH_4-N and PO_4 are very low and similar to control streams. Levels of ni in the fourth-order stream of WS 8 reflect the mixture of water from control and tre

Table 25.2. Average Annual Flow Weighted Concentrations[a] (mg/L) of Dissolved Inorganic Constituents and Flow (cm) for Streams Draining Treated Watersheds at Coweeta

Watershed Number	Vegetation Type	Flow	NO_3-N	NH_4-N	PO_4	Cl	K	Na	Ca	Mg	SO_4	SiO_2
1	White pine	67	0.02	0.003	0.008	0.68	0.52	1.06	0.65	0.36	0.41	5.42
6	Grass-to-forest succession	100	0.67	0.005	0.007	1.04	0.55	1.00	0.99	0.60	0.44	6.59
7	Coppice regrowth	118	0.04	0.004	0.007	0.65	0.52	0.95	0.90	0.38	0.52	7.67
8	Combination of control and treated	132	0.01	0.003	0.005	0.52	0.38	0.78	0.81	0.32	0.65	6.65
13	Coppice regrowth	122	0.04	0.003	0.004	0.49	0.38	0.64	0.45	0.26	0.39	5.73
17	White pine	80	0.13	0.004	0.006	0.53	0.39	0.79	0.51	0.23	0.48	6.72
28	Combination coppice regrowth, even-aged poplar cove, and mature hardwoods	196	0.13	0.004	0.005	0.51	0.43	0.85	0.96	0.44	0.47	NA
37	Coppice regrowth	201	0.18	0.004	0.004	0.47	0.38	0.64	0.73	0.31	1.14	4.64
40	Uneven-aged mixed hardwoods	147	0.005	0.004	0.008	0.61	0.54	1.12	1.04	0.40	0.45	NA

[a] Period of record (June–May water year): For WS 6, 7, 8 and 17 all ions for the period 1973–1983 except for SO_4, 1974–1983 and SiO_2, 1975–1983. For WS 1 and 13 all ions for the periods of 1973–74 and 1982–83 except no SO_4 data in 1973 and SiO_2 data in 1973–74. For WS 28 all ions for the period 1973–74 except no SO_4 in 1973. For WS 37 all ions in 1973–74 and 1983 except no SO_4 data for 1973 and SiO_2 data in 1973–74. WS 40, data available only for 1973.

watersheds. The high SO_4 concentration on WS 37 is in agreement with high concei tions observed for controls, also located at high elevations. Other differences ac ions and watersheds are difficult to interpret due to influences of bedrock minera (see Chapter 6).

The second group of treated watersheds represent ungaged streams for the pe of chemistry record which typically includes two years of record; i.e., 1972–73 1980–81 (Table 25.3). Compared to the other group of treatments, these waters received less disturbance and experiments were initiated in earlier years. Nitra concentrations for most streams equal or only slightly exceed control levels. highest Ca concentrations are found on WS 3 and are influenced in part by past applications during agricultural management and in part by bedrock composi Chloride concentrations are rather uniform across watersheds, while cations s variation that may be related to bedrock mineralogy. The relatively high SO_4 con trations for all streams compared to the previous group of treated watersheds o because only one year of record was available (1980–81) and fortuitously coinc with the driest year on record, when SO_4 concentrations in all Coweeta streams highest.

Taken together, none of these disturbances have produced elemental concentra sufficient to have an adverse impact on water quality for municipalities or downst fisheries resources. Even the drastic alterations on WS 6 produced rather m increases in nutrient concentrations compared to disturbance responses in c regions of the United States. Elevated concentrations of NO_3-N appear to be a sens indicator of forest disturbance, and increased concentrations from clearcutting ap to last for at least 20 years following disturbance.

Input–Output Budgets

A second level of watershed response can be derived from nutrient budget (i output) data (Table 25.4), in which the net water budget is an important consider in interpreting nutrient fluxes. Due to much greater evapotranspiration from pine hardwoods, WS 1 and 17 show the lowest discharge and largest net water accur tions. Compared with paired hardwood covered controls, other disturbed waters have flows which are elevated above undisturbed conditions that vary with treat and time of recovery; these have already been quantified (Chapter 22).

Accumulations of NO_3-N are also indicated for some treated watersheds, but th differences are lower than for controls. WS 6 shows the most obvious contrast in parison to other ecosystems with a net N loss of 3.9 kg ha^{-1} yr^{-1}. Nitrate inputs and puts are in balance on clearcut WS 37. Net budgets for Ca and K show the smalles losses and conversely, largest within system accumulations for the white ecosystems. Highest elevation treated watersheds also produced the highest net l of Ca and K, which are mainly attributed to greater annual discharge. All of the turbed watersheds had large net annual SO_4 accumulations with values compara control watersheds.

Table 25.3. Average Annual Concentrations[a] (mg/L) of Dissolved Inorganic Constituents for Streams Draining Treated Watersheds at Coweeta

Watershed Number	Vegetation Type	NO_3-N	NH_4-N	PO_4	Cl	K	Na	Ca	Mg	SO_4	SiO_2	pH
3	White pine and yellow poplar plantations with coppice regrowth	0.013	0.004	0.005	0.55	0.42	1.05	6.28	0.48	0.74	9.30	7.00
10	Uneven-aged mixed hardwoods	0.006	0.004	0.004	0.55	0.49	0.94	1.44	0.41	0.71	9.55	6.91
19	Uneven-aged mixed hardwoods	0.002	0.003	0.004	0.50	0.32	0.70	0.40	0.23	0.80	5.85	6.69
22	50% coppice regrowth and 50% uneven-aged mixed hardwoods	0.010	0.004	0,004	0.49	0.38	0.74	0.55	0.23	0.85	6.13	6.66
41	Uneven-aged mixed hardwoods	0.010	0.005	0.004	0.58	0.49	0.99	0.97	0.40	1.05	8.06	6.79
Combination control and treated												
9		0.034	0.003	0.004	0.53	0.39	0.83	0.72	0.35	0.66	6.64	6.62
16		0.028	0.004	0.003	0.52	0.38	0.83	0.71	0.32	0.74	6.75	6.75

[a] Averages based on 2 years of records, 1972–73 and 1980–81 for all ions on all watersheds with the following exceptions: SiO_2 for all watersheds, 1980–81; SO_4 for WS 10, 19, 22 and 41, 1980–81.

Table 25.4. Average Annual Nutrient Budgets (kg/ha) for Treated Watersheds at Coweeta Hydrologic Laboratory

Watershed Number	Input	Output	Net Difference	Input	Output	Net Difference	Input	Output	Net Difference	Input	Output	Net Difference
		Water (cm)			NO_3-N			NH_4-N			PO_4-P	
1	189	67	122	2.83	0.16	+2.67	1.98	0.02	+1.96	0.25	0.05	+0.20
6	195	100	95	2.82	6.68	−3.86	1.89	0.05	+1.84	0.26	0.07	+0.19
7	188	118	70	2.69	0.42	+2.27	1.77	0.04	+1.73	0.25	0.08	+0.17
8	212	132	80	3.04	0.19	+2.85	2.02	0.04	+1.98	0.28	0.06	+0.22
13	218	122	96	3.19	0.50	+2.69	2.17	0.03	+2.14	0.30	0.05	+0.25
17	211	80	131	3.03	1.00	+2.03	2.01	0.03	+1.98	0.29	0.05	+0.24
28	277	196	81	4.10	2.50	+1.60	3.06	0.08	+2.98	0.43	0.09	+0.34
37	244	201	43	3.66	3.66	0.00	2.44	0.09	+2.35	0.35	0.09	+0.26
40	244	147	97	3.58	0.08	+3.50	2.69	0.05	+2.64	0.37	0.11	+0.26
		Cl			K			SO_4			Na	
1	5.70	4.54	+1.16	1.66	3.44	−1.78	30.32	2.71	+27.61	3.59	7.08	−3.49
6	5.42	10.38	−4.96	1.86	5.53	−3.67	30.58	4.33	+26.25	3.37	10.06	−6.69
7	5.10	7.64	−2.54	1.78	6.11	−4.33	29.20	6.07	+23.13	3.19	11.18	−7.99
8	5.81	6.87	−1.06	2.03	4.98	−2.95	33.10	8.44	+24.66	3.62	10.32	−6.70
13	6.76	5.98	+0.78	1.84	4.58	−2.74	32.25	4.52	+27.73	4.42	7.86	−3.44
17	5.85	4.24	+1.61	2.02	3.11	−1.09	32.83	3.58	+29.25	3.64	6.33	−2.69
28	10.43	9.98	+0.45	2.87	8.41	−5.54	48.01	8.94	+39.07	7.34	16.67	−9.33
37	7.98	9.40	−1.42	2.20	7.62	−5.42	38.78	21.72	+17.06	5.19	12.77	−7.58
40	8.84	8.93	−0.09	2.41	7.90	−5.49	–	–	–	6.21	16.36	−10.15
		Ca			Mg			SiO_2				
1	3.43	4.34	−0.91	0.77	2.41	−1.64	0.38	36.03	−35.65			
6	3.80	9.93	−6.31	0.78	5.99	−5.21	0.58	62.54	−61.96			
7	3.66	10.60	−6.94	0.76	4.50	−3.74	0.56	87.57	−87.01			
8	4.13	10.63	−6.50	0.87	4.25	−3.38	0.62	83.98	−83.36			
13	3.91	5.45	−1.54	0.87	3.22	−2.35	0.46	58.25	−57.79			
17	4.10	4.04	+0.06	0.87	1.86	−0.99	0.63	49.79	−49.16			
28	5.45	18.92	−13.47	1.17	8.66	−7.49	–	–	–			
37	4.56	14.59	−10.03	1.03	6.18	−5.15	0.57	86.47	−85.90			

Comparison of Control and Treated Watershed Net Budgets

A more quantitative analysis of nutrient responses to treatment can be made by c paring net budgets with the long-term net budgets of adjacent, undisturbed cor watersheds (Table 25.5). Comparisons are based on identical periods of record for ε treated watershed and its control. However, it should be pointed out that such anal are somewhat tenuous, because pretreatment calibrations are unavailable. On the o hand, inferences can be made about treatment effects, because this compara method minimizes differences in geology and weathering rates between watershe

Compared to controls, the young white pine plantations show small losses of NO no differences in NH_4-N, PO_4, and SO_4, but accumulations of 1.2 to 4.4 kg ha^{-1} for other ions (Table 25.5). Accumulations of some nutrients such as Ca, Mg, and K the pine catchments are 50 to 70% greater than net budgets for control watersheds. net gain of nutrients in the pine ecosystems is partly due to greater evapotranspira and reduced flow from pine compared to hardwoods (Chapter 22). But, the ave flow reduction of 25% observed for pine accounts for less than half of the estim cation accumulations. Biological processes are also apparently important, and the rates of pine biomass and nutrient accretions (Swank and Schreuder 1973) are major reasons for nutrient conservation by pine ecosystems.

Nitrate-N net budgets for young coppice stands shows a net loss of 2.2 kg ha^{-1} compared to mature hardwoods, and little difference in NH_4-N and PO_4. Other i except Mg, show small accumulations, and it appears that biogeochemical cycles rapidly reestablished after clearcutting. The grass-to-forest succession watershed (6) showed large losses of NO_3-N, Cl, Ca, Mg; these losses were a response to fertil tion and liming as previously noted.

Table 25.5. Net Loss or Gain of Ions for Treated Watersheds with Different Vegetative C Based on a Comparison with the Net Budgets of Adjacent Undisturbed Hardwood-Cov Watersheds.

Vegetation Type, Age and Watershed Number	NO_3-N	NH_4-N	PO_4	Cl	K	Na	Ca	Mg	S
Eastern white pine, Age 16 through 26 years (WS 1 and 17)	−0.7	−0.1	0.0	+1.8	+1.7	+4.4	+2.3	+1.2	+
Coppice, age 11 through 21 years (WS 13 and 37)	−2.2	−0.3	0.0	+1.0	+0.9	+2.8	+0.2	−0.6	+
Grass-to-forest succession, age 6 through 16 years (WS 6)	−6.8	−0.1	0.0	−4.4	−0.7	−0.1	−3.3	−2.6	−

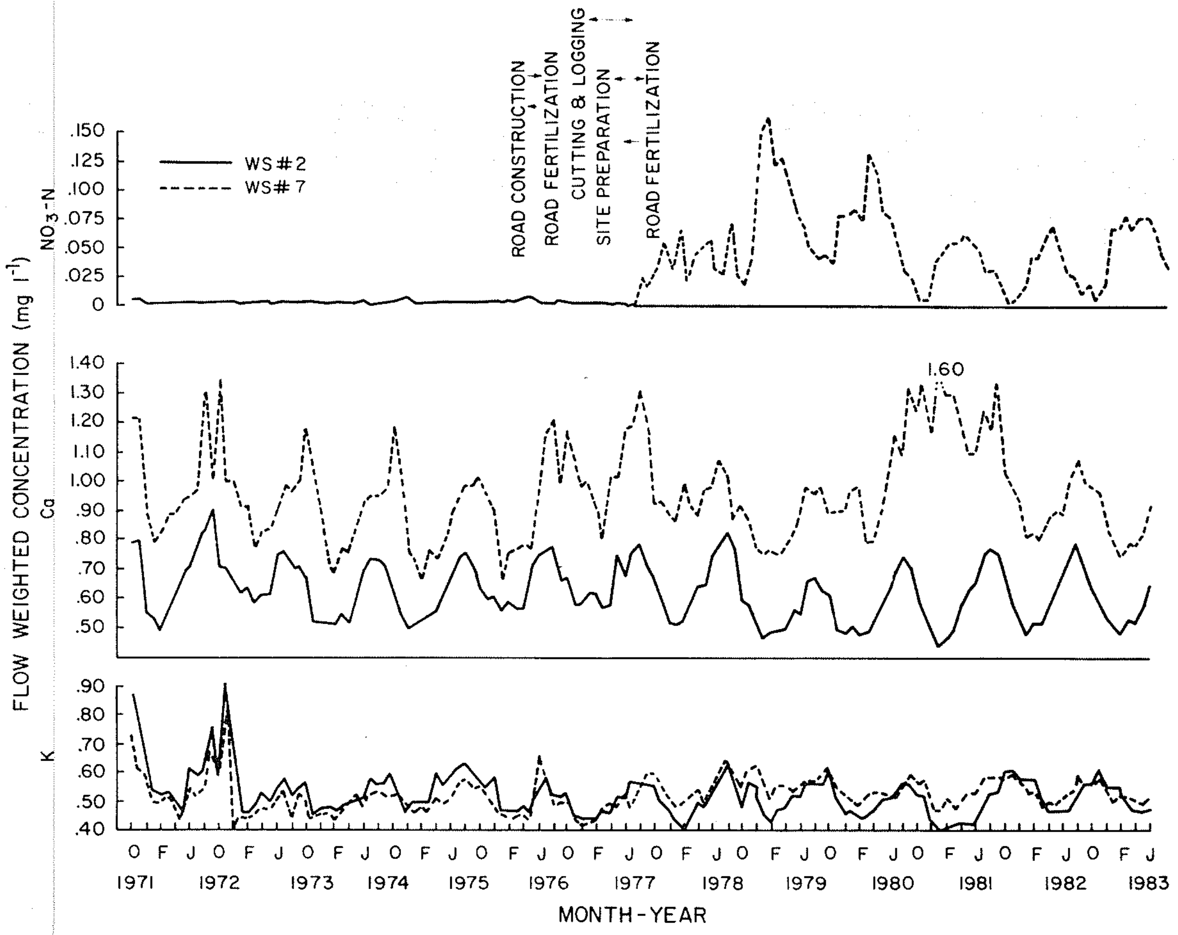
Values in kg ha^{-1} yr^{-1}.

Responses to Clearcutting, Logging, and Early Succession

The most precise documentation of effects of clearcutting and logging on st chemistry conducted at Coweeta is for WS 7, where pretreatment calibrations established. Water sample collection in the second order stream draining the 5 watershed was started in 1975 using a flow proportional sampler and also weekly samples; similar methods were used on the adjacent control watersheds (WS 2). charge on both watersheds have been measured continuously since 1935, and pro a firm basis for predicting changes in flow volumes on WS 7 due to treatment.

Management of the watershed was separated into three major operations: (1) construction and stabilization; (2) tree felling and logging; and (3) site prepara Three logging roads totaling 2.95 km were constructed on the watershed bet mid-April and mid-June 1976. Immediately after construction, road cuts and fills stabilized by seeding grass and applying commercial fertilizer (10-10-10) and l Seed, fertilizer, and lime were again applied to cuts and fills in July 1977, and t running surface of the road in June 1978. Logging began in January 1977 and completed in June. The majority of the logging was conducted from the roads w mobile cable system and the forest floor generally remained intact. The site was pared by felling the stems remaining after logging, and this operation was comp in October 1977.

Pre- and post-treatment concentrations of several selected nutrients in stream v of WS 7 and the adjacent control (WS 2) are shown in Figure 25.1. Throughout the year calibration period, mean monthly K concentrations on WS 7 were typically 15% lower than on WS 2. Elevated concentrations were observed during se months early in the summer of 1976 in response to road fertilization. Following cu and logging in 1977, K concentrations on WS 7 usually exceeded those on the co by 10 to 40% and remained elevated during most months through early 1981. Bas regression analysis, most of the monthly increases on WS 7 were statistically sig cant (0.05 level). By late 1981, the fourth year after cutting, K concentrations near expected pretreatment levels during all seasons except the summer, when cor trations were still moderately elevated. Baseline monthly Ca concentrations typically 30 to 40 mg L^{-1} higher on WS 7 compared to WS 2, but the temporal incr in Ca concentrations associated with the treatment were similar to K temporal tr (Figure 25.1). The influence of road fertilization was observed early in 1976. B ning in the summer of 1977, Ca concentrations increased significantly (0.05 l and remained elevated through late 1981. The largest changes in Ca concentratio Ws 7 (30 to 50 mg L^{-1}) occurred in the third full growing season (1981) after cut Examination of Na, Mg, and Cl concentration trends showed a similar lag betwee time of treatment and maximum response. Baseline concentrations of NO_3- streams draining undisturbed watersheds at Coweeta are typically near anal detection limits of 2 µg L^{-1} (Figure 25.1). In contrast to K and Ca, no measu increase in NO_3-N was observed at the weir when roads were fertilized in 1976, d within stream processes which probably depleted NO_3 before it reached the (Swank and Caskey, 1982). Increases in NO_3-N on WS 7 began in early fall, ab months after the initiation of cutting. Concentration changes remained low (50 µg L^{-1}) into the following summer and then peaked (100 to 150 µg L^{-1}) durin

FLOW WEIGHTED CONCENTRATION (mg l^{-1})
NO$_3$-N
.150
.125
.100
.075
.050
.025
0
WS#2
WS#7
ROAD CONSTRUCTION
ROAD FERTILIZATION
CUTTING & LOGGING
SITE PREPARATION
ROAD FERTILIZATION
Ca
1.40
1.30
1.20
1.10
1.00
.90
.80
.70
.60
.50
1.60
K
.90
.80
.70
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O F J O F J O F J O F J O F J O F J O F J O F J O F J O F J O F J O F J O F J
1971
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1974
1975
1976
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1978
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1980
1981
1982
1983
MONTH-YEAR

second winter after treatment (Figure 25.1). Thereafter, NO_3-N increases decli toward baseline values, but were still elevated the fifth year after cutting.

Taken collectively, stream solutes showed small but measurable changes in conc trations. These changes indicate disruption of nutrient recycling processes, but los must be quantified to evaluate the magnitude of management impacts. Concentrat data were combined with flow volumes to calculate total flux. Annual changes in sol fluxes were estimated from pretreatment calibration regressions of monthly flu between WS 7 and its control, WS 2, for each ion. Correlations between the watersheds were very good with r^2 values ≥ 0.92 for most ions. Exports of NO_3 NH_4-N, and PO_4 were very low on both watersheds and mean monthly values dur the calibration period were nearly identical for the two catchments. Thus, treatm effects for these ions were simply derived by difference between pre- and p treatment periods. Annual increases in streamflow and nutrient export during the 5 years after logging are shown in Table 25.6. Increased export was greatest during third year after treatment, with annual values for NO_3-N, K, Na, Ca, Mg, SO_4, anc of about 1.3, 2.4, 2.7, 3.2, 1.4, 1.2, and 2.1 kg ha^{-1}, respectively. Cutting had li effect on NH_4-N and PO_4 exports, with only small increases observed in most ye Increases in nutrient export were substantially diminished by the fifth year appeared to be approaching prelogging levels. A major factor in increased nutr export is the increased flow response that results from reduced evapotranspiration lowing cutting (Swank et al. 1982). In the first two years after cutting, annual f increased an average of 25.5 cm and then declined to 13 cm in the third year. By fifth year, flow was only 8 cm above the value expected if the watershed had not b cut. Although significant increases in solute export occurred in the first two years, m imum flow export occurred in the third year, when flow increases showed substan decline. Thus, the timing of nutrient losses is not entirely related (on an annual ba to the timing of hydrologic responses and may reflect the influence of decomposi and other nutrient recycling processes.

These relatively small changes and trends in nutrient losses clearly illustrate the c cepts of ecosystem resistance and resilience. Previous theoretical analyses sugge that mixed hardwood forests at Coweeta exhibit both high resistance and high resilie as related to changes in the N cycle associated with forest harvesting activities (Sw

Table 25.6. Annual Changes in Streamflow and Solutes Following Clearcutting and Loggin Coweeta WS 7

Time Since Treatment (May–April Water Year)	Flow (cm)	Increase or Decrease in Streamflow and Solute Export[a] NO_3-N	NH_4-N	PO_4	K (kg ha^{-1})	Na	Ca	Mg	SO_4
First 4 months	0.5	0.01	<0.01	0.04	0.43	0.42	0.24	0.26	1.17
First full year	27.3	0.26	0.03	0.12	1.98	1.37	2.60	0.96	0.81
Year 2	23.8	1.12	<0.01	0.03	1.95	2.22	2.51	1.15	−0.24
3	13.1	1.27	0.05	0.06	2.40	2.68	3.16	1.42	1.16
4	8.6	0.25	0.15	0.06	0.80	1.07	1.63	0.46	0.93
5	8.0	0.28	0.01	0.02	0.52	0.13	1.19	0.18	0.11

[a] Increase or decrease based on monthly calibration regressions.

and Waide 1980; Chapter 28). Ecosystem resistance is related to the presence of storage pools of organic matter and elements, which turn over slowly (Webster (1975) as illustrated by previously reported Coweeta data and relatively small incr(in nutrient losses shown in this study. Rapid recovery or return of nutrient loss baseline levels are indicative of high ecosystem resilience. Reasons for rapid recc of ecosystem biochemical cycles are related to high rates of net primary produ((NPP) and incorporation and storage of nutrients in successional vegetation (Ch: 12). By the third year after cutting on WS 7, aboveground NPP on mesic sites was a 60% the NPP of the original mature hardwood forest. Early successional sp exhibit high nutrient concentrations and in the first year after cutting, nutrient po(NPP for N, P, K, Mg, and Ca were already 29 to 44% of the NPP of the mature f (Boring et al. 1981). The potential roles of woody litter, soil organic matter, and r gen transformations in ecosystem nutrient retention for this clearcutting experi: are discussed in Chapters 12 and 16.

Grass-to-Forest Succession

The long-term experiment on WS 6 provides a unique opportunity to further exa the influence of successional vegetation on nutrient recycling processes as reflect(trends in stream chemistry. As noted previously, WS 6 has substantially elevated centrations of some solutes due to the nature of past disturbance. The period of w(stream chemistry determinations span vegetation succession from initial domin: by herbaceous species (1969 to 1972) to present day domination by woody spec

Mean monthly concentrations (flow weighted) of several cations for the periods to 1972 and 1979 to 1982 for WS 18, the nearby control stream, and WS 6 are sl in Figures 25.2 and 25.3 respectively. The seasonal trends of K, Ca, and Mg conce tions for the hardwood forest (WS 18) are replicated for most years, both withir across time periods. Maximum concentrations typically occur during August October, followed by declining concentrations in November and minimum valu the winter months. Concentrations begin to increase in early spring and con through the summer until a maximum is reached again in the fall season. This sea: pattern of stream cation concentrations is typical for other control hardwood w sheds at Coweeta as shown earlier in this chapter, and also for disturbed water: with different woody growth such as hardwood coppice and white pine (Johnsor Swank 1973).

Patterns of K, Ca, and Mg concentrations for WS 6 stream water (Figure 25.3) usually showed distinct seasonal trends during the herbaceous vegetation period (to 1972). However, the timing of minimum and maximum concentrations were shi That is, minimum concentrations frequently occurred in August or September w rapid increase in the fall months, maximum values in early winter, and declining centrations in the spring. In contrast, 10 years later when the cover was dominat(woody vegetation, concentration patterns appear altered (Figure 25.3) and ma returning toward trends observed for streams draining forested watersheds. For e ple, Ca, K, and Mg concentrations showed some evidence of decline during the w months; minimum concentrations frequently occurred during May or June,

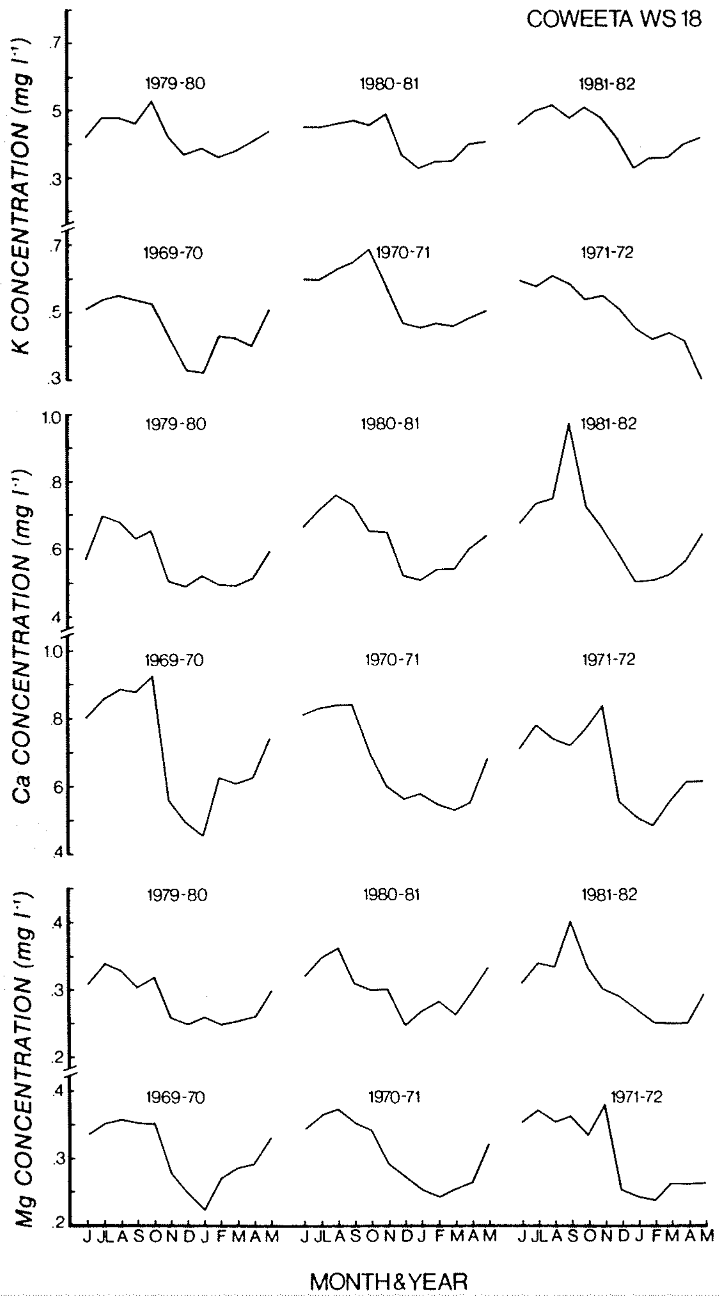

Figure 25.2. Mean monthly concentrations (flow weighted) of Mg, Ca, and K in stream v of control WS 18 during two separate 3-year periods.

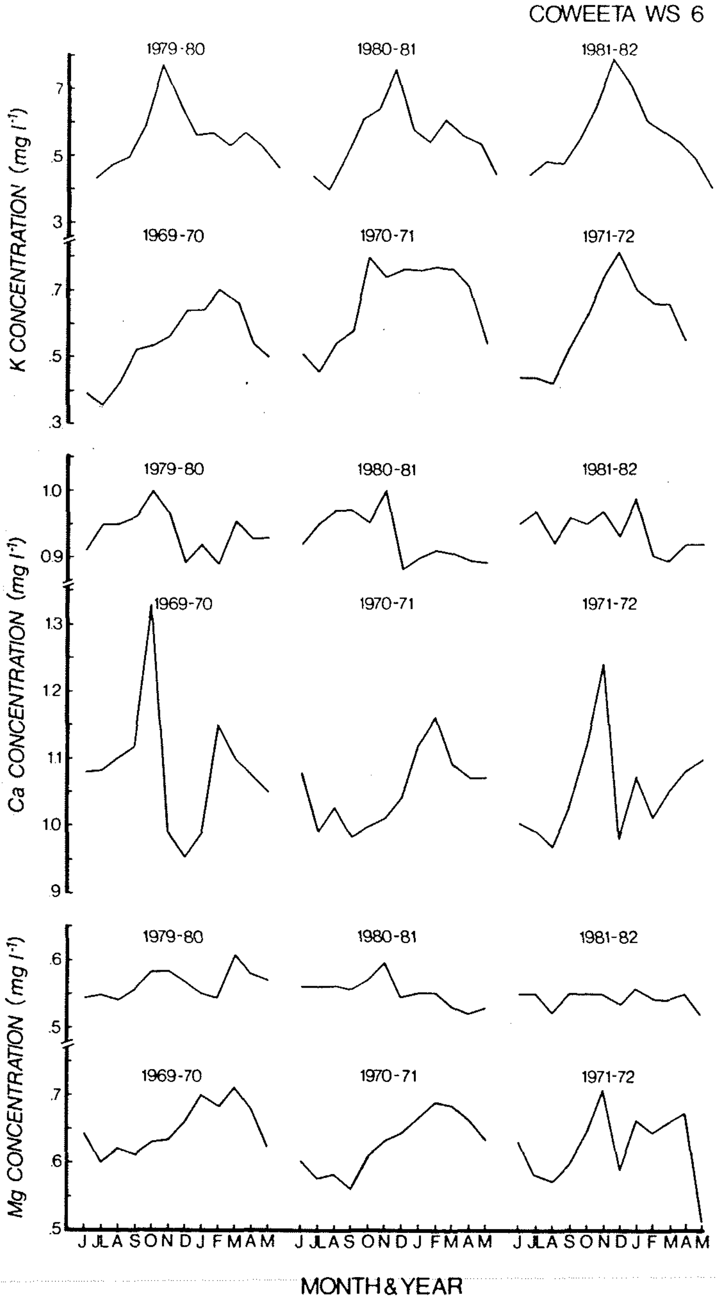

Figure 25.3. Mean monthly concentrations (flow weighted) of Mg, Ca, and K in stream wa
of WS 6 during 1969–72, when the vegetation was primarily herbaceous species compared w
monthly values in the period 1979–82, when the vegetation was dominated by woody speci

subsequent concentration increases occurred earlier in the fall months. Comparisc cation values for the early and later successional periods also indicates that the an tudes of some concentrations are damped and overall concentration levels reduced ing succession. Monthly concentrations of Ca ranged from about 0.95 to 1.25 mg in 1969 to 1972 and 0.90 to 1.00 mg L^{-1} in 1979 to 1982; Mg ranges for the two per were 0.55 to 0.70 and 0.55 to 0.60 mg L^{-1}, respectively, while K showed little cha

Monthly flow distributions and annual flows on WS 6 during these successi periods were close to those expected for a mature hardwood forest (Chapter 22). T changes in nutrient concentrations are thought to demonstrate the importance of bi processes in regulating temporal trends of cation concentrations. In the early yea succession (1969 to 1972), vegetation was dominated by a dense cover of herbac species such as horseweed (*Erigeron canadensis* L.) and cottonweed (*Erechtites i acifolia* (L.) Raf.), but by 1980 the vegetation was dominated by woody species a density of more than 1400 stems ha^{-1}. The magnitude of nutrient uptake, storage, decomposition are vastly different between herbaceous and woody plants and postulated to influence both the amount and pattern of nutrient losses. The quantit contribution of various recycling and other biological processes to nutrient dyna is unknown and difficult to ascertain, but it is hypothesized that seasonal patter stream nutrient concentrations will become reestablished as recycling proc characteristic of woody vegetation continue to develop.

Effects of Natural Disturbances on Stream Chemistry

Natural disturbances are an inherent feature of baseline ecosystems which can a nutrient supply and mobility. Insect populations and the impact of their associ activities on biogeochemical cycles have been described (Chapter 21) and der strated in several Coweeta ecosystems.

In one study, an outbreak population of the fall cankerworm (Lepidoptera: Geom dae), a spring defoliator of hardwood forests, was first observed adjacent to and o Coweeta Basin in 1969. Watershed 27, a 38.8 ha control catchment, was the pri site of infestation. Defoliation began in 1970 at the higher elevations (1400 m) o catchment and progressed toward lower elevations in ensuing years. During def tion, mean monthly concentrations of NO_3-N in stream water of WS 27 frequently above 40 mg L^{-1} (Figure 25.4). High concentrations were observed in late winte also during and immediately following the time period of cankerworm feeding April through early June). At the peak of infestation in 1974, 33% of the total leaf was consumed and NO_3-N concentrations were elevated throughout the year. Su quently, levels of defoliation were less severe, and in 1978 the population return endemic or nonoutbreak levels. The decline in the cankerworm population was ac panied by a return of NO_3-N concentrations toward baseline levels (Figure 25.4

Increased stream export of NO_3-N concomitant with defoliation was also obse on WS 36 (Figure 25.4), another high elevation catchment at Coweeta. How cankerworm infestation was not present on the catchment when stream chemistry lyses were initiated; thus, during 1972 and 1973, mean monthly NO_3-N concentra were representative of other undisturbed forest ecosystems at Coweeta (gene

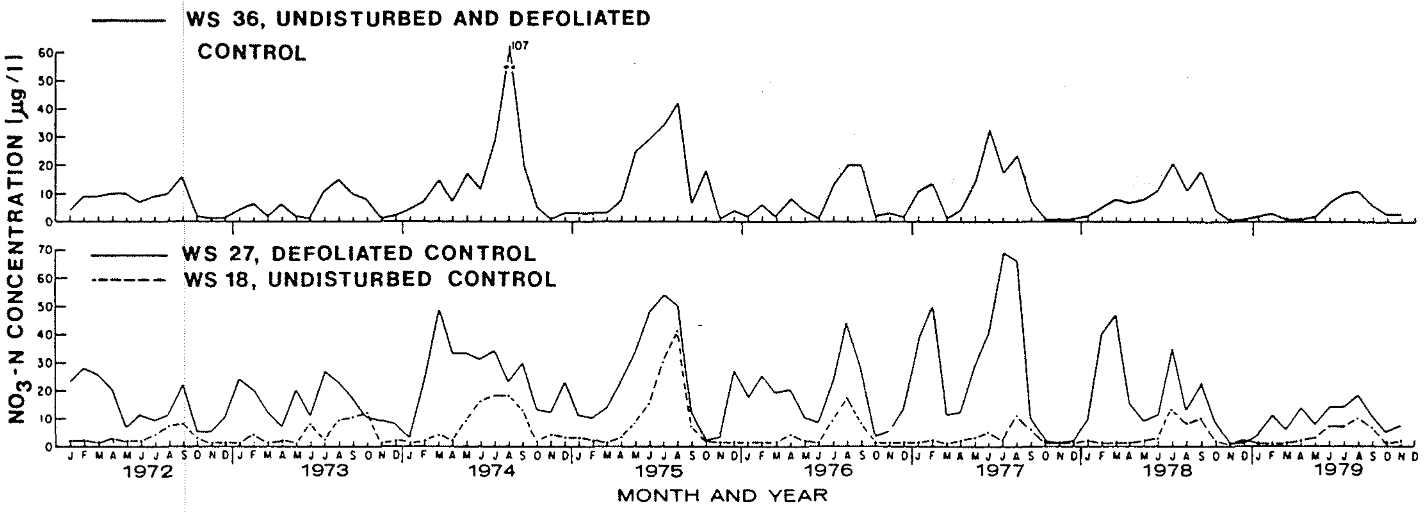

Figure 25.4. Mean monthly concentrations (flow weighted) of NO_3-N in stream water of control WS 18 compared to concentrations in streams draining two high elevation control watersheds (WS 27 and WS 36) with outbreak levels of forest defoliators. (After Swank et al. 1981. Oceologia 51:297–299.)

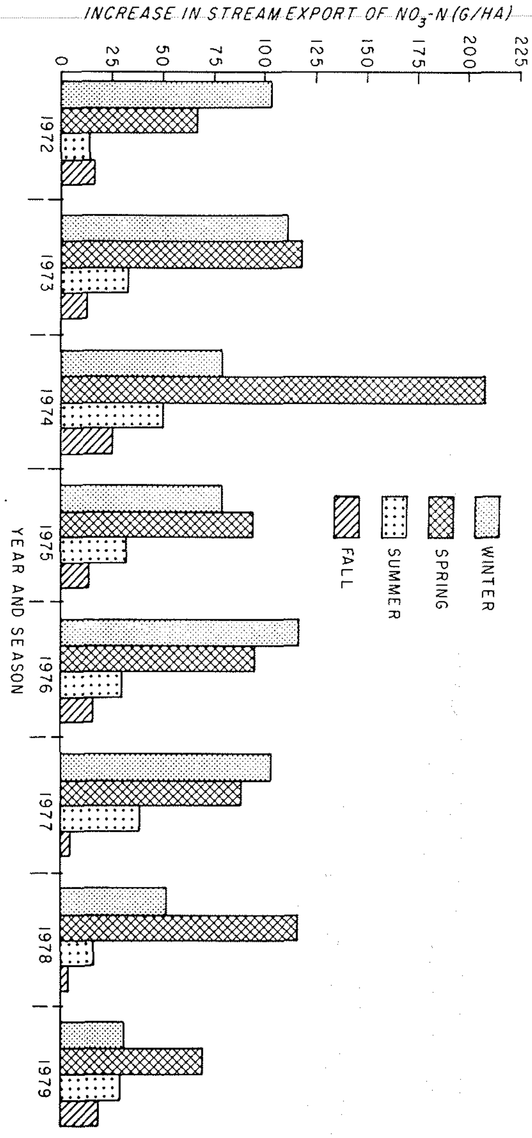

Figure 25.5. Seasonal increases in NO_3-N export from the partially defoliated hardwood forest on WS 27 during an 8 year period.

below 10 μg L^{-1}). In the late spring of 1974, concentrations began to rise and egg m surveys on trees in 1975 confirmed that infestation had occurred on the catchme although defoliation was not as severe as on WS 27. Again, by 1979, concentrati had returned to baseline levels (Figure 25.4). Elevated NO_3-N concentrations fo "control" stream in association with extensive cankerworm defoliation was a detected for another catchment about 13 km from the Coweeta Basin (Swank et 1981). The impact of defoliation on seasonal exports of NO_3-N from WS 27 are sho in Figure 25.5. Annual increased export of NO_3-N for the period shown ranged fr about 200 g ha^{-1} in 1978 to 450 g ha^{-1} in 1974, and more than 80% of the increa export occurred during the winter and spring months. This pattern was due to the co bined factors of elevated concentrations and high streamflow during these seasons co pared to the remainder of the year. Discussion of why defoliation leads to increa NO_3-N export have been given elsewhere (Swank et al. 1981).

Further evidence for insect regulation of stream nutrient responses at the ecosyst level is found on another catchment at Coweeta. Characteristics and the treatment h tory for WS 6 were previously discussed. During the period of grass and herbaceo to-forest succession, mean annual NO_3-N concentrations in stream water gradua declined from about 0.75 mg L^{-1} in 1972 to 0.50 mg L^{-1} in 1978 (Figure 25.6). Th in 1979, NO_3-N concentration showed an abrupt increase to 0.75 mg L^{-1} concurr with a heavy infestation of the locust stem borer (*Megacyllene robiniae*). Since bla locust was the dominant woody species, the infestation was distributed over most

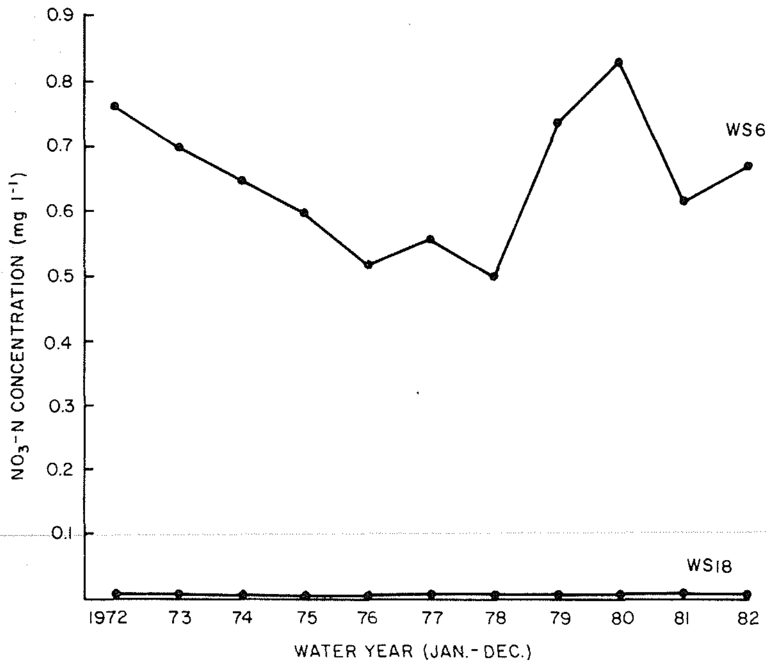

Figure 25.6. Mean annual concentrations (flow weighted) of NO_3-N in streams draining cont WS 18 and WS 6 during the period of grass-to-forest succession.

the catchment. In the subsequent year (1980), NO_3-N concentrations increased to mg L^{-1} and has remained above preinfestation levels in ensuing years. By 1982, of the black locust trees were dead, 18% were severely injured, and many of remaining stems showed some evidence of canopy decline (L.R. Boring, unpubli data). A number of hypotheses are currently under investigation to examine the f tional relationship between insect stress and increased NO_3 loss from the ecosyst these studies are focused on the effects of insect populations on nutrient uptake, q tity and quality of litterfall, nitrification, and nitrogen fixation.

Both of the preceding experiments demonstrate functional, ecosystem-level reg tion of nutrient recycling by terrestrial insects under outbreak conditions. The ca ment responses represent the integrated functional properties of an entire fc ecosystem and reflect changes in biogeochemical processes within the ecosysten both cases, changes in concentrations of other dissolved constituents such as K, Ca, and other cations are difficult to detect because baseline values are usu higher than NO_3, and differences in bedrock mineralogy between insect infested noninfested catchments influence ions sufficiently to mask small changes in i composition.

Summary

Long-term measurements of dissolved inorganic constituents of streams draining turbed watersheds have been made at Coweeta. Disturbances include comme selection cutting, commercial and noncommercial clearcutting, conversion of m hardwoods to white pine and grass covers, agricultural cropping, and natural di bances comprised of insect outbreaks. Initiation of stream chemistry studies post most watershed treatments and represent conditions at varying periods of time s disturbance. Taken together, the responses in stream chemistry to forest disturba can be summarized by the following points:

1. Over the period of observation beginning in 1972, none of the disturba produced nutrient concentrations that would have an adverse impact on water q ity for municipalities or downstream fisheries.
2. Compared to other forested regions of the United States, increases in nutrient centrations of streams are small, even for the most drastic vegetation disturban
3. Nitrate-N is a sensitive indicator of forest disturbance and although concentrat are quite low (<0.2 mg L^{-1}), elevated levels in streams draining clearcuts appe persist for at least 20 years after cutting.
4. Comparisons of annual nutrient input and output budgets for control versus turbed watersheds illustrate the importance of evapotranspiration (*Et*) process regulating biogeochemical cycles. Hardwood to white pine conversion increase reduced annual stream discharge, and consequently reduced the export of some solved nutrients. Conversely, clearcutting reduced *Et*, increased water flux, increased nutrient export.

5. Budget data, combined with process research, also demonstrate the importanc biological processes in nutrient retention and loss from forest ecosystems. Decc position, net primary production, and uptake and storage of nutrients in succ sional vegetation are important factors that regulate the magnitude and timing nutrient exports.
6. Outbreak infestations of two different insects provide evidence for insect regulat of nutrient recycling and losses at an ecosystem level as revealed by changes stream chemistry.