Water Quality After Clearcutting a Small Watershed in West Virginia[1]

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ABSTRACT

A 34-ha (85-acre) gaged watershed on the Fernow Experimental Forest, Parsons, West Virginia, was conventionally clearcut in 1969. Streamflow increased 20 cm (8 inches) during the first year after cutting, but rapid and luxuriant revegetation reduced the flow increase to only 6.4 cm (2.5 inches) during the second year. Water quality remained high. Clearcutting had a negligible effect on the stream's temperature, pH, nonstorm turbidity, and concentrations of dissolved solids, Ca, Mg, Na, K, Fe, Cu, Zn, Mn, and NH_4^+-N. Storm-period turbidity, nitrate-nitrogen, and phosphate concentrations showed slight increases, while the sulfate concentration decreased. Maximum nitrate-nitrogen concentration of 1.42 ppm was recorded during a 6.4-cm (2.5-inch) rainfall. Success in avoiding damage to water quality was attributed to careful road management, retention of a forest strip along the stream, and rapid, lush vegetative regrowth after clearcutting.

Additional Index Words: Even-aged forest management, logging, water chemistry, turbidity, specific conductance, nutrient concentrations, nutrient outflow, nitrates, stream temperature, water yield, streamflow.

More and more people are taking an interest in how our forests are managed. Responsible people are asking a valid question—how does clearcutting affect the quantity and quality of the water flowing from clearcut lands?

Years of research have shown that forest cutting increases and reforestation decreases water yield. The practical upper limit of yield increase appears to be about 4.5 mm/year for each percent reduction in forest cover, but most treatments produce less than half this amount. As reforestation proceeds after treatment water yield declines; the rate of decline varies between watersheds but appears to be related to the rate of forest recovery (3).

The question of how does clearcutting affect the quality of water flowing from clearcut lands is not as easily answered. All streams contain varying amounts of nonwater substances, either dissolved or suspended in the water. And all of these substances affect the water quality in some manner. The traditional criterion of quality in forest streams, turbidity, is no longer sufficient. Looks can be deceiving; a sparkling, crystal-clear stream may have undesirable chemical characteristics.

Only recently has research been directed to the effects of forest cutting on the chemical composition of streams draining cutover areas. A study on the Hubbard Brook Experimental Forest in New Hampshire focused attention on changes in the chemical composition of streams after deforestation (5). The treatment was strictly experimental. The trees were felled and left in place, lesser vegetation was killed, and regrowth was prevented by repeated applications of herbicide. This treatment was followed by such a large outflow of nutrients that water quality was adversely affected. Results of this experimental treatment caused many to express fears that all clearcutting will adversely affect water quality.

There is a substantial difference between the Hubbard Brook treatment and conventional clearcutting. Conventional clearcutting also features complete forest cutting; but all saleable wood is harvested and rapid forest regeneration is encouraged. On the hypothesis that large nutrient outflow is not necessarily a result of conventional clearcutting, we began a study in 1969 on the Fernow Experimental Forest to provide information about the effects of clearcutting on water quality.

In this paper *conventional clearcutting* is defined as the silvicultural method in which all trees on a given area are harvested in one cut; saleable logs and pulpwood are removed; and culls, small stems, and all other undesirable trees remaining after the harvest operation are cut or treated so that they will not interfere with the establishment of a new even-aged stand.

This report summarizes our findings and conclusions from 2 years of close observation.

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THE STUDY

The study utilized two gaged watersheds on the Fernow Experimental Forest, a USDA Forest Service research installation near Parsons, West Virginia.

A 34-ha south-facing watershed (WS 3) was clearcut while a comparable, adjacent 38-ha watershed (WS 4) was used as a control. Both watersheds had been cut between 1905 and 1910, then allowed to reforest naturally. Soils are predominantly Calvin channery silt loams derived from acid shales, siltstones, and sandstones of the Hampshire (formerly Catskill) formation (6). Slopes range between 10 and 65%. However, 20 to 30% slopes are most common. Annual precipitation averages about 1,473 mm (58 inches) and is well distributed throughout the year. The growing season has been arbitrarily determined to extend between 1 November and 30 April. A detailed description of the study area has been reported by Reinhart et al. (11).

After 7 years of calibration, a light selection cut was made on WS 3 in 1958; subsequent selection cuts were made in 1963 and 1968. These cuttings removed 14, 9, and 6% of the basal area, respectively, but had no measurable effect on discharge, dissolved solids, turbidity or temperature characteristics of streamflow. Watershed 4 has remained virtually undisturbed since its acquisition by the Forest Service in 1916. Blight-killed chestnut trees were removed during World War II, but no cutting treatment or road building has been permitted since then.

In 1969, just before it was clearcut for the present study, WS 3 supported a vigorous all-aged stand of oaks, maples, yellow-poplar, black cherry, and beech averaging 21.8 m^2/ha in trees over 12.7 cm in diameter at breast height (dbh). All operations (removal of timber, locust posts, and pulpwood, and treatments after cutting) were completed between 21 July 1969 and 11 May 1970. All stems larger than 12.7 cm dbh were cut. Smaller stems were sprayed at the base with herbicide to prevent interference with the establishment of an even-aged stand.

Since the old logging-road system was inadequate, it was reconditioned during the summer of 1969, before logging began, to permit complete access by crawler tractor and pulpwood trucks. No road was located closer than 30 m to the perennial stream channel, and where possible a 100 m spacing was maintained between roads with mineral soil exposed (Fig. 1). The system was designed so that sawlogs would be winched to the skid roads, than brought off the watershed to the landings behind a rubber-tired arch pulled by a crawler tractor. Main haul roads were located at or near the watershed boundaries. In terms of soil disturbance, the reconditioning probably was equivalent to establishing an entirely new road system.

Several steps were taken to minimize soil erosion on logging roads, the most common source of damage to water quality in managed forests. Road gradients were generally restricted to 10%. Erosion-control measures such as outsloping, broad-base dips, culverts, and gravel were used as needed. After completion of operations, the logging roads were seeded to grass. Most important, a protection strip, 10 to 20 m wide and approximately 730 m long, was left along each side of the perennial stream channel (Fig. 1). The strip extended upstream to a spring marking the head of the perennial channel.

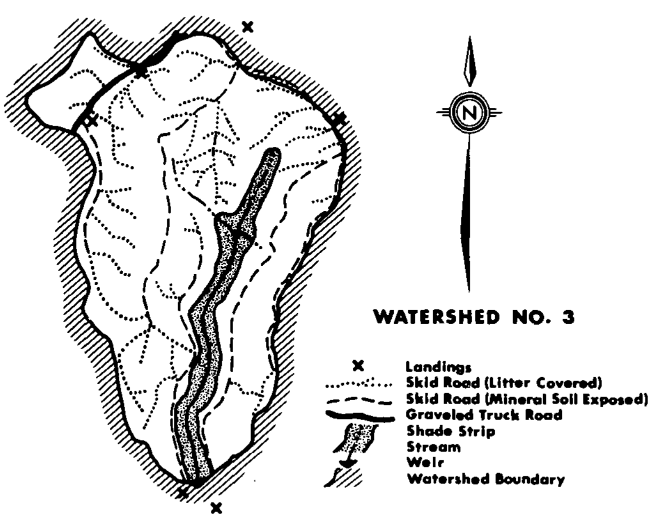

Fig. 1—Diagram of watershed 3 showing the logging road system and protection strip.

In this 3-ha strip, the large trees were harvested by selection logging. Tractors were not allowed in the protection strip; logs from the strip were winched up to the road. As a result, there was little soil disturbance close to the stream. The protection strip provided wildlife cover and an aesthetically desirable streamside environment, and prevented excessive increases in water temperature. But most important, it provided a band of highly absorbent litter-covered soil separating the roads from the stream. Cutting began at the protection strip and proceeded upslope. All logging and pulpwood cutting were limited to ridge-top areas during wet periods.

Data on *turbidity* (determined with a Hach Laboratory Turbidimeter), *specific conductance* (determined with a Solu Bridge), *pH* (determined with a Hellige Comparator), *alkalinity* (determined via the methyl orange method), and *temperature* (read weekly from maximum-minimum thermometers) extend back to 1951.[3]

Analyses of the streams' chemical composition began in July 1969. Grab samples were collected biweekly for chemical analyses from the streams draining WS 3 and WS 4—weekly after December 1970—and during high discharges produced by major storms. Storm or high flows were sampled more frequently than low or normal flows.

Concentrations of Ca, Mg, K, Na, Mn, Cu, and Zn were determined via atomic absorption procedures. Concentrations of Fe, NH_4-N, NO_3-N, SO_4, and PO_4 were determined by using Hach's FerroVer, Nessler's, NitraVer IV, SulfaVer, and PhosVer III procedures respectively (2).

Two laboratories were involved in the chemical analyses. Between July 1969 and December 1970, all water samples were shipped to the Forest Service's Regional Water Quality Laboratory at Ely, Minn. for analysis by their procedures. From 22 December to the present, all samples have been analyzed in our own laboratory, using the procedures indicated. Duplicate samples analyzed at both laboratories have yielded comparable results.

RESULTS

Clearcutting had a nonsignificant (.05) effect on maximum growing season stream temperatures measured in a shaded portion of the flowing stream just above the weir pond (Table 1). The relationship of average maximum temperature on the clearcut and control watersheds remained virtually unchanged. This was true even though increased flow caused the perennial stream to extend upchannel almost 200 m into the clearcut area, thus subjecting it to direct solar insolation. Maximum stream temperatures after treatment were in fact 4 to 5 degrees lower than a number of readings observed during the 10-year period before cutting.

Minimum stream temperatures during the growing season and maximum stream temperatures during the dormant season exhibited more variation (Tables 1 and 2). However, the confidence limits for comparable averages overlapped. There is some indication that clearcutting may have slightly lowered the average minimum stream temperature during the dormant season.

[3]The use of trade, firm, or corporation names, or specific procedures in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the US Department of Agriculture of any product, service, or procedure to the exclusion of others which may be suitable.

Table 1—Average growing-season values, 95% confidence limits, and range of selected water-quality criteria from the clearcut (WS 3) and forested control (WS 4) watersheds, Fernow Experimental Forest, Parsons, W. V.

Criterion	Water-shed	10-yr period 1959-68		1969		1970		1971	
		Average	Range	Average	Range	Average	Range	Average	Range
Dissolved solids	3	11.3±.3	(7.7-16.8)	11.3±.4	(9.1-12.6)	10.7±.4	(8.4-12.6)	12.5±.7	(10.5-16.8)
(ppm)*	4	11.7±.3	(7.0-16.8)	11.9± 5	(9.8-15.4)	11.6±.3	(9.8-13.3)	13.0±.5	(11.2-15.4)
Water temperature	3	60±1	(51-70)	60±2	(56-65)	60±1	(54-66)	61±2	(51-66)
(°F)† Maximum	4	59±1	(48-70)	58±1	(51-62)	58±1	(52-62)	58±2	(47-64)
Minimum	3	52±1	(38-62)	54±2	(43-61)	52±2	(43-58)	54±2	(39-60)
	4	51±1	(41-62)	53±2	(42-58)	52±2	(41-58)	54±2	(42-59)
Turbidity (JTU)§	3	11±8	(2-55)	26±46	(3-90)‡	16±7	(1-35)	8±3	(4-23)
Storm	4	3±1	(2-6)	5±2	(1-12)	6±3	(2-12)	5±2	(2-10)
Nonstorm	3	2±0	(0-6)	2±0	(0-2)	2±0	(0-3)	4±1	(0-7)
	4	2±0	(0-6)	2±0	(0-2)	2±0	(0-3)	4±1	(0-7)
pH	3	6.0±.0	(5.6-6.6)	6.0±.0	(5.9-6.2)	6.0±.0	(5.8-6.2)	6.0±.0	(5.8-6.2)
	4	5.9±.0	(5.6-6.6)	6.0±.0	(5.8-6.2)	6.0±.0	(5.8-6.2)	6.0±.0	(5.7-6.0)

* Determined as specific conductance: Dissolved solids = 0.7 × specific conductance. † Average of weekly maximum and minimum temperatures respectively from maximum-minimum thermometers. ‡ Value of 550 ppm resulting from breakdown of erosion control features on main logging road not included. § Values obtained before July 1970 are imprecise. Earlier data were recorded as "C" when visually adjudged to be free of turbidity. Subsequent examination of 500 samples adjudged to be free of turbidity revealed they averaged 2 JTU. Thus for computation, all values recorded as "C" were arbitrarily assigned the value of 2 JTU.

Table 2—Average dormant-seasonal values, 95% confidence limits, and range of selected water-quality criteria from the clearcut (WS 3) and forested control (WS 4) watersheds, Fernow Experimental Forest, Parsons, W. V.

Criterion	Water-shed	10-yr period 1959-68		1969-70		1970-71		1971-72	
		Average	Range	Average	Range	Average	Range	Average	Range
Dissolved solids	3	9.8 ± .3	(7.0-21.0)	9.9±.5	(8.4-12.6)	11.2±.8	(8.4-18.2)	11.8±.6	(9.8-16.1)
(ppm)*	4	10.7±.3	(8.4-24.5)	10.1±.3	(9.1-12.6)	10.7±.4	(9.1-13.3)	11.9±.5	(10.5-15.4)
Water temperature	3	47±1	(36-57)	44±2	(36-56)	48±2	(41-55)	50±2	(40-58)
(°F)† Maximum	4	46±1	(34-57)	43±2	(38-50)	45±2	(40-52)	48±2	(40-56)
Minimum	3	37±1	(30-46)	36±2	(30-42)	37±2	(28-48)	39±2	(31-53)
	4	37±1	(27-47)	36±2	(29-44)	38±2	(32-48)	41±2	(35-54)
Turbidity (JTU)‡	3	5±2	(2-25)	9±3	(1-40)	6±1	(2-12)	11±6	(7-16)
Storm	4	4±3	(2-25)	3±1	(1-8)	3±1	(1-9)	7±3	(3-10)
Nonstorm	3	2±0	(0-6)	2±0	(0-3)	2±0	(0-3)	2±0	(0-3)
	4	2±0	(0-9)	2±0	(0-2)	1±0	(0-4)	1±0	(0-2)
pH	3	6.0±0	(5.6-6.4)	6.0 ±	(5.7-6.2)	6.0±.0	(5.8-6.1)	6.0±.1	(5.2-6.2)
	4	5.9±.0	(5.5-6.4)	6.0±.0	(5.8-6.1)	5.9±.0	(5.7-6.0)	6.0±.1	(5.5-6.2)

* Determined as specific conductance: Dissolved solids = 0.7 × specific conductance. † Average of weekly maximum and minimum temperatures respectively from maximum-minimum thermometers. ‡ Values obtained prior to July 1970 are imprecise. Earlier data were recorded as "C" when visually adjudged to be free of turbidity. Subsequent examination of 500 samples adjudged to be free of turbidity revealed they averaged 2 JTU. Thus for computation, all values recorded as "C" were arbitrarily assigned the values of 2 JTU.

The turbidity data were divided into storm and nonstorm periods to provide a clearer understanding of clearcutting effects (Tables 1 and 2). Experience has shown that most of our stream turbidity is storm-related. During nonstorm periods the turbidity level is normally low, even though substantial stream discharge is occurring. For this study, stormflow was sampled during precipitation or within 30 min afterward; water samples taken at other times, regardless of stream stage, were considered of nonstorm origin. It should be emphasized that total stream discharge during storm periods (during or within 30 min after precipitation) represents less than one-third of the annual stream discharge from the watersheds.

An observation during the study emphasized the importance of roads as a source of turbidity. In late summer 1969, logging roads near the protective strip were in active use. A severe thunderstorm developed during the late afternoon of 2 September. Erosion-control structures were damaged by logs skidding on a heavily used segment of the road, and water bars were not bulldozed into the roadway. The ensuing high-intensity rain, 11.5 mm in 20 min, with a total storm yield of 34.3 mm in 2 hours, produced a rivulet that ran down the roadbed for about 90 m before leaching the road. From this point, the muddy water flowed across approximately 30 m of the protective strip before entering the stream. Turbidity was 550 JTU in water samples collected where this road runoff mingled with the stream, but was only 25 JTU a few meters upstream.

The effectiveness of the protective strip and care in use and management of the logging roads is apparent from the data (Tables 1 and 2). Except for the one incident in which our erosion control broke down, the highest turbidity recorded in the clearcut's stream was 90 JTU. This is remarkedly good when one considers that 46.6 cu m/ha (671,305 board feet) of sawlogs and 55.5 cu m/ha (521 cords) of pulpwood were removed from the watershed.

Clearcutting had no effect on stream turbidity during nonstorm periods (Tables 1 and 2). During reconditioning of the old logging-road system and while the logging roads closest to the protection strip were in active use, some increase in storm-period turbidity occurred. Because this was also the same period in which approximately one-third of the total harvest volume was removed from the watershed, a precise separation of the effects of tree cutting *per se* and the effects of removing the products from the watershed cannot be made. However, except for skid-road areas, little soil disturbance could be found. There was no evidence of overland stormflow or soil erosion on nonroad areas during or after clearcutting.

Clearcutting did not affect stream pH (Tables 1 and 2).

Clearcutting had almost no influence on the dissolved solid content of the stream draining the clearcut watershed (Tables 1 and 2). The average dissolved solid concentration (calculated as dissolved solids = 0.70 × specific conductance) for the 1969 growing season remained the same as the 10-year average despite the fact that approximately one-third of the total harvest volume was removed from the watershed between 21 July and 31 October 1969. There was a slight decrease in dissolved solid concentration in the first growing season after clearcutting and a slight increase during the second growing season; in the third dormant season the concentration was up to 11.8 ppm from the 10-year average of 9.8 ppm. It should be pointed out that the differences between comparable control and clearcut values are relatively consistent, that confidence limits for comparable averages generally overlapped, and that extreme values obtained after clearcutting fell within the range of values recorded during the 10-year reference period.

Since clearcutting and sampling for chemical analyses both began in July 1969, we do not have pretreatment references data for WS 3 and must rely on a direct comparison between the clearcut and control watersheds. We feel that a direct comparison of data from the two watersheds is valid because 20 years of measurements have shown that the streams from the two watersheds have always had similar levels of dissolved solids.

Comparison of the nutrient data from WS 3 and WS 4 reveals that, in general, the concentrations of various nutrients tended to increase or decrease similarly in both streams (Fig. 2). While the nutrient data are not easily evaluated, it appears that nitrate-nitrogen and phosphate concentrations increased irregularly and temporarily after clearcutting. Calcium and sulfate concentrations appear to have decreased. Slight, variable increases may also have occurred in the sodium, potassium, ammonium-nitrogen, copper and manganese concentrations.

A minor increase in nitrate-nitrogen concentration is apparent in the clearcut stream during July and August 1970; highest values recorded were 0.40 and 0.59 ppm, respectively. After a decline to control level, the concentration started to increase again in November, reaching a maximum of 1.42 ppm during a 64 mm rainfall on December 22. The nitrate-nitrogen concentration then declined rather rapidly through February and reached the control level during July 1971. A second increase, of much lower magnitude (maximum concentration recorded was 0.43 ppm), occurred during the second dormant season after clearcutting.

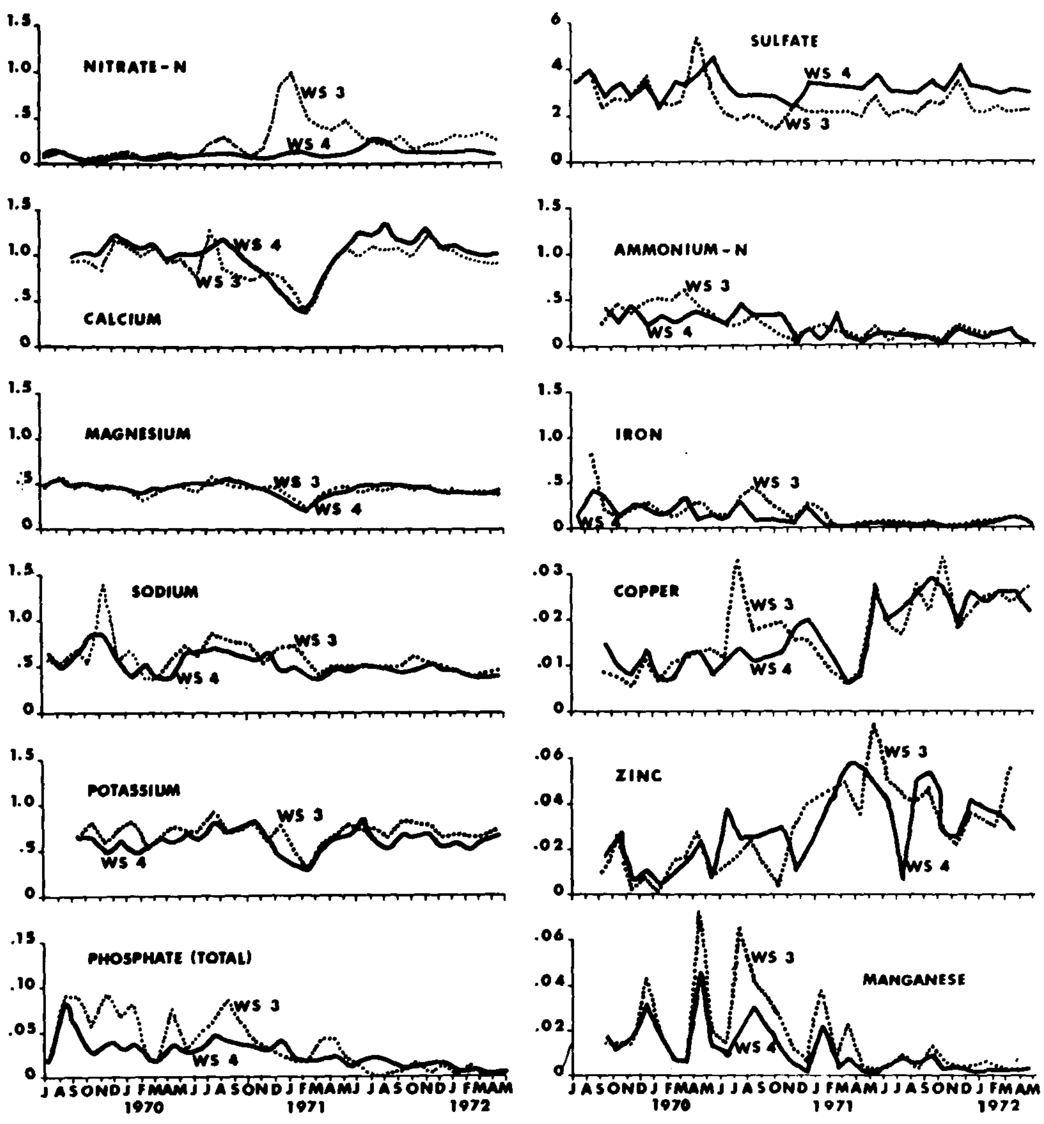

Fig. 2—Average monthly concentrations of selected nutrients from the clearcut (WS 3) and forested control (WS 4) watersheds, Fernow Experimental Forest, Parsons, W. V.

The phosphate picture is less clear because of considerable variation among measurements. However, the overall trend indicated that the phosphate content was slightly higher in water from the clearcut than in the control stream from August 1969 through November 1970.

Clearcutting may have decreased the sulfate and calcium concentrations in the stream draining the clearcut watershed. The decrease in sulfate was noted at the beginning of the first growing season after clearcutting. Since then, the sulfate concentration has been consistently about 1 ppm lower in the clearcut's stream than in the control. Calcium concentrations were substantially lower in the clearcut than the control stream during the growing seasons. Dormant season calcium concentrations were similar for the two watersheds.

Without adequate pretreatment reference data, it is impossible to interpret the differences in NH_4^+-N, Na, K, Mg, Fe, Zn, Cu, and Mn concentrations. However, the data indicate that ammonium-nitrogen concentrations in the clearcut stream increased about twofold during the dormant season while clearcutting was in progress. The concentration then dropped below that of the control stream during the first growing season. Ammonium-nitrogen concentrations have since been essentially the same for both watersheds. Sodium concentration in the clearcut stream exhibited a short-term threefold increase during clearcutting. Subsequent values were slightly higher than the controls. Potassium had a slightly, but consistently, higher concentration in the clearcut than in the control stream. Clearcutting appeared to have no effect on the Mg or Fe concentrations. Despite what may appear to be substantial differences in Zn, Cu, and Mn concentrations between the watersheds, the actual differences in concentrations and the magnitude of changes are small. This is evident when one considers the low, narrow range of concentrations for these nutrients in both streams.

Changes in streamflow volume due to treatment can be estimated by regression analysis, using measured flows from the treated and control watersheds (11). The effect of clearcutting WS 3 on stream discharge was estimated, using the regression equation developed from pretreatment calibration data. We found that flow increased 3.4 cm during the water year (May 1969 through April 1970), in which clearcutting and silvicultural treatments were in progress. Most of this increase occurred from July through October 1969, the period in which approximately one-third of the total harvest volume was removed from the watershed. During 1970, the first growing season after clearcutting, flow increased by 16.3 cm; 1970-71 dormant season flow increased 3.8 cm. An additional 6.4 cm flow increase occurred during the May 1971 through April 1972 water year.

Natural revegetation of the watershed was rapid and luxuriant. By early summer, tree sprouts and seedlings, grapevines, briars, grass, ferns, and other herbs covered about 25% of the land surface. By the end of the 1970 growing season, the cover was practically complete. Throughout the second growing season, dense thickets of tree sprouts and seedlings, brambles, briars, and other herbaceous and woody plants covered the watershed. Water demand by these plants was so great that streamflow was only 6.4 cm greater than it would have been had cutting not taken place.

When nutrient concentration and stream discharge were considered together, substantially more nutrients were discharged during the growing season from the clearcut than from the control watershed (Table 3). However, the clearcut and control watersheds had similar total nutrient discharge during the dormant seasons. Because the average concentration of the various nutrients did not differ greatly between the clearcut and control streams, most of the increased nutrient loss resulted from increased stream discharge after clearcutting.

Totaling the amount of dissolved solids discharged from the two watersheds over the 34 months of record, we find that 228 kg/ha of dissolved solids were discharged from the clearcut and 189 kg/ha from the control watershed. Thus an average of 1.1 kg/ha per month of additional dissolved solids was produced by clearcutting.

In terms of nitrate-nitrogen, 5.7 kg/ha were discharged over the 34 months of record from the clearcut and 1.9 kg/ha from the control watersheds. This means that the amount of nitrate-nitrogen discharged was increased an average of 0.1 kg/ha per month by clearcutting the watershed.

DISCUSSION

The effects of clearcutting on stream discharge were as expected: streamflow increased after clearcutting, then declined as revegetation took place. These observed changes in water yield after clearcutting are consistent with the results of 30 years of other forest hydrology research (3). Most of the increase occurred during summer months when streamflow normally is low and water demands near maximum. The increase in streamflow represents a diversion of rainfall from evapotranspiration to streamflow. As reforestation continues, transpiration and

Table 3—Nutrients discharged* from the clearcut (WS 3) and forested control (WS 4) watersheds, Fernow Experimental Forest, Parsons, W. V.

Criterion	Watershed	Growing season			Dormant season		
		1969	1970	1971	1969-70	1970-71	1971-72
		kg/ha					
Calcium	3	1.20	2.26	2.14	4.30	3.90	5.62
	4	0.87	0.61	0.59	4.58	3.77	5.86
Magnesium	3	0.64	1.15	0.94	1.87	2.22	2.32
	4	0.46	0.29	0.63	1.82	2.14	2.05
Potassium	3	0.93	1.86	1.50	3.33	3.12	3.78
	4	1.57	0.41	0.89	2.25	2.72	3.16
Sodium	3	0.73	1.79	0.94	2.56	2.85	2.48
	4	0.54	0.38	0.62	1.89	2.51	2.15
Manganese	3	0.02	0.07	0.01	0.16	0.08	0.02
	4	0.01	0.01	0.01	0.11	0.03	0.01
Copper	3	0.01	0.04	0.04	0.04	0.07	0.12
	4	0.01	0.01	0.03	0.04	0.07	0.12
Zinc	3	0.02	0.03	0.10	0.06	0.18	0.17
	4	0.02	0.01	0.09	0.06	0.18	0.19
Iron	3	0.46	0.64	0.15	1.10	0.58	0.48
	4	0.25	0.09	0.08	0.87	0.37	0.40
Phosphate (total)	3	0.08	0.13	0.02	0.29	0.18	0.03
	4	0.03	0.02	0.01	0.15	0.12	0.03
Sulfate	3	4.18	5.18	4.83	15.44	11.61	13.49
	4	2.97	1.94	4.55	13.44	15.71	17.04
Ammonium-N†	3	0.47	0.82	0.25	2.00	0.74	0.81
	4	0.30	0.27	0.15	1.22	0.57	0.71
Nitrate-N‡	3	0.11	0.40	0.61	0.48	2.59	1.51
	4	0.09	0.07	0.21	0.36	0.53	0.65
Dissolved solids§	3	14.30	25.16	25.23	40.39	59.01	63.49
	4	10.12	6.63	17.34	40.10	56.17	59.48

* Based on stream discharge and average nutrient concentration for each period.
† Presented in terms of ammonium-nitrogen (N). To express as ammonia (NH_3), multiply value by 1.21. To express as ammonium (NH_4^+), multiply value by 1.29.
‡ Presented as nitrate-nitrogen (N). To express as nitrate (NO_3^-), multiply value by 4.4. § Determined as specific conductance; Dissolved solids = 0.70 × specific conductance.

rainfall interception by the developing regrowth will increase, and streamflow will decline to pre-clearcutting level. We expect this level to be reached 4 to 6 years after cutting (12).

Clearcutting WS 3 had little effect on turbidity, the traditional criterion of forest water quality. The combination of a protective strip and carefully managed logging roads minimized soil erosion. During nonstorm periods, only minimum turbidity could be detected in the stream; however, some minor increases in stream turbidity were observed during storm periods. Greatest increases occurred during and just after the logging nearest the protective strip. Three factors were involved: (i) heavy use of the logging roads near the protective strip; (ii) some disturbance of the forest floor due to the cutting and removal of logs; and (iii) channel extension and channel scour brought about by increased stream discharge. It is quite probable that most of the increased turbidity observed during storm periods resulted from channel extension or channel scour, or both, because, except for logging and skid-road areas, little soil disturbance was observed. No evidence of overland stormflow or soil erosion was observed on non-road areas during or after logging; and any soil particles washed from the roads had to pass across the protective strip.

The fact that growing-season stream temperature increased only negligibly can be attributed to the shade strip, which prevented direct solar insolation to the channel. Although no measurements were made, the temperature probably was higher in that portion of the stream extending into the unshaded clearcut than in the shaded area above the weir pond. Presumably, part of the higher latent heat of the water flowing from the unshaded clearcut was absorbed by the cooler channel area under the shade, and part was dissipated within the cooler water which had moved through soil under the protective strip into the stream channel. There is an indication that clearcutting increased stream temperature fluctuations and lowered minimum temperatures during dormant seasons. The reason is unknown, but may be associated with increased wind movement through the clearcut area.

Our most extensive guide to water quality was specific conductance (dissolved solids). These data indicated that the dissolved solids in the clearcut stream were virtually unaffected by clearcutting. Since specific conductance (dissolved solids) reflects total ionic activity, the absence of change indicated that water quality was not impaired by clearcutting the watershed. However, this does not imply that minor changes in ionic composition did not occur.

Minor changes in ionic concentrations apparently did occur (Fig. 2). These changes were generally slight, rather irregular, and short-lived. Quantifying these changes accurately is impossible without preclearcutting reference data. However, we interpret the similarity of data from the clearcut and the control as evidence of little or no effect of clearcutting on the usefulness of the water produced.

An important point is the concentration level at which the nutrients occur in our streams. Relatively speaking, the water flowing from both our clearcut and control watersheds is of very high quality. With water of such quality, a two or threefold increase in ionic concentrations has little significance.

The differences noted in sulfate, ammonium- and nitrate-nitrogen and perhaps phosphate concentrations probably are related to clearcutting.

It is postulated that the decrease in sulfate concentration in the clearcut stream may be indirectly related to the effect of clearcutting on stream discharge. There appeared to be an inverse relationship between the sulfate concentration and increased streamflow; that is, sulfate concentrations decreased as streamflow increased after clearcutting. If this apparent relationship is valid, it indicates that sulfate was released from the watershed at a relatively constant rate and that differences in concentration were due to diluting effects of the increased flow. Our decrease in sulfate concentration after clearcutting differs from the increase reported by Fisher et al. (1) after the deforestation and herbicide treatment of Hubbard Brook. These authors propose a "very simple precipitation input-stream removal cycle for sulfur in the Hubbard Brook area." They interpret their increased sulfate concentration after deforesting and herbiciding as being supplied from a source other than atmospheric precipitation, probably dissolution of sulfur-bearing minerals, decay of plant material after absorption of gaseous sulfur compounds, or direct atmospheric absorption. Additional precipitation and stream data being collected at both locations will help to clarify the sulfate-streamflow relationship.

The increase in ammonium-nitrogen during the dormant season while clearcutting was in progress may somehow have been associated with the process of cutting and removing forest products from the watershed, but the time of year when this increase occurred would seem to rule out all possibilities except analytical. Before 1 January 1971, all water samples were shipped to an out-of-state laboratory for analysis. Although subsequent duplicate analyses between the out-of-state and Fernow laboratories produced comparable values, it is possible that changes in the ammonium-nitrogen concentration could have occurred between sampling and analyzing during the period in question.

The marked increase in nitrate-nitrogen concentration during the 1970–71 dormant season probably resulted from a flushing out of nitrates from the soil by high flows characteristic of the dormant season. It is postulated that during the growing season more nitrates had been released from decaying slash than could be taken up by the existing vegetation. Without substantial rainfall and associated subsurface water movement, part of the released nitrates remained in the soil until autumn rains had recharged the soil moisture. Subsequent winter rains then flushed the released nitrates into the stream.

The apparent increase in total phosphate concentration during and after clearcutting may also be related to the process of cutting and removing the timber products from the watershed, but the considerable variation among measurements and the relatively low range encountered suggest that the difference is more apparent than real.

Increased soil moisture, temperature, and nutrient availability undoubtedly accounted for the lush forest regrowth that followed clearcutting on WS 3, as well as the large nutrient outflow that followed deforestation of the New Hampshire watershed. The outflow of nutrients that follows conventional clearcutting elsewhere in New Hampshire (9) may be peculiar to that region's podzol soils (10) or a result of a slow revegetation in a cool climate. However, clearcutting caused no change in composition of a stream in northern Minnesota (13).

In another New England study, nutrient outflows were found to be related to the rate of revegetation, and they rapidly returned to the steady-state levels observed before deforestation (7). These authors hypothesized that dense revegetation following severe forest disturbance, such as clearcutting, acts to minimize nutrient losses from the ecosystem. Their hypothesis probably explains the low rates of nutrient loss observed after the clearcutting of Fernow WS 3.

Neither soil moisture nor soil temperature was measured on our clearcut, but data concerning both has been recorded on a nearby deforested watershed. There, soil moisture remained at substantially higher levels than in the forested watershed throughout the growing season (8). Soil temperature probably was higher, too; since in a previous study, thermal emission values corresponded to temperatures of 90F for the deforested surface as opposed to 65F for the forested surface (4).

Close observation of the clearcut watershed and its control is continuing, but there is ample reason to believe that further effects of treatment are unlikely to occur. Rapid vegetative regrowth continues with correspondingly declining streamflow. Because the concentration of dissolved solids remains virtually unchanged, the nutrient loss accompanying the decreasing streamflow necessarily will decline too. The threat of erosion has been eliminated by revegetation and the logging roads are healing over. In short, a near steady-state of nutrient cycling has been restored and it seems likely to prevail in the foreseeable future.

CONCLUSIONS

Conventional clearcutting on the Fernow Experimental Forest had only minor influences on a stream's chemical composition and nutrient discharge. We feel that these findings are of major importance. Major changes in the chemical composition and nutrient outflow of our forest streams can be avoided by responsible clearcutting. It seems reasonable to extrapolate our results to similar forested areas in central Appalachia and perhaps to most of the eastern hardwood region. We conclude that similarly forested land can be conventionally clearcut, using simple common-sense precautions, without seriously impairing the quality of water draining from the cutover areas.

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LITERATURE CITED

1. Fisher, D. W., A. W. Gambell, G. E. Likens, and F. H. Bormann. 1968. Atmospheric contributions to water quality of streams in the Hubbard Brook Experimental Forest, New Hampshire. Water Resour. Res. 4(5):1115-1126.
2. Hach Chemical Company. 1969. Colorimetric procedures and chemicals for water and wastewater analysis. 3rd Ed. Ames, Iowa. 103 p.
3. Hibbert, Alden R. 1967. Forest treatment effects on water yield. Int. Symp. Forest Hydrol. Pergamon Press, London. p. 527-543.
4. Hornbeck, J. W. 1970. The radiant energy budget of clearcut and forested sites in West Virginia. Forest Sci. 16(2):139-145.
5. Likens, Gene E., F. Herbert Bormann, Noye M. Johnson, and others. 1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook Watershed ecosystem. Ecol. Monog. 40:23-47.
6. Losche, Craig K., and W. W. Beverage. 1967. Soil survey of Tucker County and part of northern Randolph County, West Virginia. USDA SCS. 78 p.
7. Marks, P. L., and F. H. Bormann. 1972. Revegetation following forest cutting: Mechanisms for return to steady-state nutrient cycling. Science 176:914-915.
8. Patric, James H. 1973. Deforestation effects on soil moisture, streamflow, and water balance in the central Appalachians. USDA Forest Serv. Res. Pap. NE-259, 12 p.
9. Pierce, Robert S., C. Wayne Martin, Calvin C. Reeves, and others. 1972. Nutrient loss from clearcuttings in New Hampshire. Symp. on Watersheds in Transition, Proc. (Fort Collins, Colorado). Amer. Water Resour. Ass., Urbana, Ill. p. 285-295.
10. Reinhart, K. G. 1973. Timber-harvest clearcutting and nutrients in the Northeastern United States. USDA Forest Serv. Res. Note NE-170, 5 p.
11. Reinhart, K. G., A. R. Eschner, and G. R. Trimble, Jr. 1963. Effect on streamflow of four forest practices in the mountains of West Virginia. USDA Forest Serv. Res. Pap. NE-1, 79 p.
12. Swank, W. T., and J. D. Helvey. 1970. Reduction of streamflow increases following regrowth of clearcut hardwood forests. IASH-UNESCO—Symp. on the Results of Research on Representative and Experimental Basins (Wellington, N. Z.). p. 346-360.
13. Verry, Elon S. 1972. Effect of an aspen clearcutting on water yield and quality in northern Minnesota. Symp. on Watersheds in Transition, Proc. (Fort Collins, Colorado). Amer. Water Resour. Ass., Urbana, Ill. p. 276-284.