Sediment and Stream Water Quality in a Changing Environment: Trends and Explanation
(Proceedings of the Vienna Symposium, August 1991) IAHS Publ. no. 203, 1991.

EFFECTS OF SEASON AND SILVICULTURAL PRACTICES ON THE CHEMISTRY OF FIRST-ORDER STREAMS IN THE OZARK NATIONAL FOREST, ARKANSAS, U.S.A.

K.F. STEELE
Arkansas Water Resources Research Center and Department of Geology, University of Arkansas, Fayetteville, Arkansas 72701 USA
M.S. LYBRAND
Woodward-Clyde Consultants, Jackson, Mississippi 39206 USA
G.L. WHEELER
Department of Horticulture and Forestry, University of Arkansas, Fayetteville, Arkansas 72701 USA
E.R. LAWSON
Department of Forest Resources, University of Arkansas at Monticello, Monticello, Arkansas 71655 USA
J.B. WAIDE
U.S.D.A. Forest Service, Southern Forest Experiment Station, Oxford, Mississippi 38655 USA

ABSTRACT Four first-order streams in the Ozark Mountains exhibit higher concentrations of Ca, Na, K, Mg, NH_4, and Cl during the later summer months. These high concentrations are attributed to soil moisture depletion by evapotranspiration. Biological activity in the watersheds reduced the concentration of NO_3 in the streams during the growing season. Comparison with the control watershed pre-treatment data indicates that conversion from hardwoods to pines caused increases in Ca, Mg and NO_3 concentrations in stream stormflow; whereas, clearcutting with removal of trees caused a decrease in Ca, Na, K and NO_3. Thinning had minor impact.

INTRODUCTION

Four small watersheds in the Ozark National Forest, Arkansas, U.S.A., three of which received different silvicultural treatments in 1982 and have pre-treatment stream stormflow water chemistry data, provided an excellent opportunity to evaluate the seasonal and long-term forest practice effects on first-order streams. The watersheds are located along East Fleming Creek about 55 km southeast of Fayetteville, Arkansas, in northern Franklin County (Fig. 1). The watersheds are similar with the exception of forest cover and some minor soil differences.

Watershed Characteristics

The untreated and virtually undisturbed watershed serves as the control. Overstory vegetation on the watershed is mixed hardwoods, primarily of various oaks and hickories, red maple and black gum (Lawson *et al.*, 1985). One watershed was converted from mixed-hardwoods to pine. In April 1982, loblolly pine and shortleaf pine seedlings were planted into the existing hardwood stand. Two days later, hexazinone was applied at 2.0 kg ha^{-1}

active ingredient using spot-gun sprayers (Bouchard *et al.*, 1985). The hardwoods have since died and at the present time the pine trees are about 4 m high. Another watershed received modified shelterwood harvest (hereafter referred to as thinning) leaving a basal area of about 4.5 m^2 ha^{-1}. Selected trees were harvested to provide adequate spacing of residual trees which resulted in about 60% reduction of the fully stocked basal area. The fourth watershed was clearcut and regenerated by seedlings and sprouts. All merchantable trees were harvested and all others were either deadened chemically to reduce competition as in the thinned watershed or cut down to provide new sprout regeneration.

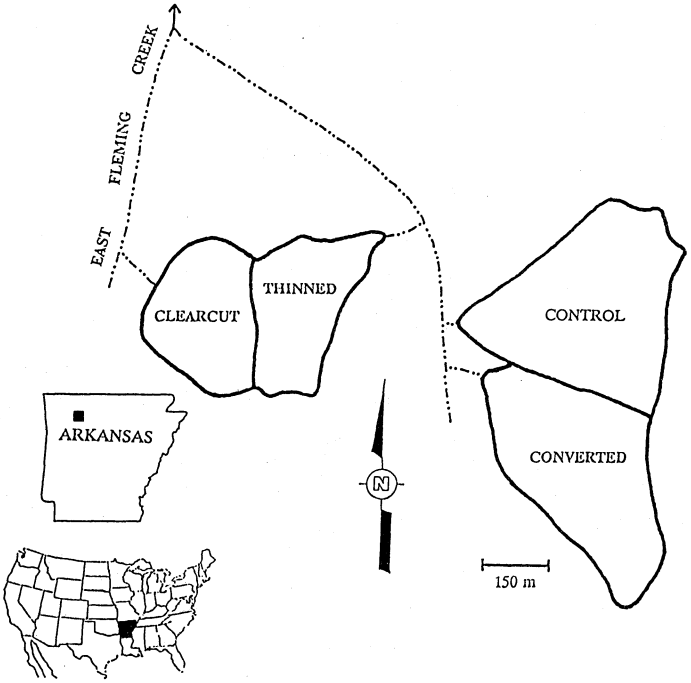

FIG. 1 Location and spatial relation of watersheds.

TABLE 1 Characteristics of watersheds.

Watershed Treatment	Drainage Area (ha)	Aspect	Elevation (m)	Relief (m)	Average Slope (°)	Soil Thickness (cm)
Converted to pine	11.47	NW	591-727	136	13	20-50
None	13.45	W	581-726	145	16	20-50
Thinned	5.93	NE	579-721	142	22	130-200
Clearcut	7.03	NW	592-691	99	15	>130

Precipitation and Hydrologic Characteristics

The 30-year average annual precipitation at Fleming Creek is 127.0 cm. During the eight-year pre-treatment study (1973 to 1980), annual precipitation ranged from 92.4 to 216.7 cm and averaged 144.4 cm (Lawson *et al.*, 1985). During the recent one-year (June 1988-July 1989) study, precipitation was about 7 cm greater than for the eight-year average (i.e., 151.1 cm).

Runoff from all four watersheds primarily is storm discharge. The streams draining the control, thinned and clearcut watersheds are intermittent with virtually no flow occurring from July through October when potential evapotranspiration is at a maximum (and soil moisture levels are low). The stream draining the converted watershed flows all year; however, the flow is exceedingly small during the summer. During the pre-treatment study (1973-1980), annual runoff ranged from 20.6 cm to 114.3 cm and averaged 55.1 cm.

Geology

The surface rocks in the study area are from the Atoka Formation which consists of interbedded thick shales and thinner sandstones. Some surface outcrops are exposed within the watersheds. Soils are generally characterized by gravelly or stony, fine, sandy loam surface horizons and gravelly or stony, clay loam subsoils. These soils are classed as Lithic Hapludult, Typic Hapludult and Typic Paleudult. There are some chemical differences in the soils among the watersheds and deeper soils are prevalent in the thinned and clearcut watersheds (Table 1) (Lawson *et al.*, 1985).

TABLE 2 Combined monthly averages of parameters in the four watersheds. All ionic concentrations are in mg l^{-1} except Fe and Zn which are in μg l^{-1}, specific conductance (SC) is in uS cm^{-1}, and # is the number of samples.

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Ca	1.79	1.77	1.39	1.06	1.24	1.34	0.96	0.78	0.75	0.90	0.98	1.09
Mg	0.96	0.90	0.89	0.99	0.80	0.78	0.70	0.59	0.61	0.69	0.67	0.78
Na	2.01	2.27	1.94	1.32	1.08	1.04	0.93	0.75	0.89	0.93	0.96	0.97
K	6.56	9.59	5.56	1.61	1.05	0.60	0.92	0.77	0.48	1.76	2.14	0.99
Fe	16.	26.	20.	28.	48.	32.	13.	22.	30.	35.	14.	26.
NO_3	0.24	0.14	<0.10	0.25	0.43	0.83	0.68	0.30	0.58	0.40	0.22	1.58
Cl	6.52	9.02	4.28	1.03	0.40	0.81	1.57	3.43	0.48	2.29	2.70	1.38
SO_4	1.78	2.06	1.60	1.60	1.73	1.76	1.77	1.79	1.88	1.48	1.58	1.36
NH_4	0.30	0.42	0.55	0.49	0.21	0.10	0.10	0.14	0.14	0.10	0.67	0.55
pH	6.98	6.61	6.77		6.43	6.99	6.74	6.58	6.40	6.29	7.66	7.19
Zn	33.	37.	18.	28.	22.	29.	11.	8.	11.	13.	10.	21.
SC	51.0	62.6	42.3	33.5	22.4	20.7	19.5	17.8	17.5	24.8	28.5	23.0
#	5	5	4	4	12	9	11	6	4	15	13	11

SEASONAL VARIATIONS

Stream samples from the Fleming Creek watersheds were collected and analyzed on a weekly basis for one year, beginning in July 1988. During the dry months of late summer and early fall, only the stream in the converted watershed flowed. Although there were differences in ion concentrations among the streams, all of the streams exhibited the same general seasonal concentration trends except for NO_3. Because of the similarity of the seasonal variation among the watersheds, monthly means for all four watersheds have been averaged to depict seasonal patterns (Table 2).

Concentrations of Ca, Mg, Na, K, NH_4, Cl and Zn increased during the summer and fall months (Table 2). These increases maybe attributed to concentration by soil moisture depletion which is primarily the result of evapotranspiration. Leaf decay during the fall also may have contributed to these higher concentrations directly, or indirectly by the production of carbonic acid which results in more vigorous chemical weathering (Cleaves *et al.*, 1970 and Slack & Feltz, 1968). The variation in pH values is consistent with these explanations. Also, some of the cations (e.g., Ca and Na) may be moving with NO_3 when it increases during the winter. Concentrations of ions were lowest during the late fall and early spring when evapotranspirational losses are less and dilution from rain runoff during these periods coincides with the highest streamflow.

Nitrate concentrations are low in all streams except the one in the converted watershed (Table 3); therefore, the seasonal variation of NO_3 concentrations in Table 2 primarily reflect only this one stream. An inverse relationship between NO_3 and most other ions was observed for the converted watershed (Table 2). Streamwater concentrations of NO_3 reached maximums during the winter and early spring months and had minimum values during late summer. The nitrate concentration in a stream is highly dependent on seasonal biological activity in the watershed. Nitrogen is removed from the soil by plants during the growing season. Consequently, very little nitrogen reaches the stream. During the dormant season, a lesser demand for nitrogen exists, therefore, nitrogen (i.e. nitrate) is more easily leached from the soil during this period. Similar seasonal trends for nitrate in streams have been observed by others, e.g. Bormann & Likens (1979) and Likens *et al.* (1970).

Although iron concentrations were low, concentrations were highest in fall and spring (Table 2). In other studies in the Ozark Highlands (Lawson *et al.*, 1984) and in the Ouachita Mountains (Lawson & Hileman, 1982), iron concentrations exhibited similar patterns. Greater reduction potential caused by increased soil moisture levels during these periods could allow iron concentrations in the streamwater recharge to increase.

Sulfate concentrations remained remarkably constant throughout the year (Table 2). The constancy of the sulfate concentration suggests that most of the sulfate enters the watersheds in precipitation and very little, if any, is the result of rock weathering or biological processes. A similar seasonal sulfate pattern in streamwater is reported by Cleaves *et al.* (1970).

COMPARISON OF WATERSHEDS

Despite the general similarity of the watersheds there were differences in water chemistry among the streams at baseflow, at about 6.5 l s-1 (Table 3). The stream in the thinned watershed had higher Ca and Mg concentrations and turbidity values than the other three watersheds. Na concentrations are highest in the control and thinned watersheds and K concentrations are highest in the converted and control watersheds. Sulfate concentrations are lowest in the clearcut watershed. The converted watershed has the highest nitrate concentrations. There was little variation of Cl and NH_4 concentrations and pH values among the watersheds. These observations generally are similar to those made by Lawson *et al.* (1985) for stormflow during the pre-treatment study, except that the thinned watershed contained the lowest Mg concentration during this study. Lawson *et al.* (1985) concluded that variations in chemical characteristics among the four streams prior to treatment may be attributed to differences in soil characteristics among the watersheds.

The relatively high turbidity values for the thinned watershed (Table 3) may be caused by several factors. First, the average slope of the thinned watershed (22°) is considerably higher than the average slopes (13-16°) of the other watersheds (Table 1). The steeper gradient for the thinned watershed may produce a greater rate of erosion and may be more capable of transporting particles than the other streams. Secondly, this watershed contains large amounts of Enders and Leesburg Series soils. These soils, which are less significant or non-existent in the other watersheds, are much thicker than major soils in the other watersheds and may influence stream turbidity.

TABLE 3 Average ionic concentrations (mg l^{-1}) and turbidity values (NTU) for baseflow from the watersheds. Only samples collected when all four watersheds (n = 9) were flowing are included in the averages.

Parameter	Control	Thinned	Converted	Clearcut
Ca	0.89	1.35	0.88	0.95
Mg	0.63	0.81	0.68	0.68
Na	0.99	0.99	0.86	0.84
K	1.12	0.93	1.34	0.87
Fe	0.03	0.04	0.02	0.03
NO_3	<0.10	<0.10	1.29	0.59
Turbidity	1.19	2.12	6.14	2.57
Zn	0.01	0.01	0.02	0.01
Cl	1.23	1.36	1.20	1.14
SO_4	2.03	1.91	1.79	1.21
NH_4	0.17	0.16	0.20	0.15
pH	6.50	6.6	6.35	6.55

LONG-TERM IMPACT OF SILVICULTURAL PRACTICES

Pre-treatment streamwater chemistry was based on the rising stage of the hydrograph; therefore, similar data from the post-treatment study were for comparisons between the two studies. Although there are similarities between pre- and post-treatment streamwater chemistry among the watersheds at Fleming Creek, major concentration differences were encountered that may be attributable to the impact of silvicultural practices. However, there are several complicating factors: (a) this study began six years after watershed treatments were performed in 1982, and (b) the results of this study only represent one year; whereas, the pre-treatment study represents eight years (1974-1981). Although most streamwater chemical responses from silvicultural practices are commonly thought by some researchers to last for only a few years, differences in the water quality of these streams indicates long-term effects (at least six-years).

TABLE 4 Percent change of post-treatment streamwater chemistry compared to pre-treatment data (Lawson et al., 1985). The top number is % Total Change, the middle number in ( ) is the % Change due to Treatment and the bottom number [ ] is the average ion concentrations as mg l^{-1} and turbidity as NTU for the rising stage of the hydrograph.in pre-treatment analytical data is <10% (Lawson et al., 1985).

Watershed	Ca	Mg	Na	K	Fe	NO_3	Turbidity
Control	+109 (----) [0.92]	+71 (----) [0.70]	-2 (----) [1.02]	-2 (----) [0.77]	-67 (----) [0.06]	-38 (----) [1.09]	-55 (----) [11.8]
Thinned	+125 (+16) [1.26]	+50 (-21) [0.84]	-14 (-12) [0.80]	-37 (-35) [0.71]	-77 (-10) [0.07]	-47 (-9) [1.10]	-52 (+3) [19.3]
Converted	+149 (+40) [1.32]	+140 (+69) [0.91]	-25 (-23) [0.73]	-4 (-2) [0.82]	-48 (+19) [0.07]	-18 (+20) [1.50]	-48 (+7) [10.0]
Clearcut	+82 (-27) [1.04]	+79 (+8) [0.74]	-21 (-19) [0.71]	-30 (-28) [0.72]	-62 (+5) [0.08]	-77 (-39) [0.50]	-62 (-7) [13.2]

Chemical data were obtained from the rising stage of the hydrograph for the four streams for both studies. Discrepancies between the pre- and post-treatment stream chemistry may be related to any or all of the following factors: (a) meteorological differences for the two studies, (b) variation because of length of records, (c) variation in biological activity, and (d) use of data from two analytical laboratories. Because of these factors, it is necessary to normalize the data (see below), so that meaningful comparisons can be made.

$$\text{(Avg POST - Avg PRE) (Avg PRE)}^{-1} \times 100 = \text{\% Total Change} \qquad (1)$$

where Avg POST= average Post-treatment annual stormflow concentration
Avg PRE = average Pre-treatment annual stormflow concentrations.

If the % Total Change is greater than 0, concentration (indicated by + in Table 4) for the post-treatment samples increase relative to the pre-treatment samples; whereas, if the % total change is less than 0, a decrease has occurred (indicated by - in Table 4). For the control stream, the concentrations of Ca and Mg in stormflow during the post-treatment study are much greater (109% and 71% increases, respectively); whereas, Fe and NO_3 are lower (67% and 38%, respectively). Na and K concentrations are essentially the same for the two studies. As noted above these differences may be due to several factors (a - d) or to the silviculture practices.

Changes in streamwater concentrations that may be attributed to silvicultural practices in the watersheds are more easily assessed if the percent change in a parameter is expressed relative to that in the control stream (Table 4) as shown in equation 2.

$$(\%\ \text{Total Change for stream}) - (\%\ \text{Total Change in control}) = \%\ \text{Treatment Change} \quad (2)$$

Large values (positive or negative) for ions in Table 4 suggest that watershed treatment had a major effect on stormflow stream chemistry and small values indicate little or no effect. Although the pre- and post-treatment data have been normalized, this procedure may not have removed all the "noise" caused by other potential factors associated with possible differences between the two studies. Because of this situation and because there are not enough data to perform statistical analyses, only % Treatment Change values >15% (in absolute value) are considered meaningful. This value seems conservative and a reasonable choice because the variation

In the converted watershed, concentrations of Ca, Mg, Fe and NO_3 are higher in post-treatment water samples. K concentrations remained about the same and Na decreased following conversion. The changes in these ions may be indirectly caused by the deadening of the trees. After conversion was performed, a lesser amount of these nutrients would be susceptible to nutrient cycling by the trees and, therefore, more of these ions would be leached from the soil during rain events. Perhaps more importantly, the dead trees left in the watershed may have created a new source for some of these ions. The conversion from hardwoods to pines also may contribute to increased base cation concentrations in the streams because pines cycle nitrogen less efficiently and are less dense than hardwoods and thus have demand for less base cations (Kimmens, 1987) which makes more of these ions available for leaching and release into streamwater.

Despite the similarities between thinning and clearcutting, all ions decreased in concentration in the clearcut watershed except Mg and Fe, both of which showed little change (Table 4). The fact that most of the trees were removed from the clearcut watershed and the deadened trees were left in the converted watershed may explain this difference in ion concentrations. This decrease in ion concentration in the clearcut watershed relative to that in the converted watershed, supports the earlier hypothesis that the deadened trees in the converted watershed are a major source of ions (Ca, Mg, NO_3 and Fe), directly or indirectly, during stormflow.

In the thinned watershed, Ca showed a slight increase while Mg and K decreased (Table 4). Changes in ion concentrations in the thinned watershed would not be expected to be as great as those in the converted and clearcut watersheds since the degree of disturbance in this watershed is relatively low.

The % changes and post-treatment stormflow turbidity values are shown in Table 4. Although turbidity values for both studies are relatively low, average turbidity levels for all four watersheds are about one half of those previously reported. This observation suggests that the storms for the one year post-treatment study were less intense, i.e., caused lower turbidity or there were biological activity differences. However, because the percent differences of the treated watersheds relative to the control watershed are all less than 8%, it is apparent that these silvicultural practices did not have a long-term effect on turbidity levels in the watershed streams. Regrowth of vegetation within the watersheds apparently has reduced any excess erosion which may have been initially caused by treatments. It is estimated that the vegetation density on the clearcut watershed is about 5 times greater than that on the converted watershed.

In summary, dead trees left in the converted watersheds apparently have contributed Ca and suspended organic matter (increased turbidity) to the streams. In addition, conversion to pines would tend to increase Ca, Mg, Fe and NO_3 concentrations because conifers do not accumulate as much base cations and N as hardwoods. streamwater data suggest that clearcutting and removal of the cut trees has lowered Ca, Na, K and NO_3 stream concentrations and thinning has resulted in lower K and Mg concentrations.

ACKNOWLEDGEMENTS U.S. Forest Service Southern Forest Experiment Station, University of Arkansas Agricultural Experiment Station and Arkansas Water Resources Research Center provided support for this project.

REFERENCES

Arnold T. & Cash, B. (1977) Fleming Creek Experimental Watersheds--Soil Report. USDA Forest Service and Soil Conservation Service, Russellville, AR.

Bormann, F.H. & Liken, G.E. (1979) *Pattern and Process in a Forested Ecosystem.* Springer-Verlag, New York.

Bouchard, D.C., Lavy, T.C. & Lawson, E.R. (1985) Mobility and persistence of hexazinone in a forest watershed. *J. Envir. Qual.* **14**:229-233.

Cleaves, E.T., Lynch, J.A., & Bricker, O.P. (1970) Geochemical balance of a small watershed and its geomorphic implications. *Geol. Soc. Amer. Bull.* **81**:3015-3032.

Kimmens, J.P. (1986) Forest Ecology. MacMillan Publishing Company, New York, NY.

Lawson, E.R., Rogerson, T.L. & Hileman, L.H. (1985) Water quality of stormflows form hardwood forested catchments in the Boston Mountains. In: *Proceedings Fifth Central Hardwood Forest Conference, Urbana-Champaign, IL*, 215-221.

Lawson, E.R., Rogerson, T.L. & Hileman, L.H. (1984) Nutrients in storm runoff from hardwood-forested watersheds in the Ozark highlands. In: *Proceedings Third Biennial Southern Silviculture Research Conference*, Atlanta, Ga, 558-564.

Lawson, E.R. and Hileman, L.H. (1982) Nutrient distributions in runoff from Ouachita Mountain watersheds. In: *Proceedings Second Biennial Southern Silviculture Research Conference*, Atlanta, Ga, 477-482.

Likens, G.E., Bormann, R.S., Pierce, R.S., Eaton, J.S. & Johnson, N.M. (1977) *Biogeochemistry of a Forested Ecosystem.* Springer-Verlag. New York.

Slack, K.V. & Feltz, H.R. (1968) Tree leaf control on low flow water quality in a small Virginia stream. *Envir. Sci. & Tech.* **2**:126-131.