WATER QUALITY OF STORMFLOWS FROM HARDWOOD FORESTED CATCHMENTS IN THE BOSTON MOUNTAINS[1]

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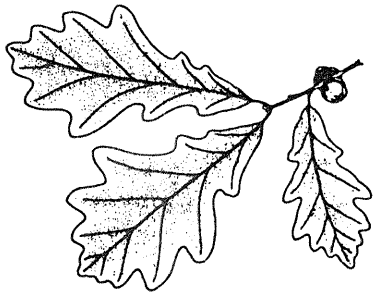

ABSTRACT.--Water quality of stormflows from four forested watersheds in the Boston Mountains of Arkansas was monitored for 8 years. Analyses focused on: P, K, Ca, Fe, Na, NH_3-N, Mg, Mn, NO_3^-, HCO_3^-, and total hardness. Turbidity, pH, and specific conductance were also determined. Concentrations of Fe, Mg, HCO_3^-, Mn, K, NH_3-N, and NO_3^- in stormflow were found to vary among watersheds, reflecting differences in soils or vegetation. Seasonal changes were also evident for Ca, K, Na, HCO_3^-, Mn, P, and total hardness. The data provide basis for determining downstream loading of nutrients.

INTRODUCTION

Nutrient levels in surface waters are becoming increasingly important as water-quality considerations in managing streams and lakes (Douglass 1974). Excesses of certain nutrients can greatly increase the algal productivity of streams and lakes, thus decreasing suitability of habitat for other aquatic organisms. Such excesses can also create problems when water is used for municipal, industrial, or agricultural purposes. The catchments evaluated in this study are in the Upper White River Basin, which provides water for several municipalities in northern Arkansas. Little information on nutrient loading in the region is available for use by stream and lake managers.

The objective of this study was to determine nutrient levels and characteristics of stormflow from relatively undisturbed hardwood forested watersheds in Arkansas's Upper White River Basin.

STUDY AREAS

The four small headwater catchments used in this study are located in northwest Arkansas on the Ozark National Forest southeast of Fayetteville, AR. Aspects range from west to northeast, elevations from 1,920 to 2,375 feet, and slopes average 30 percent. The watersheds, WS-1, WS-2, WS-3, and WS-4, have areas of 28.3, 33.2, 14.6 and 17.4 acres. Hydrologic characteristics of the watersheds were previously reported by Rogerson and Lawson (1982).

The watersheds are on flat-bedded sandstone and shales and have similar topography, geology, soils, and forest cover. Soils are derived from sandstone, siltstone, and shale of the Atoka formation of the Pennsylvanian Age. Soil series are Mountainburg stony fine sandy loam and Hartsell fine sandy loam on the ridges and upper slopes; Leesburg stony, fine sandy loam on the middle and lower slopes; and small scattered areas of Nella, Linker, and Enders gravelly, fine sandy loams. The Mountainburg and Hartsell soils are 1.3 to 2.6 feet deep, low in fertility, rapidly permeable and strongly acidic. Leesburg and Nella soils are 4.0 to 6.0 feet deep, moderate in fertility and permeability, and medium to strongly acidic (Garner *et al.* 1977). Linker and Enders soils are low in fertility, strongly acidic, and slow to moderately permeable. Enders soils may be more than 6.0 feet deep, but Linker soils have depths of only about 2.4 feet. Mountainburg soils are classed as loamy-skeletal, siliceous thermic family members of the Lithic Hapludult subgroup. Hartsell and Linker soils are fine-loamy, siliceous, thermic, Typic Hapludults. Leesburg and Nella series are members of the fine-loamy, siliceous, thermic family of Typic Paleudults. The Enders soils are classed as clayey, mixed, thermic, Typic Hapludults (Garner *et al.* 1977).

Overstory vegetation on the watersheds can be classified as mixed hardwoods and consists primarily of white oak (*Quercus alba* L.), red oak (*Q. rubra* L.), various hickories (*Carya spp.*), black oak (*Q.*

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velutina Lam.), red maple (Acer rubrum L.), and black gum (Nyssa sylvatica Marsh.). Other species encountered less frequently in the overstory were black cherry (Prunus serotina Ehrh.), white ash (Fraxinus americana L.), black locust (Robinia pseudoacacia L.), Ozark chinkapin (Castanea ozarkensis Ashe), and sugar maple (Acer saccharum Marsh.). The primary understory species were dogwood (Cornus florida L.), serviceberry (Amelanchier arborea Michx.), ironwood (Ostrya virginiana Mill), sassafras (Sassafras albidum Nutt.), and witch-hazel (Hamamelis virginiana L.).

Trees greater than 2.5 inches d.b.h. occurred at an average density of 311 per acre on the four watersheds. Forty-six percent of the stems were saplings (2.5 to 4.5 inches d.b.h.), 43 percent were poletimber sized (4.6 to 10.5 inches d.b.h.), and 11 percent were sawtimber sized (greater than 10.5 inches d.b.h.). Basal area averaged 84.9 ft^2 per acre. Saplings accounted for 11 percent of the basal area, poletimber 41 percent, and sawtimber 48 percent. More than 60 percent of the stems were oaks and another 14 percent were hickories. The oaks accounted for more than 70 percent of the basal area (red, 40 percent; white, 21 percent; and black, 10 percent), and hickories comprised 11 percent.

Warm summers and moderately cold winters depict the climate of the study sites. The mean annual temperature is 59.4°F, with a January average of 38.1°F and a July average of 90.2°F. Temperatures of 0°F or slightly lower can occur during the winter months. The average growing season is slightly over 200 days, occurring from early April to late October. Long-term, average, annual precipitation is 50 inches (U.S. Department of Commerce 1982). Precipitation is distributed fairly evenly throughout the year, although the growing season rainfall averages more than 31.5 inches. Most precipitation occurs as rainfall, but light snow normally falls a few times each year.

STUDY METHODS

Field Measurements

Stormflow from the 4 watersheds used in this study was measured using 3-foot H-flumes. Depth of flow in the flumes was measured with FW-1 water level recorders and converted to volume. Nearly all of the stormflow in these ephemeral to intermittent flowing streams originates as subsurface flow.

During the period 1974 to 1981, 1-liter water samples were automatically collected at stage heights of 0.05, 0.10, 0.20, 0.30, 0.50, 0.75, and 1.00 feet in the flumes. The technique developed by Sartz and Curtis (1967) allows sampling during the rising stages only and prevents water from flowing out of the sample bottle once it is full. Samples were usually, but not always, collected at the same stage heights in a given runoff-producing storm. Date of storm occurrence was recorded for each sample. Samples were transported as soon as possible after each runoff-producing storm and were stored in a refrigerator or freezer until analyses could be performed.

Laboratory Analyses

All laboratory analyses and measurements were performed by the University of Arkansas Soil Testing Laboratory at Fayetteville, Arkansas, using standard methods (American Public Health Association 1980). These methods are compatible with Environmental Proctection Agency standards (U.S. Environmental Protection Agency 1976). Analyses of all individual elements were not made throughout the entire study period due to equipment availability or to insufficient quantity of water collected. Analyses were made on unfiltered samples.

The following determinations were made for each sample, except where sample quantities were insufficient: pH, iron (Fe), manganese (Mn), total phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), total hardness, ammonia nitrogen (NH_3-N), nitrate (NO_3^-), bicarbonate (HCO_3^-), specific conductance, and turbidity. All nutrient data are given in milligrams per liter (mg/l). Specific conductance is reported in micromhos/cm at 25°C, and turbidity is reported in nephelometric turbidity units (NTU).

Data Analyses

Water sample data for most nutrients were collected during the entire period (1974 to early 1981). The number of samples collected for each storm varied from one to seven, depending on stormflow response of each watershed. The total number of samples for most nutrients ranged from 159 on watershed WS-3 to 243 on watershed WS-1 over the study period.

The statistical analyses to provide means, standard deviations, and standard errors for watersheds, years, and seasons were performed using the Means Procedure provided by Statistical Analysis System Institute, Inc. (1979).

RESULTS AND DISCUSSION

Some differences in average nutrient concentrations in runoff were found (table 1), even though large variations among these similar watersheds would not be expected. Watershed WS-3 showed higher levels of Fe, Mg, and HCO_3^- than watersheds WS-1, WS-2, and WS-4. Also, Mn, K, NH_3-N, and NO_3^- levels were higher on WS-3 than at least one other watershed. Watersheds WS-1 and WS-2 had the lowest concentrations of these nutrients.

Average concentrations of P, Ca, Na, and total hardness did not differ greatly among the four watersheds. Levels of P in this study were low and similar to those found in the Ouachita Mountains (Lawson and Hileman 1982) and in the Springfield-Salem Plateau (Lawson et al. 1985). Calcium levels found in the latter region were much higher than those in this study and in the Ouachita Mountains study. Average levels of Na are low for all watersheds, but slightly higher than those found in the studies mentioned above.

TABLE 1.--Average nutrient concentrations (mg/l) and standard errors (SE) in stormflow from Boston Mountain watersheds (1974-1981).

Nutrient	Watershed									
	WS-1		WS-2		WS-3		WS-4		All-WS	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Fe	0.13	0.012	0.18	0.020	0.32	0.029	0.20	0.017	0.20	0.010
Hardness	30.83	2.653	28.03	1.999	26.86	1.934	27.49	2.104	28.30	1.148
Mn	0.05	0.006	0.04	0.007	0.07	0.011	0.08	0.012	0.06	0.004
P	0.16	0.011	0.17	0.012	0.23	0.019	0.18	0.013	0.18	0.007
K	0.85	0.045	0.79	0.040	1.12	0.069	1.01	0.057	0.92	0.026
Ca	0.53	0.052	0.44	0.038	0.56	0.048	0.56	0.054	0.51	0.024
Mg	0.38	0.021	0.41	0.023	0.56	0.029	0.42	0.024	0.43	0.012
Na	0.97	0.036	1.04	0.035	0.93	0.055	0.90	0.052	0.96	0.022
NH_3-N	0.27	0.021	0.34	0.038	0.44	0.042	0.36	0.039	0.34	0.018
NO_3^-	1.84	0.102	1.76	0.092	2.06	0.125	2.14	0.108	1.93	0.053
HCO_3^-	10.72	0.618	10.80	0.581	14.06	0.834	11.49	0.639	11.56	0.330

Differences in nutrient concentrations in stormflow from the four watersheds are probably related to variations in soil and hydrologic response characteristics. Watersheds WS-3 and WS-4 were found to have less stormflow and higher overall nutrient concentrations in water sampled during this study period compared to watersheds WS-1 and WS-2 (Rogerson and Lawson 1982). This suggests that dilution may occur during the stormflow processes. Leesburg soils tend to be more prevalent on watershed WS-3 and WS-4 than on WS-1 and WS-2, especially along the main stream channels (Arnold and Cash 1977). Watershed WS-3 also contains some Ender and Nella series soils that are deeper and have thicker surface layers. Watersheds WS-1 and WS-2 contain Leesburg soils but they have a larger percentage of their area mapped as Mountainburg soil series or the Mountainburg-Nella association. Differences in soil characteristics among the watersheds seem to influence the chemical characteristics of stormflow. These soil characteristics are described in the "Study Areas" section. Differences in characteristics of vegetative cover could also influence water quality of streams. Similar variability was found by Martin et al. (1984), who reported that differences in stream nutrient levels among uncut watersheds in the same forest type were as large as changes in nutrient levels that might occur due to various levels of cutting.

Average concentrations of several nutrients varied among months of the year and showed seasonal trends. Levels of Ca, K and Na increased substantially during the summer and early fall months, although Ca levels declined sooner (fig. 1). Wagner and Steele (1982) found that the levels of Ca, K and Na ions in wet atmospheric deposition were greatest in the spring and late summer months. Thus, seasonal differences in nutrient content of stormflows may also be influenced by varying inputs of nutrients in precipitation. It is also possible that seasonal changes in hardwood vegetation and decomposition of litterfall may result in seasonal differences in nutrient levels in stormflow.

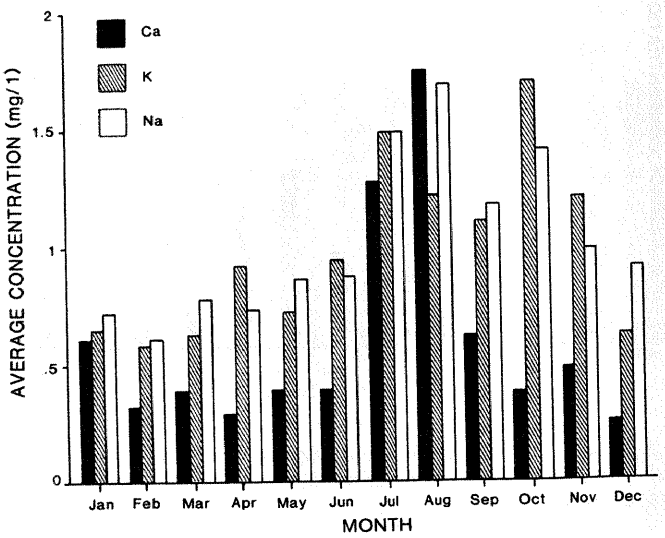

FIGURE 1.--Average monthly concentrations of Ca, K, and Na in runoff from Boston Mountain watersheds (1974-1981).

Total hardness levels were greatest in July, August, and September, and lowest in April and May (fig. 2). Bicarbonate (HCO_3^-) concentrations also showed seasonal trends with the highest values occurring in the summer (fig. 2). Manganese concentrations in stormflow were highest in July and August, but somewhat variable in other months (fig. 3). Levels of P tended to peak in March, followed by a decline and another peak in September (fig. 3).

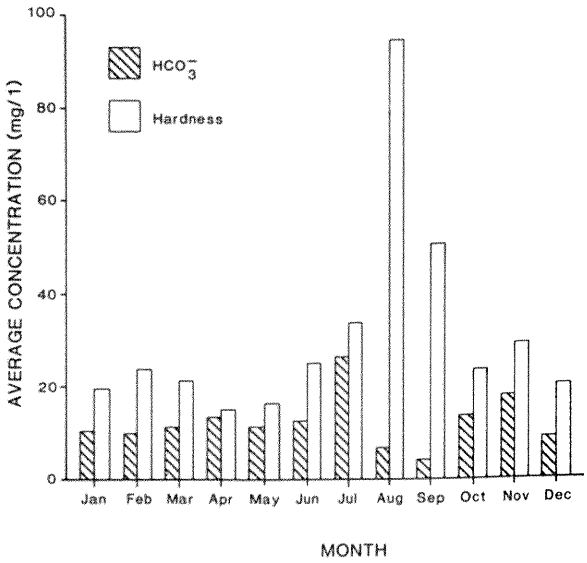

FIGURE 2.--Average monthly concentrations of HCO_3^-, and total hardness in runoff from Boston Mountain watersheds (1974-1981).

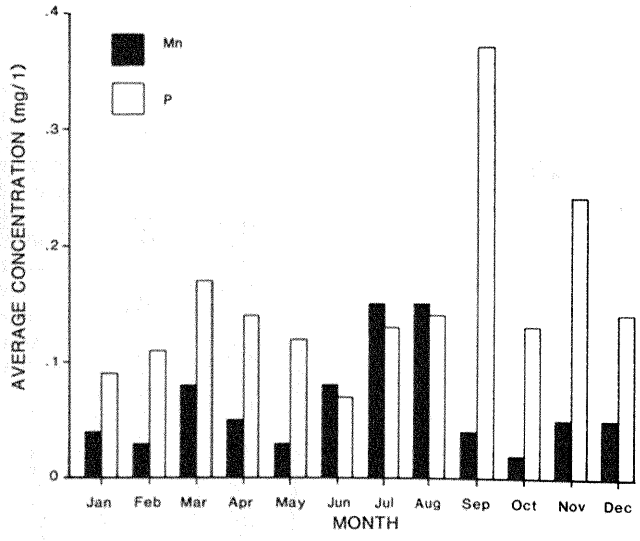

FIGURE 3.--Average monthly concentrations of Mn and P in runoff from Boston Mountain watersheds (1974-1981).

Nitrate (NO_3^-) levels varied considerably among months with a peak of about 3.5 mg/l occurring in July and August, and a second peak of about 2.4 mg/l in March (fig. 4). In this study, average monthly NH_3-N peaked at 1.0 mg/l in August. However, in another study, atmospheric input of ammonium (NH_4) and nitrate (NO_3^-) nitrogen has been reported to be greatest during the spring months (Wagner and Steele 1982). Nitrogen chemistry of two small watersheds in the eastern United States was significantly influenced by atmospheric deposition of nitrogenous compounds (Moore and Nuchols 1984).

The average pH of stormflow varied somewhat among the four watersheds, with WS-4 having a lower

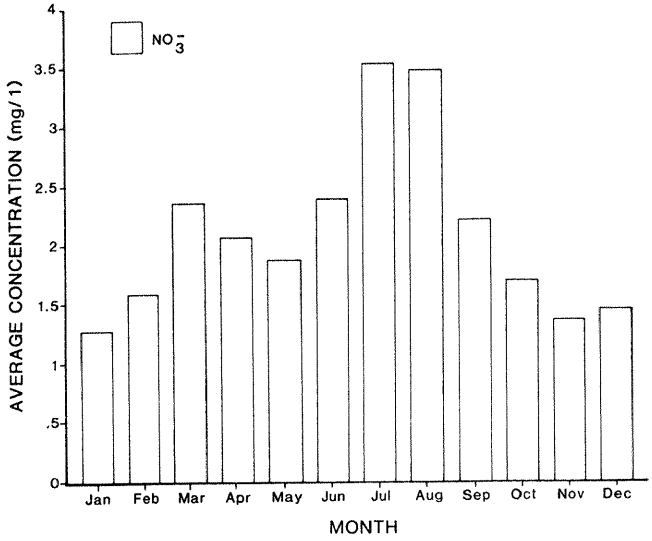

FIGURE 4.--Average monthly concentration of NO_3^- in runoff from Boston Mountain watersheds (1977-1981).

value than watersheds WS-1, WS-2 and WS-3 (table 2). Average monthly pH ranged from 5.8 in June to 6.3 in January, but did not show any seasonal trends (Unpublished data). However, seasonal changes in pH of stormflow in Arkansas have been reported, with generally lower values during the summer months (Lawson and Hileman 1982). The pH of precipitation is also known to vary somewhat with season (Wagner and Steele 1982) and may cause similar variations in the pH of stormflow. Soil pH levels have also been reported to show seasonal trends (Keogh and Maples 1972).

Average annual pH also changed considerably during the study, declining from about 6.1 to 5.6 between 1974 and 1981 (fig. 5). The cause for this decline is unknown, but pH and chemical changes in atmospheric deposition are suspect. A similar trend was found for pH of stormflow in the Ouachita Mountains (Lawson and Hileman 1982), but not in the Springfield-Salem Plateau region of Arkansas (Lawson et al. 1985) where calcareous soils strongly buffer streamflow, as evidenced by the high average of pH of about 7.0. An annual decline in pH of surface water was found in Illinois during the same time period (Brozka et al. 1981). Stormflow from forested watersheds generally occurs as lateral flow in the upper porous soil layers and rarely as overland flow above the soil surface. Thus, differences in soil chemical properties are likely to be reflected in corresponding differences in properties of runoff.

Specific conductance of stormflow samples from watershed WS-3 was found to be much higher than the other three watersheds (table 2), which probably reflects a greater concentration of nutrients. Watershed WS-4 stormflow provided the second highest specific conductance levels, reflecting its high ranking for several nutrients. The average specific conductance levels found over the 8-year study are slightly lower than those found in the Ouachita Mountains (Lawson and Hileman 1982) and much lower

TABLE 2.--Average pH, specific conductance and turbidity in stormflow from Boston Mountain watersheds (1974-1981).

Item	Watershed									
	WS-1		WS-2		WS-3		WS-4		All WS	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
pH	5.99	0.031	6.02	0.033	6.00	0.033	5.83	0.029	5.96	0.016
Conductance[1]	20.13	0.626	19.78	0.529	24.47	1.015	21.42	0.918	21.17	0.382
NTU[2]	19.18	5.371	26.38	7.036	40.14	8.752	34.70	11.196	29.12	4.021

[1] Specific conductance in micromhos/cm.

[2] NTU = Nephelometric Turbidity Units. Data from 1975-1980 only.

than those reported in the Ozark Highlands (Lawson et al. 1985). Specific conductance of all watersheds combined was also found to vary considerably among months of the year, with the highest levels occurring in summer and early fall (fig. 6). These specific conductance levels generally coincided with the higher concentrations of most nutrients. Average conductance levels found in stormflow from these watersheds are relatively low, indicating small amounts of dissolved minerals.

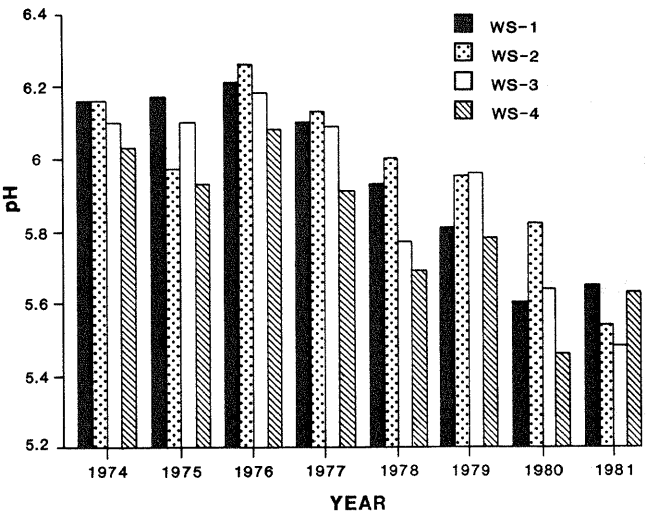

FIGURE 5.--Average annual pH of runoff from Boston Mountain watersheds (1974-1981).

Turbidity of stormflow was found to be highly variable among watersheds (table 2), with levels ranging from about 19.2 to 40.1 NTU. The high average turbidity levels and variability are largely the result of high values recorded for a very few stormflows. Variations in average turbidity reported by Lawson and Hileman (1982) in the Ouachita Mountains and Lawson et al. (1985) in the Ozark Highlands were even larger than those reported in this study. The high turbidity levels and variations in stormflow from these forested watersheds are also believed to be strongly influenced by organic materials. Sediment yields are also highly variable from storm to storm and year to year.

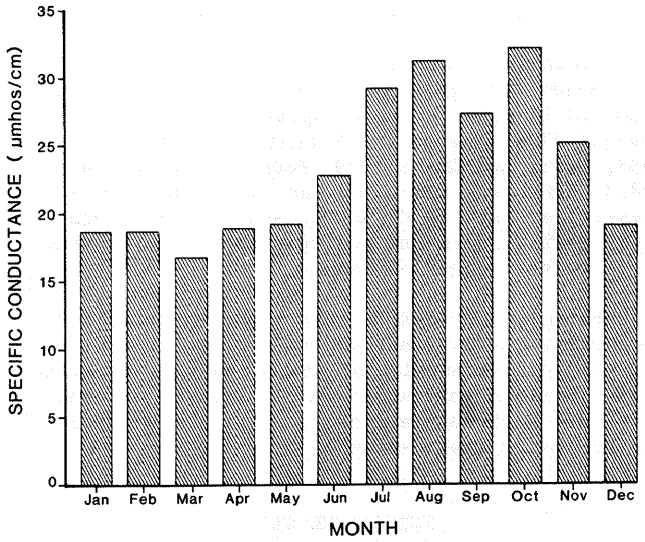

FIGURE 6.--Average monthly specific conductance of runoff from Boston Mountain watersheds (1975-1981).

Several factors may have contributed to the variability of results. Due to precipitation patterns, there may be little or no stormflow from these watersheds in a given month compared with the same month in another year. A similar variation among seasons and years is characteristic of stormflow patterns. Also, there are some inherent differences in stormflow response among watersheds that affect sampling frequency. Watersheds WS-1 and WS-2 provided the largest number of stormflow samples. Antecedent soil moisture affects the amount of stormflow and therefore, the amount of leaching that takes place in response to a storm. Thus, previous leaching may have caused changes in nutrient concentrations or other chemical and physical properties of storm runoff. Nutrient release is known to be

affected by soil moisture and soil temperature (Pritchett and Wells 1978).

SUMMARY

In the present study, differences occurred in nutrient content of stormflow among undisturbed watersheds and on a seasonal basis. The differences indicate the strong influence of soils, vegetation, and perhaps atmospheric deposition. Concentrations of Fe, Mn, K, Mg, NH_3-N, and HCO_3^- in stormflow varied considerably among the four watersheds, while levels of P, Ca, Na and total hardness were fairly uniform. Seasonal differences in nutrient levels were also found for Ca, K, Na, Mn, P, HCO_3^-, total hardness and NO_3^-.

Turbidity levels in stormflow were highly variable and average levels among the four watersheds were relatively large. Specific conductance levels of stormflow were different among the watersheds, and exhibited seasonal trends.

Stormflow from watershed WS-4 was considerably lower in pH than that from the other three watersheds. Average annual pH on all watersheds was found to decline during the 8-year study period.

Levels for most nutrients in stormflow from the watersheds were generally within the range of those reported in other areas (Douglass and Swank 1975, Hewlett 1979, Lawson and Hileman 1982, Lawson et al. 1985, Lewis and Grant 1979, Peterson and Rolfe 1982). However, some nutrient levels and chemical properties, such as Ca, HCO_3^-, and specific conductance, reflect soil and geologic conditions characteristic to a specific region.

The data provided in this study will be useful for estimating nutrient yields and other chemical and physical properties of stormflow from watersheds having similar characteristics. Average concentrations for each nutrient or property are provided for use in making these estimates.

LITERATURE CITED

AMERICAN PUBLIC HEALTH ASSOCIATION. 1980. Standard methods for the examination of water and wastewater. 13th edition, Amer. Public Health Assoc., Amer. Water Works Assoc., and Water Pollution Control Fed. 1134 p.

ARNOLD, T. and B. CASH. 1977. Fleming Creek experimental watersheds--soil report. USDA, For. Serv. and Soil Conservation Serv.

BROZKA, R.J., G.L. ROLFE, and L.E. ARNOLD. 1981. The quantity and quality of runoff from a shortleaf pine plantation in southern Illinois. For. Res. Rep. No. 81-3. Dep. of For., Agric. Exp. Sta., University of Illinois, Urbana-Champaign. 5 p.

DOUGLASS, J.E. 1974. Watershed values important in land use planning on southern forests. J. For. 72(10):617-621.

DOUGLASS, J.E. and W.T. SWANK. 1975. Effects of management practices on water quality and quantity: Coweeta Hydrologic Laboratory, North Carolina. P. 1-13. In Municipal Watershed Management Symposium, Proc. U. S. Dep. Agric., For. Serv. Gen. Tech. Rep. NE-13.

GARNER, B.A., F.M. VODRAZKA, W.K. GODDARD, and J.W. VENARD. 1977. Soil survey of Johnson County, Arkansas. USDA For. Serv. and Soil Conserv. Serv. in cooperation with the Agric. Exp. Sta. 80 p. + maps.

HEWLETT J.D. 1979. Forest water quality: an experiment in harvesting and regenerating piedmont forest. A Georgia For. Res. Pap., School of Forest Resources, Univ. Georgia, Athens, GA. 22 p.

KEOGH, J.L. and R. MAPLES. 1972. Variations in soil test results as affected by seasonal sampling. Bull. 777., Arkansas Agric. Exp. Sta., Univ. of Arkansas, Fayetteville, AR.

LAWSON, E.R. and L.H. HILEMAN. 1982. Nutrient distributions in runoff from Ouachita Mountain watersheds. P. 477-482. In Proc. Second Biennial Southern Silvicultural Research Conference. Earle P. Jones, Jr. (ed). Atlanta, GA, November 4-5, 1982. U. S. Dep. Agric., For. Serv., Southeast. For. Exp. Sta.

LAWSON, E.R., T.L. ROGERSON, and L.H. HILEMAN. 1985. Nutrients in storm runoff from hardwood-forested watersheds in the Ozark Highlands. In Proc. Third Biennial Southern Silvicultural Research Conference. Atlanta, GA, November 7-8, 1984. Atlanta, GA. U. S. Dep. Agric., For. Serv., South. For. Exp. Sta. (In Press).

LEWIS, W.M. JR., and M.C. GRANT. 1979. Changes in the output of ions from a watershed as a result of the acidification of precipitation. Ecol. 60(6):1093-1097.

MARTIN, C.W., D.S. NOEL, and C.A. FEDERER. 1984. Effects of forest clearcutting in New England on stream chemistry. J. Environ. Qual. 13(2):204-210.

MOORE, I.D. and J.R. NUCKOLS. 1984. Relationship between atmospheric nitrogen deposition and the stream nitrogen profile. J. Hydrol. 74(1984):81-103.

PETERSON, D.L. and G.L. ROLFE. 1982. Precipitation components as nutrient pathways in floodplain and upland forests of central Illinois. For. Sci. 28(2):321-332.

PRITCHETT, W.L., and C.G. WELLS. 1978. Harvesting and site preparation increase nutrient mobilization. P. 98-110. In Proc. A Symposium on Principles of Maintaining Productivity on Prepared Sites. Tom Tippin (ed.). Mississippi State Univ., March 21-22, 1978. U.S. For. Serv. and the Southern Region of the Assoc. of State College and Univ. For. Res. Organ.

ROGERSON, T.L. and E.R. LAWSON. 1982. Hydrologic characteristics of mixed hardwood watersheds in the Boston Mountains. P. 344-349. In Proc. Fourth Central Hardwood Conference. Robert N. Muller (ed.). University of Kentucky, 1982.

SARTZ, R.S. and W.R. CURTIS. 1967. Simple sediment sampler for flumes. Agric. Eng. 48:224.

STATISTICAL ANALYSIS SYSTEMS INSTITUTE, Inc. 1979. SAS user's guide 1979 edition. SAS Institute, Inc., Cary, NC. 494 p.

U. S. DEPARTMENT OF COMMERCE. 1982. Climatological data--annual summary Arkansas 1982. 87(13):1-23. National Oceanic and Atmospheric Administration.

U. S. ENVIRONMENTAL PROTECTION AGENCY. 1976. Manual of methods for chemical analysis of water and wastes. U.S. Environ. Protect. Agency. Document No. EPA-625/6-74-003a. 298 p.

WAGNER, G.H. and K.F. STEELE. 1982. Wet and dry fallout of nutrients and acid in northwest Arkansas. Arkansas Farm Res. 29(4):8.