BASELINE CHARACTERIZATION OF FORESTED HEADWATER STREAM HYDROLOGY AND WATER CHEMISTRY IN SOUTHWEST GEORGIA

David G. Jones, William B. Summer, Masato Miwa, and C. Rhett Jackson[1]

Abstract—Stream hydrology and water quality in headwater streams are important components of ecosystem health. The Dry Creek Long-Term Watershed Study is designed to evaluate the effects of upland forestry operations and stream management zone (SMZ) thinning on stream hydrology, water quality, benthic macroinvertebrates, and other biologic indicators. The study also tests the effectiveness of Georgia Best Management Practices (BMP). The study was established in the Spring of 2001 and monitors four adjacent first-order stream watersheds that range in size from 26 to 48 ha. Monthly grab samples and stormflow samples were taken and analyzed for nitrate/nitrite (NO_3^-/NO_2^-), ammonium (NH_4^+), total nitrogen (TN), ortho-phosphate (O-PO_4^-), total phosphorus (TP), and total suspended solids (TSS). Preliminary water quality analysis indicated that nutrient concentrations fluctuate seasonally with similar trends among watersheds. However, nutrient concentrations during storm events are highly variable with very few consistent trends.

INTRODUCTION

Understanding stream hydrology and water quality in a forest ecosystem is critically important to evaluate how forest management practices affect ecosystem health. This is especially true in headwater systems where terrestrial and aquatic ecosystems interact closely. First- and second-order streams comprise nearly three quarters of the total stream length in the United States (Leopold and others 1964), yet effects of human disturbance on these vital components of watershed and ecosystem health are not well documented. Improving knowledge of headwater stream response to forest management is especially important in the southeast where forestry encompasses over 215 million acres (Wear and Greis 2002) and almost 40 percent of the nations forestland (FAO 2001).

This paper describes baseline hydrology and water quality conditions in small, relatively undisturbed headwater systems during the pretreatment period of a long-term watershed study. Discussion includes: (1) seasonal variation in nutrient concentrations, (2) nutrient behavior during storm events, and (3) relationships between nutrients and watersheds.

METHODS

Study Site

The study watersheds are located on International Paper's Southlands Forest in the southwest corner of Georgia (fig. 1). The study lies on the Pelham escarpment between the Tifton Upland and the Dougherty Plain found within the Coastal Plain physiographic region. The soils are predominately well-drained Ultisols with sandy surfaces. The Esto series comprises the riparian area of all 4 watersheds. The slopes are Eustis series soils with the Wagram, Lakeland, Norfolk and Orangeburg series comprising a majority of the upland soils (Soil Survey Report 1980). The streams in this study drain four adjacent watersheds with similar aspect, size, shape, soils and vegetative cover type. One

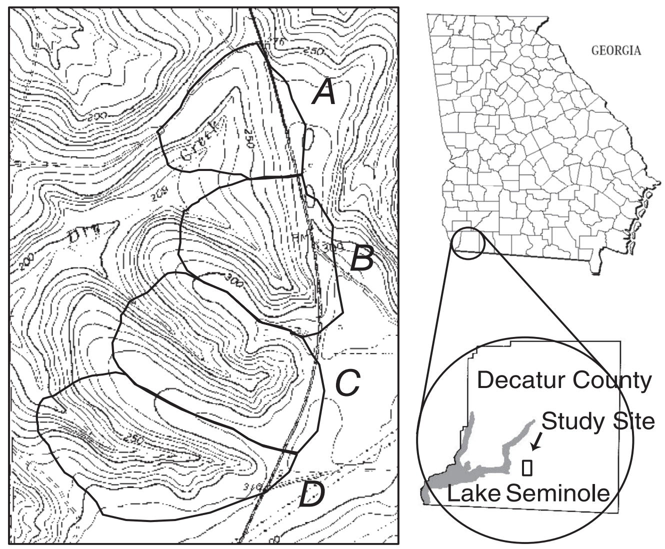

Figure 1—Study site (left), study location (right).

of the few apparent differences is the valley floor geometry. Watersheds A and B have broad, flat valleys with riparian wetlands while watersheds C and D have more channelized streams running through steeper, v-shaped valleys (Summer 2003).

Study Design

The overall statistical study design is a completely randomized design with two replications. The control watersheds are A and D, and the treatment watersheds are B and C (fig. 1). The control will receive no silvicultural treatment for the duration of the study. The treatment watersheds will be clearcut with the exception of an SMZ; each SMZ will be divided into an upper and lower section. An undisturbed SMZ treatment will be located at the upper section of the

[1]Dry Creek Study Technician, Southlands Forest, 719 Southlands Rd., Bainbridge, GA 39819; M.S. candidate, Forest Hydrology, University of Georgia, Daniel B. Warnell School of Forest Resources, Athens, GA 30602; Forest Hydrologist, Southlands Forest, 719 Southlands Rd., Bainbridge, GA 39819; and Associate Professor of Hydrology, The University of Georgia, Daniel B. Warnell School of Forest Resources, Athens, GA 30602, respectively.

Citation for proceedings: Connor, Kristina F., ed. 2004. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 594 p.

stream, and a partially harvested SMZ treatment will be located at the lower section of the stream. The partially harvested SMZ's will be thinned in accordance with Georgia BMP's, which require a minimum of 50 percent canopy cover or a residual 50 square feet of BA, evenly distributed. Treatments will be installed in the Fall of 2003.

Data Collection

Automated stream monitoring stations are located at the outlet of each watershed (four sites) and at the lower boundary of the upstream SMZ treatment (two sites). Stream stage and discharge is recorded every 15 minutes by Isco Model 4230 Bubbler Flow Meters. An Isco Model 6712 automated sampler collects seven water samples starting at the beginning of stormflow on 15 minute intervals. Monthly in-situ measurements and grab samples are taken from a downstream and midstream location within each watershed as well as at an upstream boundary-line location in the B & C watersheds. Data presented in this paper include monthly grab samples and in-situ pH measurements between October 2001 and November 2002 and 13 storm events during the same period. All water samples were analyzed for NO_3^-/NO_2^-, NH_4^+, TN, O-PO_4^-, TP, and TSS.

Methods of Analysis

Inorganic nutrient concentrations were determined with a Lachat (Milwaukee, WI) Quikchem 8000 using a flow-injection colorimetric method (Lachat Instruments 2001). In-stream measurements of pH were determined using an OAKTON (Vernon Hills, IL) pHTestr 2. TN and TP concentrations were determined with a CEM (Matthews, NC) MDS-2000 using a persulfate microwave digestion method (Johnes and Heathwaite 1992). TSS were determined by filtering a known volume of homogenized sample onto preweighed glass fiber filters [Gelman (Ann Arbor, MI) A/E, 1 μm], dried and reweighed. A Pearson's correlation analysis was conducted to determine correlations between variables within watersheds and correlations between like variables in different watersheds (SPSS Inc. 1997). Variable correlation plots were constructed based on two highest principle component scores of variables for each watershed (MINITAB Inc. 1996).

RESULTS AND DISCUSSION

Temporal Change in Nutrient Concentrations

In this section, we discuss Watershed B data to illustrate the general trends exhibited by all four watersheds. Monthly grab sample NO_3^-/NO_2^- concentrations indicated seasonal trends and consistent spatial relationships. The fluctuation patterns of NO_3^-/NO_2^- were similar for all sampling sites within the stream, and concentrations decrease from upstream to downstream (fig. 2). Similar fluctuation patterns of NO_3^-/NO_2^- at the three sites within the stream may indicate stable groundwater inputs and soil nitrate processes. The concentration decrease from upstream to downstream could have been caused by assimilative reduction (organism uptake), denitrification, and leaching. Several studies have shown that one, if not all, of these processes play an important role in the N removal process of Coastal Plain riparian forests (Ambus and Lowrance 1991, Correll and others 1994, Hendrickson 1981, Jacobs and Gilliam 1985, Jordan and others 1993, Lowrance 1992, Lowrance and others 1984). NO_3^-/NO_2^- concentrations were also higher during the dormant season compared to the growing season. Seasonal fluctuation of NO_3^-/NO_2^- concentrations has been observed in many other studies (Owens and others 1991, Pionke and others 1999) showing that soil moisture often shifts from a growing season deficit to a dormant season excess causing the remobilization of excess soil NO_3^-/NO_2^-. Temporal fluctuations of NO_3^-/NO_2^- generally followed a similar pattern as the pH. This could be due to the relationship between anion exchange capacity and pH, with fewer nitrates being exchanged in the soil as the pH increases, thus allowing more nitrates to move in solution (Bellini and others 1996, Qafoku and others 2000).

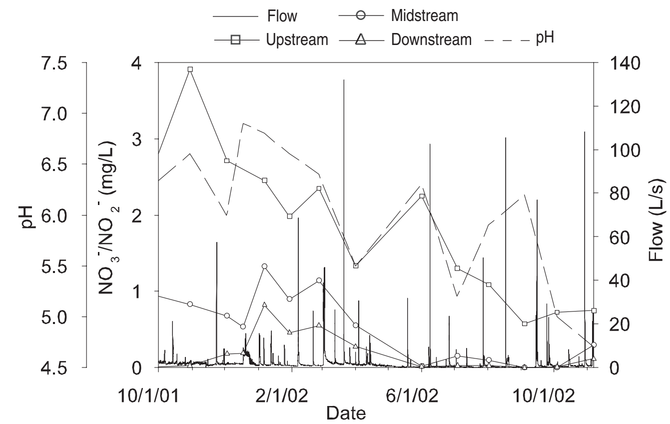

Figure 2—Seasonal fluctuations of monthly grab sample NO_3^-/NO_2^- and pH in the B-Watershed with the corresponding hydrograph for that period.

Monthly grab sample NH_4^+ concentrations had similar fluctuation patterns for all sampling sites within the stream (fig. 3). The upstream site had the lowest NH_4^+ concentration; the highest concentrations were recorded at the midstream site. NH_4^+ concentrations were, on average, higher during the growing season than in the dormant season.

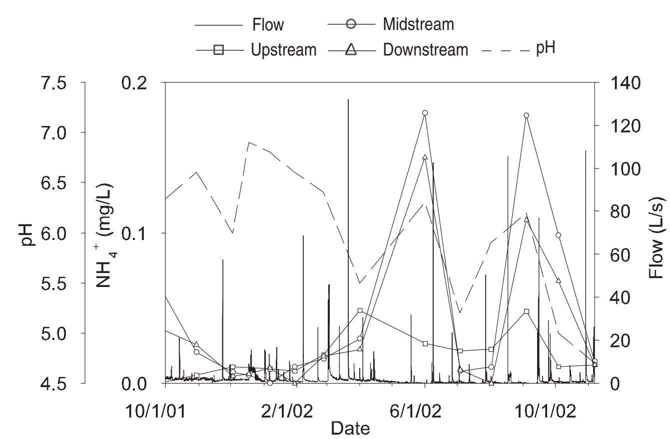

Figure 3—Seasonal fluctuations of monthly grab sample NH_4^+ and pH in the B-Watershed with the corresponding hydrograph for that period.

Similar NH_4^+ temporal fluctuations have been observed in other studies (Verchot and others 1997). This could be caused by increased mineralization as the riparian soil environment becomes more aerobic during the growing season. The NH_4^+ appeared to have a weaker relationship with pH compared to the relationship between NO_3^-/NO_2^- and pH.

Monthly grab sample O-PO_4^- concentrations had similar fluctuation patterns for all sampling sites within the stream, and the concentrations generally increased from upstream to downstream (fig. 4). O-PO_4^- concentrations were, on average, higher during the growing season than in the dormant season. Seasonal fluctuations of O-PO_4^- concentrations have been observed in many other studies (Gburek and Heald 1974, Mulholland and Hill 1997, Pionke and others 1999). This could be explained in part by the relationship between P sorption capacity and saturated soil conditions. Holford and Patrick (1979) have shown that P sorption capacity of an oxidized soil can increase during periods of saturation and reduction due to the formation of amorphous ferrous hydroxides, which have a greater surface area and more sorption sites than the more crystalline, oxidized, ferric forms. This process may explain why there were lower concentrations of O-PO_4^- in solution during the dormant season when the soil in these riparian areas was saturated. The O-PO_4^- fluctuation appeared to have a weak inverse relationship with pH.

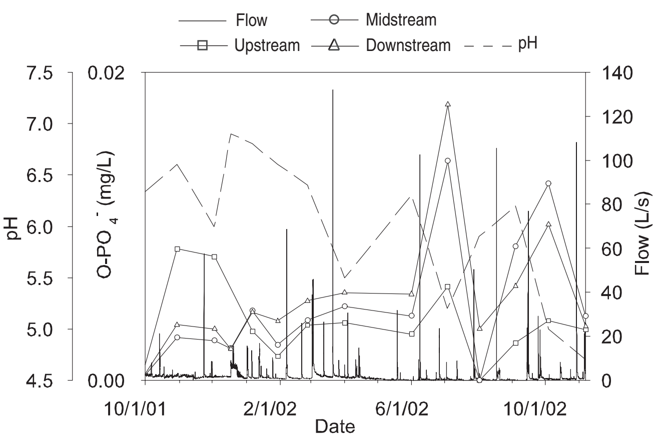

Figure 4—Seasonal fluctuations of monthly grab sample O-PO_4^- and pH in the B-Watershed with the corresponding hydrograph for that period.

Stormflow Nutrient Concentrations and Correlations

Concentrations from 15-minute sampling during storm events varied by event and season with few consistent trends; some decreased, increased, or remained approximately equal as flow increases. Additionally, nutrient levels occasionally spiked at varying times in an event. A combination of these characteristics made it difficult to predict nutrient concentrations and flow relations. In order to analyze the data, average nutrient concentrations for an event were calculated from seven 15-minute storm samples and were compared to determine any correlations within and between watersheds.

In general, inorganic nutrients were poorly correlated to other nutrient concentrations within watersheds. However, TN, TP, TSS, and flow were relatively well correlated within watersheds. The Pearson correlations for Watershed C are shown in table 1 as an example, although correlation characteristics were similar within all four watersheds. Correlations between control and treatment watersheds for inorganic nutrient concentrations were poor for like nutrients with the exception of O-PO_4^- between watersheds A-B and C-D. TP, TSS, and flow were relatively well correlated

Table 1—Pearson correlation of variables within watershed C

		NH_4^+	TN	O-PO_4^-	TP	TSS	Flow
NO_3^-/NO_2^-	r^2	0.207	0.066	-0.567	-0.395	-0.427	-0.028
	P	0.541	0.855	0.069	0.259	0.190	0.934
NH_4^+	r^2		-0.377	0.007	-0.495	-0.407	-0.198
	P		0.284	0.982	0.145	0.214	0.560
TN	r^2			-0.276	0.875	0.814	0.712
	P			0.440	0.001	0.004	0.021
O-PO_4^-	r^2				-0.002	0.009	-0.149
	P				0.996	0.979	0.662
TP	r^2					0.918	0.569
	P					<0.001	0.086
TSS	r^2						0.773
	P						0.005

NO_3^-/NO_2^- = nitrate/nitrite; NH_4^+ = ammonium; TN = total nitrogen; O-PO_4^- = orthophosphate; TP = total phosphorus; TSS = total suspended solids.

between watersheds, with TN being somewhat less related (table 2). These results may indicate that concentrations of inorganic nutrients are highly influenced by dynamic environmental factors that control biogeochemical processes, such as temperature, soil moisture, pH, microbial activity, etc., while total nutrient concentrations are more stable.

Variable correlation plots showed similar relationship trends between control watershed A and treatment watersheds B & C. TN, TP, and TSS were closely located in all three watersheds (fig. 5). Additionally, NO_3^-/NO_2^- and NH_4^+ in watersheds A & B are somewhat negatively related to flow. Control watershed D had somewhat different nutrient relationships. The NH_4^+, O-PO_4^-, and TN were relatively well correlated, and there was some relationship shared between TP, TSS, and flow.

The between watershed correlation analysis indicated that the TN, TP, and TSS of the treatment watersheds could be predicted from like nutrients of the control watersheds. Furthermore, high correlations between TN, TP, and TSS within watersheds may strengthen predicting equations through the addition of highly correlated variables, a relationship which can be seen in the orientation of nutrients on the variable correlation plots. A more detailed analysis of the data may illustrate trends and correlations that were not observed in this analysis.

CONCLUSIONS

The patterns and trends of nutrient concentrations observed in these headwater streams appeared to be representative of what other studies have found under similar circumstances. Variations in grab sample inorganic nutrient concentrations exhibited trends that have been relatively well documented; yet detailed analysis showed inorganic nutrient stormflow concentrations were poorly correlated. However, total nutrient stormflow concentrations had very high correlations. This may suggest that the relatively stable total nutrient concentrations can be used for more long-term monitoring of nutrient trends and the more dynamic inorganic nutrient concentrations can be used for short-term process oriented studies.

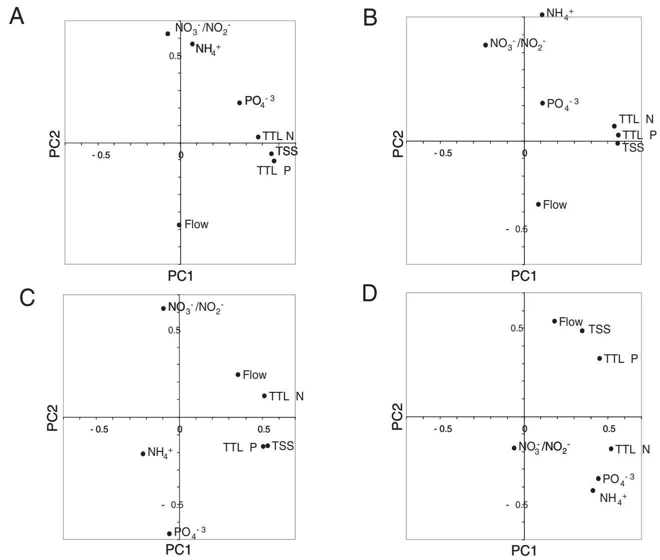

Figure 5—Variable correlation plots based on a principle component analysis for the four watersheds.

ACKNOWLEDGMENTS

The National Council for Air and Stream Improvement, International Paper, J.W. Jones Ecological Research Center, and the Georgia Forestry Commission are responsible for funding and support of the project. William B. Summer is responsible for a majority of the data collected that was presented in this paper.

LITERATURE CITED

Ambus, P.; Lowrance, R. 1991. Denitrification in two riparian soils. Soil Science Society of America Journal. 55: 994-997.

Bellini, G.; Summer, M.E.; Radcliffe, D.E.; Qafoku, N.P. 1996. Anion transport through columns of highly weathered acid soil: adsorption and retardation. Soil Science Society of America Journal. 60: 132-137.

Correll, D.L.; Jordan, T.E.; Weller, D.E. 1994. Failure of agricultural riparian buffers to protect surface waters from groundwater contamination. In: Proceedings of the international conference for

Table 2—Pearson correlation between control watersheds and treatment watersheds for NO_3^-/NO_2^-, NH_4^+, TN, O-PO_4^-, TP, TSS, and flow

		NO_3^-/NO_2^-	NH_4^+	TN	O-PO_4^-	TP	TSS	Flow
A - B	r^2	0.193	-0.174	0.828	0.740	0.578	0.802	0.874
	P	0.528	0.570	0.002	0.004	0.062	0.002	< 0.001
A - C	r^2	-0.310	-0.195	0.543	-0.021	0.782	0.445	0.922
	P	0.354	0.565	0.105	0.952	0.008	0.171	< 0.001
D - B	r^2	0.672	0.417	0.634	-0.001	0.921	0.781	0.919
	P	0.033	0.230	0.126	0.999	0.003	0.013	< 0.001
D - C	r^2	0.644	0.103	0.127	0.838	0.932	0.870	0.839
	P	0.061	0.791	0.787	0.005	0.002	0.002	0.005

NO_3^-/NO_2^- = nitrate/nitrite; NH_4^+ = ammonium; TN = total nitrogen; O-PO_4^- = ortho-phosphate; TP = total phosphorus; TSS = total suspended solids.

groundwater/surface water ecotones. Ambridge, MA: Cambridge University Press.

FAO. 2001. Global forest resources assessment 2000: Main Report. 2001. FAO Forestry Papers v. 140. Rome, Italy: Food and Agriculture Organization of the United Nations. http://www.fao.org/forestry/fo/fra/main/index.jsp.

Gburek, W.J.; Heald, W.R. 1974. Soluble phosphate output of an agricultural watershed in Pennsylvania. Water Resources Research. 10(1): 113-118.

Hendrickson, O.Q., Jr. 1981. Flux of nitrogen and carbon gases in bottomland soils of an agricultural watershed. Athens, GA: The University of Georgia. 210 p. Dissertation.

Holford, I.C.R.; Patrick, W.H., Jr. 1979. Effects of reduction and pH changes on phosphate sorption and mobility in an acid soil. Soil Science Society of America Journal. 43: 292-297.

Jacobs, T.C.; Gilliam, J.W. 1985. Riparian losses of nitrate from agricultural drainage waters. Journal of Environmental Quality. 14: 472-478.

Johnes, P.J.; Heathwaite, A.L. 1992. A procedure for the simultaneous determination of total nitrogen and total phosphorus in freshwater samples using persulfate microwave digestion. Water Resources. 26(10): 1281-1287.

Jordan, T.E.; Correll, D.L.; Weller, D.E. 1993. Nutrient interception by a riparian forest receiving inputs from adjacent cropland. Journal of Environmental Quality. 22: 467-473.

Lachat Instruments. 2001. Methods manual for automated ion analyzers. Lachat Instruments, Milwaukee, WI.

Leopold, L.E.; Wolman, M.G.; Miller, J.P. 1964. Fluvial processes in geomorphology. San Francisco, CA: W.H. Freeman and Company.

Lowrance, R. 1992. Groundwater nitrate and denitrification in a Coastal Plain riparian soil. Journal of Environmental Quality. 21: 401-405.

Lowrance, R.R.; Todd, R.L.; Fail, J.L. [and others]. 1984. Riparian forests as nutrient filters in agricultural watersheds. Bioscience. 34: 374-377.

MINITAB Inc. 1996. MINITAB user's guide. State College, PA: MINITAB Inc.

Mulholland, P.J.; Hill, W.R. 1997. Seasonal patterns in streamwater nutrient and dissolved organic carbon concentrations: Separating catchment flow path and in-stream effects. Water Resources Research. 33(6): 1297-1306.

Owens, L.B.; Edwards, W.M.; Van Keuren, R.W. 1991. Baseflow and stormflow transport of nutrients from mixed agricultural watersheds. Journal of Environmental Quality. 20: 407-414.

Pionke, H.B.; Gburek, W.J.; Schnabel, R.R. [and others]. 1999. Seasonal flow, nutrient concentrations and loading patterns in stream flow draining an agricultural hill-land watershed. Journal of Hydrology. 220: 62-73.

Qafoku, N.P.; Summer, M.E.; Radcliffe, D.E. 2000. Anion transport in columns of variable charge subsoils: nitrate and chloride. Journal of Environmental Quality. 29: 484-493.

Soil Survey Report. 1980. Bainbridge, GA: International Paper. 71 p.

SPSS Inc. 1997. Sigma Stat user's guide. Chicago, IL: SPSS Inc.

Summer, W.B.; Jackson, C.R.; Jones, D.; Miwa, M. 2003. Characterization of hydrologic and sediment transport behavior of forested headwater streams in southwest Georgia. In: Proceedings of the 2003 Georgia water resources conference. Athens, GA: Institute of Ecology, The University Georgia.

Verchot, L.V.; Franklin, E.C.; Gilliam, J.W. 1997. Nitrogen cycling in piedmont vegetated filter zones: I. Surface Soil Processes. Journal of Environmental Quality. 26: 327-336.

Wear, D.N.; Greis, J.G., eds. 2002. The southern forest resource assessment. Gen. Tech. Rep. SRS-53. Ashville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 635 p.