EFFECTIVENESS OF STREAMSIDE MANAGEMENT ZONES ON WATER QUALITY: PRETREATMENT MEASUREMENTS

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ABSTRACT: The objective of this paired watershed study is to quantify the effects of upland forest harvesting and Streamside Management Zones (SMZs) on stream water quantity and quality in North Carolina. Four watersheds ranging from 12 to 28 hectares (i.e., two on Hill Forest and two on Umstead Research Farm) with perennial stream channels were gauged for flow monitoring and water quality sampling. We are also monitoring two additional larger (i.e., 32 and 46 hectares) watersheds at Hill Forest. The study started in 2007 and the first two years will be used to calibrate watershed runoff and stream water quality. During year three, one watershed from each pair will be treated. The treatment watersheds will be completely harvested with the exception of the SMZs, which will be maintained according to the NC 'Neuse River Buffer Rules' (a mandatory 50-foot buffer along streams in the Neuse River Basin). The two remaining watersheds will remain undisturbed as controls. A severe drought in 2007 caused one of the streams in the Umstead watershed to stop flowing, so it was excluded from analysis. Pretreatment daily runoff (measured in mm/day) from the two smaller paired and two larger watersheds at Hill Forest were significantly correlated (r^2 0.93, p = 0.0001 and r^2 0.96, p = 0.0001, respectively). We also found that turbidity, total suspended solids, and discharge were generally related to precipitation. We will continue to monitor the watersheds to document SMZs influence on water quality and understand the hydrologic process of headwater piedmont watersheds.
Keywords: best management practices, streamside management zones, riparian buffer, water quality

INTRODUCTION

Reducing sediment and nutrient loading from nonpoint sources to forests, streams, wetlands, and other water bodies are key factors in watershed protection and management. The 1972 Clean Water Act and subsequent amendments require that nitrogen and sediment be reduced to avoid impairment. For example, the 1987 Clean Water Act amendments included nonpoint source pollution prevention and required states to develop forest management guidelines to ultimately reduce nonpoint source pollution during timber production and harvest. Because of these federal mandates, Best Management Practices (BMPs) have emerged as the most effective tool for managing watersheds and increasing water quality protection from nonpoint source pollution (Prud'homme and Greis, 2002). Forestry BMPs in North Carolina are defined as a practice or combination of practices that is determined to be an effective and practical means of preventing or reducing the amount of pollution generated by non-point sources to a level compatible with water quality goals (Raval, 2005). SMZs or riparian buffers, a major component of BMPs, are accepted as a standard strategy or measure to protect water quality in forest operations and activities, along with other BMP techniques (Vowell and Frydenborg, 2004).

SMZs are areas adjacent to intermittent and perennial streams, modified natural streams, and perennial water bodies that require extra care and protection during forest operations such as tree harvesting, site preparation, and machine planting. SMZs also contribute significantly to wildlife production and stability in addition to filtering pollutants that can be harmful and toxic to aquatic wildlife. However, designing an appropriate stream buffer width for specific watersheds requires site-specific information such as upland land slope, groundcover conditions, soil type, sediment sources, and the type and water bodies to be protected. Another important consideration is the potential economic conflict with landowners. According to estimates by Woodman and Cubbage (1994) BMP compliance cost in Georgia averaged $24.33 per acre for forest industry lands and $41.65 per acre for non-industrial private forests. The 2006 North Carolina Forestry BMP Manual provides recommendations for buffer width; however, it is suggested the recommendations are still best guess/best judgment (Technical Advisory Committee, NC DENR-Division of Forest Resources). Although across the state of North Carolina BMP compliance is 82% (Raval, 2005), science-based field data are needed to document the effectiveness of certain BMPs as well as North Carolina's mandatory riparian buffer rules, as they relate to forestry activities. Therefore the overall objective of this study is to evaluate the effectiveness of SMZs in maintaining high water quality and to document the hydrological processes in headwater streams in the piedmont region of North Carolina. This manuscript in particular will focus primarily on the pretreatment or calibration phase of the study.

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MATERIALS AND METHODS

Study Sites

One of the principle criteria for site selection was to locate sites in the Neuse River Basin to evaluate the effectiveness of Neuse River Buffer Rules in controlling sediment and nutrient loading to natural stream channels. Four watersheds ranging from 12 to 28 hectares with perennial stream channels were gauged for flow monitoring and water quality sampling. The first pair, HF1 and HF2, is located at North Carolina State University's Hill Forest in northern Durham County, NC. The other pair, UF1 and UF2, is located in the North Carolina Department of Agriculture and Consumer Services Umstead Research Farm in Granville County, NC. The linear distance between sites is about 5 miles. We are also monitoring hydrological processes in two larger (i.e., 24 and 39 hectares) watersheds at Hill Forest, HFW1 and HFW2. Figure 1 shows the watershed, weir, flume, and weather station locations and Table1 highlights the similarities in geomorphology within the paired watersheds. The major differences, however, between Hill Forest and Umstead are the ecoregions that has allowed for differences in stream channel formation. Streams found in Hill Forest (HF1, HF2, HFW1 and HFW2) are generally shallow, connected to their floodplain and have relatively steep upland slopes. Conversely, streams in Umstead (UF1 and UF2) have deeper stream channels that are detached from their floodplain with gentle upland slopes.

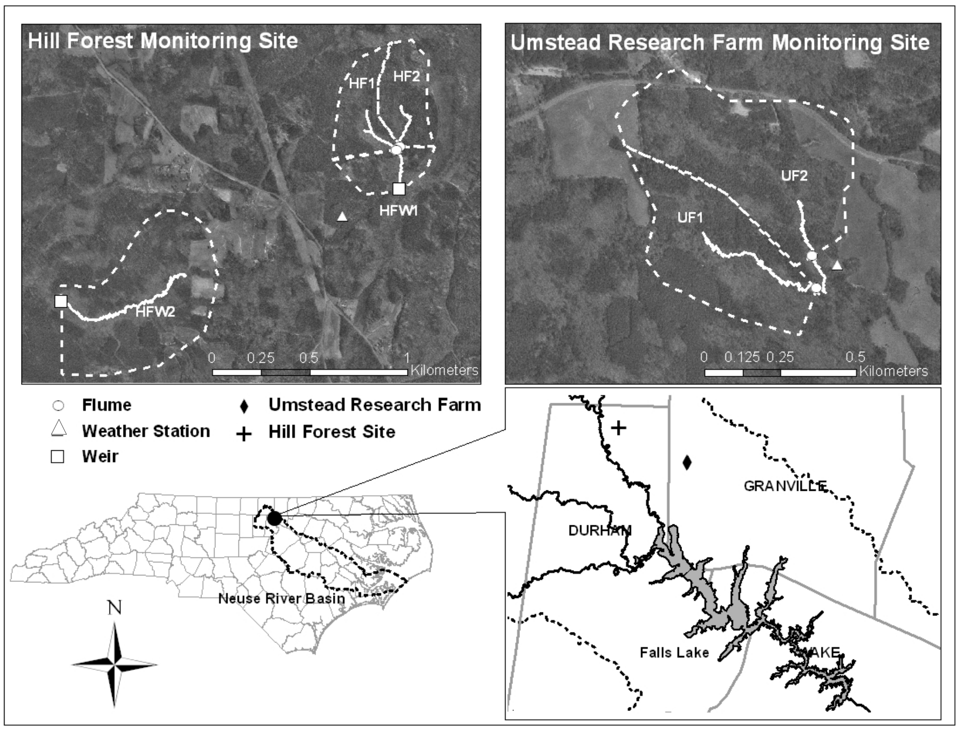

Figure 1. Watershed, weir and flume locations.

Table 1. Watershed characteristics.

	HF1	HF2	UF1	UF2	HFW1	HFW2
Size (hectares)	12	12	28	18	32	46
Aspect	S	S	SE	SE	S	S
Soil texture	SL, SiL	SL, SiL	L, SL	L, SL	SL, SiL	SL, SiL
Soil series	TaE	TaE	TaE	HeB	TaE	TaE WmD
Level IV. Ecoregion	Carolina Slate Belt	Carolina Slate Belt	Triassic Basin	Triassic Basin	Carolina Slate Belt	Carolina Slate Belt
Outlet elevation (meters)	174	174	130	134	166	138

Study Design and Measurements

One watershed from each pair will serve as the reference watershed (no harvesting within the watershed) throughout this five-year study. The first stream flow measurements were taken in October 2007, marking the beginning of the calibration period. The first two years will serve as a calibration period for all watersheds, which is essential to capture the seasonal and annual climatic variability and collect sufficient data to establish the relationships among the water parameters prior to treatments. At the end of the second year of baseline watershed monitoring and calibration, two of the watersheds will be selected to receive treatments. The treatment watersheds will have a riparian buffer for forest management established that follows those prescriptions outlined in N.C. Administrative Code 15A NCAC 2B .0233, commonly known as the Neuse Buffer Rule. Utilizing this treatment on one of each pair of watersheds will provide replication and account for site variability.

All four paired watersheds and the two larger watersheds are equipped with a flow integrated water sampler (Sigma 900Max) to collect water samples during peak flow, monitor water level changes, and calculate discharge. In-stream turbidity and water temperature measurements are also being measured at each outlet point. To determine and track changes in water quality parameters we are also measuring several response variables to precipitation inputs including total suspended solids (TSS), total nitrogen and phosphorus, nitrate, ammonium and dissolved organic carbon. These species are being measured from the water samples collected by the Sigma sampler during peak flow conditions and from bi-weekly grab samples. To preserve water sample quality by reducing microbial activity 2ml of H_2SO_4 is added to each sample bottle before being placed in the field. A meteorological station (Onset Corporation, Bourne, MA) is located on the Hill Forest site to monitor weather conditions including precipitation, relative humidity, wind speed/direction/gust, air temperature, dew point, and solar radiation. Precipitation is also being measured at the Umstead site with a tipping bucket (Hobo, Onset Corporation, Bourne, MA) and manual rain gauge to evaluate climate variations between sites. Data analysis was completed using SAS (SAS Institute, Inc.).

RESULTS AND DISCUSSION

This project began in one of the driest years in North Carolina's history with approximately 700 mm of precipitation falling on our sites. This is approximately 60% of the average precipitation for this area. As a result, one of the streams in the Umstead watershed (UF1) had very limited stream flow, so it was excluded from analysis. Five months of runoff data from the remaining watersheds generated predictive models that suggest the paired watersheds are responding similarly to precipitation inputs (Figures 2 and 3) and are good enough to detect the treatment effects once they occur. All slopes of the linear equations are near one with y-intercepts near zero. When the independent variable x equals zero, the dependent variable y will be zero or near zero.

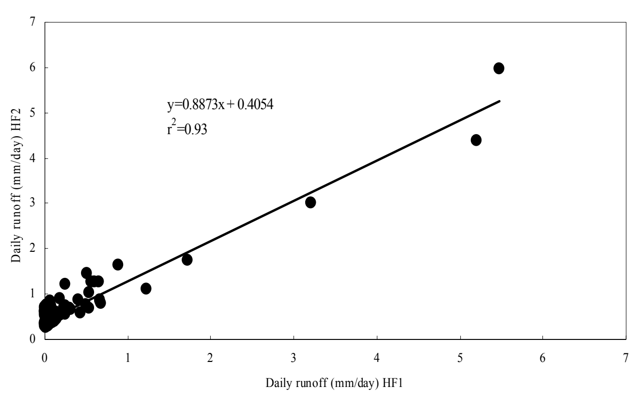

Figure 2. Daily runoff relationship in paired watersheds (HF1 and HF2) during calibration period, Hill Forest.

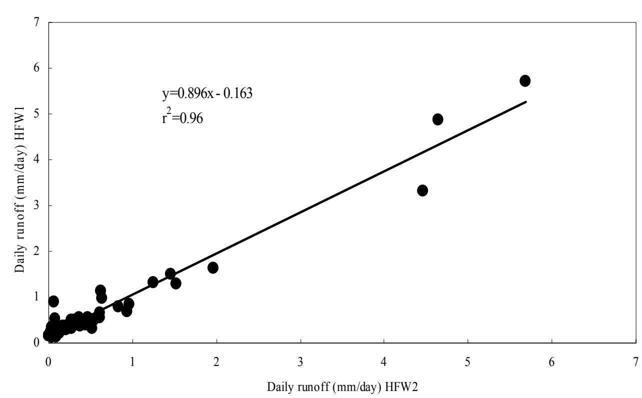

Figure 3. Daily runoff relationship in two larger watersheds (HFW1 and HFW2) during calibration period, Hill Forest.

Daily turbidity, discharge, and TSS in HF2 demonstrated the clearest rise and fall with precipitation when compared to HF1 (Figure 4). Turbidity and TSS values in HF1 were generally flat except during the months of November 2007 and March 2008. The hydrological components (discharge timing, frequency, and duration) of the watersheds, however, are similar and comparable. Given this and the similarities in watershed geology, soil, surface cover, and topography we expected the turbidity and TSS response to rainfall to be similar. This slight difference in turbidity and TSS response suggest that there are underlining controls in the watersheds restricting or reducing (in the case of HF1) or creating (in the case of HF2) preferential flow pathways for the movement of particles after significant rain events. Eisenbies et al. (2007) found through a review of forest operation and storm flow that there are components of the hydrological process that should be considered when assessing storm or peak flow conditions or impacts. These components were linked primarily to direct (stream channel), rapid (overland), slow (shallow groundwater) and base flow (deep and shallow groundwater).

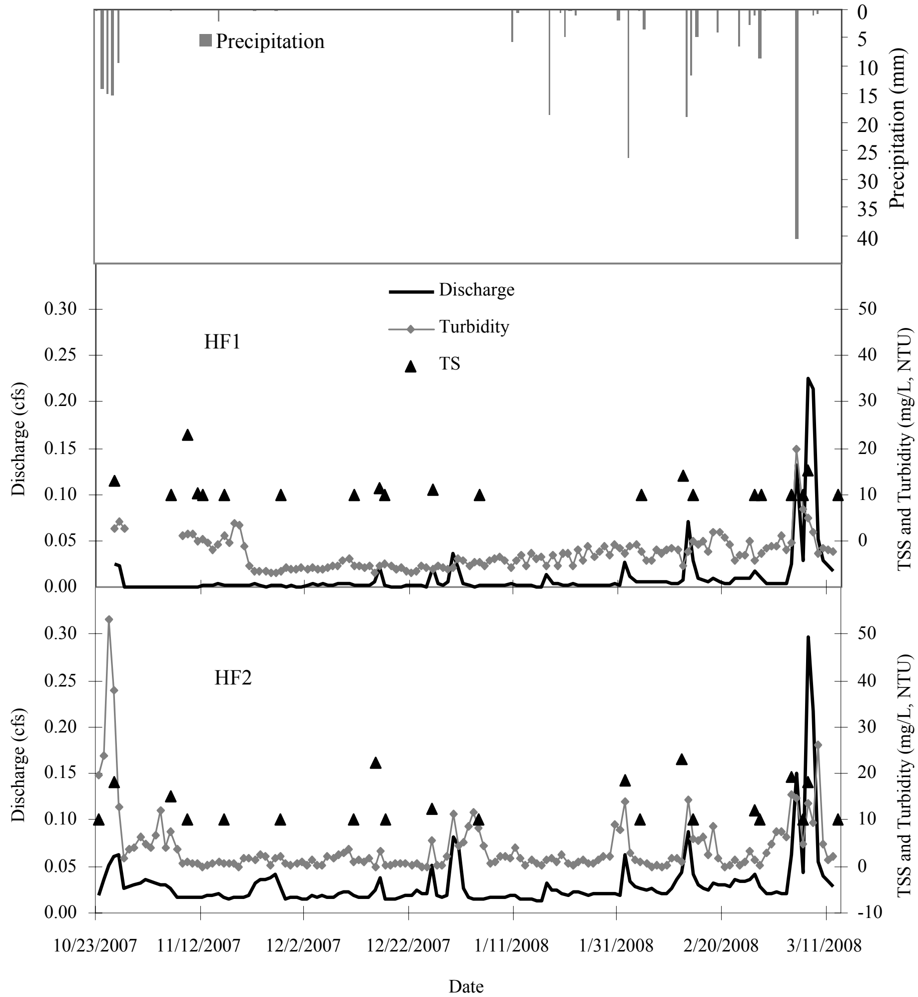

Figure 4. Daily precipitation, stream flow, turbidity and total suspended solids (TSS) patterns during calibration period for paired watersheds HF1 and HF2, Hill Forest.

Pretreatment calibration as noted by (Swank et al. 2001) is a major factor to assessing and developing predictive models of treatment effects in a paired watershed design. However, the calibration period for determining these effects varies across watersheds due to different controlling factors such as watershed size, soil types, surface cover, and topography (Brooks et al. 2003). Based on five months of stream runoff data, we calculated the calibration time for our watersheds and the data are present below. We are presenting these data, however, with the understanding that 1) we have not captured yearly seasonal climatic variability; 2) this has been a dry year thus most data points represent the extreme; and 3) that over time these calibration points might change due to climatic and other naturally occurring conditions or events. Monthly runoff data from HF1 and HF2 were used in the computation because their flow data sets were the most complete. Wilm (1944, 1948) developed the following equation to determine the minimum length of calibration time required for a watershed to predict treatment effects with a reasonable level of certainty:

$$k = \frac{s^2_{y.x}\ F}{d^2}$$

where k equals the number of observations from each of the two data sets, $s^2_{y.x}$ is standard error of estimate ($\hat{y}$) in mm/month, *F* statistic equals F{2+[F/(k-1)]}, and d equals smallest noteworthy change in monthly runoff. The *F* statistic was set at α=0.05 and α=0.01 to examine different levels of significance and d at 2 mm/month because it represents about 10% of the expected monthly runoff from our watersheds. Hewlett (1982) found that 10-34% of precipitation from a typical rain event (>25mm) in an eastern US headwater watershed will runoff as stream flow. Based on Wilm's equation, calibration between the two paired watersheds (HF1 and HF2) will be achieved in 10 months at α=0.05 and 32 months at α=0.01.

Runoff coefficient which expresses percentage of rainfall or precipitation that is converted to runoff was different between HF1 and HF2 (Table 2). We believe this difference is due primarily to ground water inflow from the upper reaches of HF2. A watershed generally has land surface conditions that can be used to separate them from each other thus marking the drainage area for the catchment. However, studies have shown that ground water watersheds or divides do not always coincide with surface water watersheds (Hunt et al. 2001). Consequently, water inflow from other sources can influence surface water quantities and conditions. Daily runoff during base flow (<1.0 mm/day) in figure 2 falls above the intercept suggesting that daily runoff values in HF2 are higher than those that would be determined by HF1. The linear model in figure 2 also had a higher y-intercept than figure 3, deviating from zero by +0.4. Winter et al. (2003) and Holmes et al. (2000) found that surface water bodies can receive considerable quantities of water from ground water and from sources beyond their local surface watersheds. We believe, however, that this source of water that seems to be beyond our watershed boundary will not significantly undermine the paired watershed design given the highly significant relationships of daily stream runoff between the two watersheds.

Nitrate and ammonium concentrations during peak flow were near zero for all streams except one in the Umstead watershed (Table 4). In this stream ammonium concentration was around 0.2 mg/L probably due to the close proximity of an agricultural field. This stream also had the highest TOC concentration, 12.86. Overall, the nutrient and particle values from the water samples are similar between the pairs with TP, TKN, and TSS showing the largest differences.

Table 2. Flow characteristics and mean nutrient and sediment concentrations for paired and larger watersheds.

Site	Runoff	Precipitation	Runoff	TOC	NH_4	NO_3	TP	TKN	TSS	n
	---------mm------------		%	------------------------mg/L**---------------------						
HF1	12	184	6	8.23	0.00	0.00	0.05	0.22	11.30	96
HF2	40	184	22	12.17	0.00	0.01	0.05	0.41	18.14	84
HFW1	27	184	15	7.16	0.00	0.00	0.04	0.24	14.95	60
HFW2	17	184	9	6.26	0.03	0.01	0.10	0.43	22.22	68
UF1*										
UF2	41	173	24	12.86	0.01	0.22	0.04	0.37	13.53	59

*Data not available

**Nutrient and sediment data represent mean concentrations during peak flow conditions.

TOC = total organic carbon, NH_4 = ammonium, NO_3 = nitrate, TP = total phosphorus, TKN = total kjeldahl nitrogen, TSS = total suspended solids.

CONCLUSIONS

Watershed scale studies are invaluable as a mean of understanding and managing many of our natural resource areas and for examining SMZs effectiveness on reducing nutrient and sediment loading to streams. The quality of results and level of model predictability of treatment effects from these studies are closely linked to the experimental design, watershed calibration, and various other controlled and non-controlled factors. Within our study, the paired watersheds are meeting many of the assumptions required to develop a good-fit model. For example, the daily runoff from the paired watersheds is significantly related. Consequently, the models generated from these relationships are explaining almost all of the variability around daily stream runoff. The relationship between turbidity, TSS, discharge and precipitation was more pronounced in HF2 than in HF1 probably due in part to the differences in runoff coefficient and other flow and non-flow controls. However, more sediment data are needed for a complete assessment of this relationship and pattern. Future research will focus on describing treatment effects on water quality and hydrological processes, evaluating stream quality and exploring model development for practical uses in managing and guiding BMP designs.

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