HYDROLOGIC AND SEDIMENT TRANSPORT RESPONSE TO FORESTRY; SOUTHWEST GEORGIA HEADWATER STREAMS

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Abstract. Properly established streamside management zones (SMZs) reduce potential impacts of timber harvesting on stream sediment fluxes. However, effects of partial harvesting within SMZs on water quality are not well documented. The objectives of this study are to examine the effects of forestry activities on hydrology and sediment export in undisturbed first-order streams as part of a long-term paired watershed study. The study design includes two reference (no harvest) and two treatment watersheds (all are between 26 – 48 hectares in size). The entire treatment watersheds were harvested except for SMZs, which were divided into upper and lower sections. The upper sections had an intact SMZ, while the lower sections were thinned according to Georgia best management practices (BMP) guidelines. Flow and sediment concentrations were monitored at the outlet of each treatment and reference watershed for two years prior to and one year following harvest. Though peak flow rates have not significantly increased in treatment watersheds as a result of harvest, cumulative flows have doubled. Observations of variable source areas indicate water tables have risen in treatment watersheds.

INTRODUCTION

Sediment is the largest contributor by volume to non-point source water pollution in the U.S. (Neary et al., 1988) and the most important potential pollutant from managed operational forested lands (Phillips, 1989). When soil is exposed as a result of a timber harvest or site preparation, sediment has an increased potential of being transported down slope and into a stream. Elevated sediment inputs can bury gravel and cobble substrates, reducing the quality of habitat for macro-invertebrates and fish. This process, known as sedimentation, causes a reduction in biodiversity and biomass in aquatic systems (Waters, 1995).

Much of the land use in the Southeast U. S. is currently in forestry. In Georgia alone there are 23.6 million acres of commercial forest land, comprising nearly 10% of the state (Georgia Forestry Commission, 1999). Thousands of miles of waterways have potential to be impacted by forestry activities.

BACKGROUND

Like most states that have significant forestry operations, Georgia has developed a set of best management practices (BMPs) to minimize non-point source pollution from forestry activities. Best management practices are defined as methods, measures, practices and techniques designed to maintain water quality within forested watersheds (Aust et al., 1996). An example of a BMP is a streamside management zone (SMZ). SMZs are areas adjacent to a stream in which vegetation is managed and maintained to protect stream water quality (Georgia Forestry Commission, 1999). SMZs are intended to reduce the amount of sediment and other pollutants from reaching the stream in overland flow from storm runoff. Intact vegetation in SMZ's is expected to slow runoff which in turn allows water to infiltrate into the ground and reduces its capacity to transport sediment (Hewlett, 1982). For example, more and larger sediment particles are trapped at the edges of SMZs than are deposited within SMZs (Cooper et al., 1987). This implies that the competence of storm flow to carry sediment is reduced as it enters the SMZ. Streamside management zones have been shown to be an effective BMP for reducing the effects of timber harvesting on sediment flux in streams (Ward and Jackson 2002, Rivenbark and Jackson 2002).

BMPs vary from state to state, as do requirements for SMZ widths. Georgia's recommended buffer width for a perennial stream begins at 40 feet and increases as slope of the adjacent hillside increases (Georgia Forestry Commission, 1999). Georgia's recommendations allow some timber to be harvested within SMZ's. This practice, known as thinning or partial harvesting within SMZs, may be conducted until there is a minimum of 50 square feet of basal area per acre or 50% canopy cover remaining. The effects of this practice are not well known, and few studies include partial harvesting treatments.

Research publications regarding buffer effectiveness are numerous. However, few studies have been conducted in the coastal plain of the southeast United States. Furthermore, the effects of partial harvesting within SMZs on water quality are not well documented. Research needs to be done to fill in gaps that currently exist regarding SMZ effectiveness in the coastal plain and effects of partial harvesting within SMZs. Results from this study will aid regulatory agencies in determining / revising forestry BMPs and provide needed information about the effects of particular forest practices on stream hydrology in the coastal plain.

METHODS

Study Site

The study site is located in the southwestern corner of Georgia in the Coastal Plain physiographic province approximately 16 km south of Bainbridge. (Figure 1) The physiographic district of the study site is the Pellham escarpment, which is the scarp between the Tifton upland and the Dougherty plain. The soils in the study sites are dominated by Ultisols with the riparian area being comprised of the Cheifland and Esto series which are classified as well drained fine sands over clay loams. The slopes are Eustis series soils, which are loamy sands over sandy loams and classified as somewhat excessively well drained, and the upland soils are comprised of Wagram, Norfolk, Lakeland, Orangeburg, and Lucy which are generally well drained loamy sands over sandy clay loams, with the exception of the Lakeland Unit which has a sandy texture throughout and is characterized as excessively well drained (International Paper soil survey report - 1980).

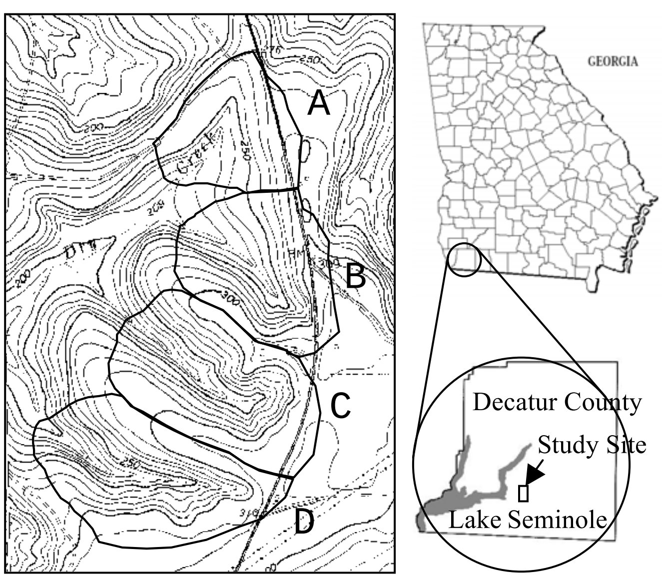


Figure 1. Study site (left), study location (right).

The streams in this study drain four adjacent watersheds with similar aspect, size, shape, soils and vegetative cover type. One of the few apparent differences is the valley floor geometry. Watersheds A and B have broader, flatter valley floors with several wetlands areas while C and D have more channelized streams running through steeper, v-shaped valleys. These geomorphologic differences were used to pair the watersheds into what was initially believed to be the most optimal groups (A+B and C+D).

Study Design

This study is part of a larger multi-disciplinary study designed to examine the effects of forest practices. The statistical design is BACI (Before After Control Impact) consisting of two watershed pairs. The contributing area for these streams varies from 26 to 48 ha (Figure 1 and Table 1). Watersheds A and D were selected as references at the outset of the study and did not receive any silvicultural treatments. The remaining two watersheds (B & C) were clearcut in the fall of 2003 with the exception of the SMZs which were divided into an upstream and downstream section. The upper section of SMZ remains completely intact while the lower section was thinned in accordance with Georgia BMPs. We chose to use basal area as a guideline for thinning and measured every tree to ensure that we met our target.

Data Collection

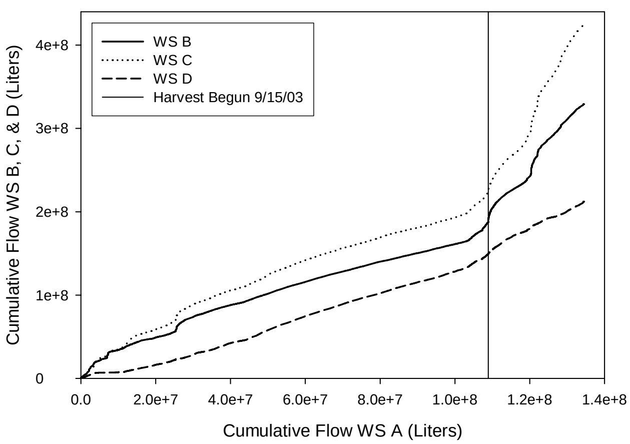
Most of the data is automatically collected at six sites: one in the stream at the outlet of each watershed (4 sites) and one in the stream at the lower boundary of the upstream SMZ treatment (2 sites). Stream stage and discharge is recorded every 15 minutes by Isco Model 4230 Bubbler Flow Meters connected to a 9 inch Parshall flume. Sediment samples are collected by an Isco Model 6712 automated sampler during baseflow using flow proportioned sampling and stormflow on 15 minute intervals and are analyzed for total suspended solids (TSS) and organic and inorganic portions. Precipitation, temperature, relative humidity, wind speed, wind direction and solar radiation are recorded at the weather station which is located on a ridge in the center of the study. There is also a second tipping bucket rain gage located on the other side of the study site in place to detect any spatial variation in precipitation.

In addition to this data, surveys were done before and several times after the harvest to assess where water and sediment were flowing across the SMZ boundary. The boundary was walked and details of any occurrence were recorded, such as evidence of sediment movement intruding into the SMZ.

RESULTS AND DISCUSSION

Hydrology

Stream discharge statistics for the first 27 months of pretreatment data are summarized in table 1. Despite assumptions made about these watersheds based on their physiological characteristics, baseline data reveal their flow characteristics to be quite different. Catchment area, which is the determinate factor of discharge - other things being equal, does not have the expected relationship as seen by the statistics (Tables 1 and 2). In addition, virtually all of the data show that the two most similar watersheds are the two treatments (B & C) and not either of the intended pairs. The selection of treatment and reference watersheds was done at the outset of the study based on watershed characteristics such as shape, size, slope and vegetation. Though the hydrologic data does not match the initial assumptions, good predictive models were established before harvest ensuring that we would be able to detect any changes post harvest. In some cases, models were improved by used both references (A & D) in the model for each treatment watershed.



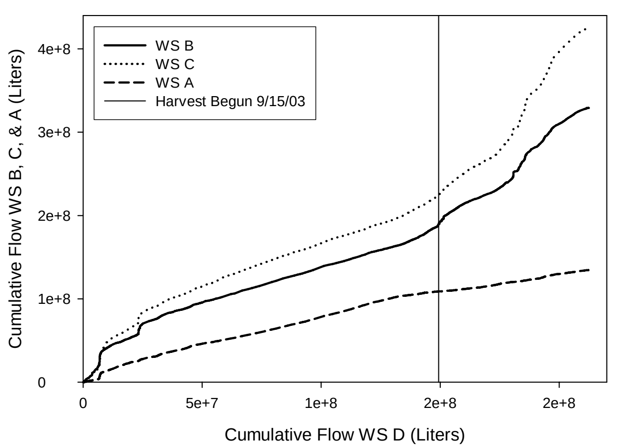


Figure 2. Double mass curves for watersheds. Vertical lines denote when the treatments were imposed.

Table 1. Flow statistics - first 27 months (pre-treatment).

Site	*Area (ha)*	*Mean Q (L/s/ha)*	*Max Q (L/s/ha)*	*Zero Flow Days (/822)*
A	25.8	.055	8.37	163 (20%)
B	34.7	.074	14.08	6 (.7%)
C	42.7	.073	9.91	2 (.02%)
D	48	.042	7.17	206 (25%)

Table 2. Water budget for first 27 months.

Site	*Precipitation (mm)*	*Runoff Depth (mm)*	*Yield (%)*
A	2537	432	17%
B	2537	573	22.6%
C	2537	559	22.0%
D	2537	324	12.8%

Table 3. Percent change in flow after harvest (from double mass curve).

Site Treatment (Reference)	*Pre-Harvest Slope*	*Post-Harvest Slope*	*Increase (%)*
B (comp w/ A)	1.73	5.14	197%
B (comp w/ D)	1.26	2.15	70%
C (comp w/ A)	2.06	7.61	270%
C (comp w/ D)	1.50	3.18	112%

The double mass curves (Figure 2) and the resulting summary table (Table 3) clearly show a change in flow in the treatment watersheds post harvest. These curves, which plot the cumulative flow of a reference against the cumulative flow of the other streams, denote an increase in flow for the streams plotted on the Y axis by an increase in slope of the line. The figures include the same data with different X axes, both A and D, not only to verify the result with two different references but also to show what appears to be a shift in the flow for Watershed D. Although Ws D is still completely forested within its surface catchment boundaries, land directly adjacent to it on both sides has been harvested – which may have resulted in a shift in groundwater input.

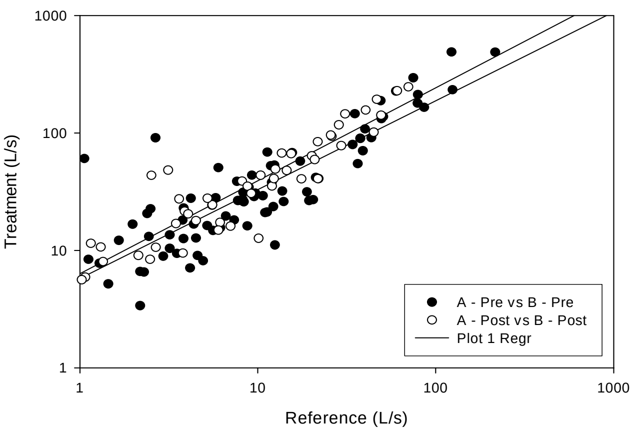
Peak flow rates were also examined from 130 storms during the pre- and post-treatment period. Though there appears to be a small treatment effect (figure 3), the slopes and intercepts of the regressions do not differ significantly at $\alpha = 0.05$.

SMZ "Breakthrough" Surveys

The surveys revealed little evidence of sediment or concentrated flow movement across the proposed SMZ boundary before the harvest in any of the four watersheds. The historic agricultural gullies, though present, were stable and showed no signs of being active. Though there were expectations of potential re-activation of these gullies after the harvest, very few showed any change. However, there were many seeps that appeared in the treatment watersheds after harvest. These usually occurred at the toe-slope within approximately 10 meters of the SMZ boundary on average and flowed across the boundary into the stream. These were the result of elevation of the water table associated with vegetation removal. Because they occurred at the bottom of the slope they likely lack any real power to entrain and move sediment however they do increase the variable source area and are therefore of some management concern. Care needs to be taken to avoid herbicide application in those areas to prevent them from being a direct pathway to the stream. This is a relatively easy task as hand application of herbicide on steeper slopes is generally common practice due to the limitations of machine travel on those areas.

Sediment Data

At this time, the recent sediment data have not been analyzed and space only allows for a brief description. Earlier data suggests that behavior varies between the four streams, and does not show the typical positive correlation with flow. Watersheds A and B show a dilution effect with stormflow and C and D have varied responses. Patterns suggest that there are predictable mechanisms for sediment generation that require more variables than flow to predict. Further investigation is currently underway. We hypothesize that sediment concentrations in these watersheds may be driven by processes within the wetland areas of the channel.



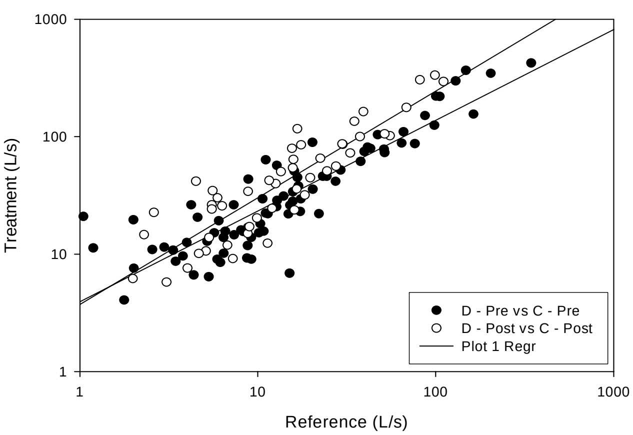


Figure 3. Pre– and post-treatment peakflow regressions for watershed pairs A & B (top) and C & D (bottom). Shown in log scale.

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