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Flat Branch Monitoring Project: Stream Water Temperature and Sediment Responses to Forest Cutting in the Riparian Zone

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Abstract

Stream water protection during timber-harvesting activities is of primary interest to forest managers. In this study, we examine the potential impacts of riparian zone tree cutting on water temperature and total suspended solids. We monitored stream water temperature and total suspended solids before and after timber harvesting along a second-order tributary of the Coleman River in northeastern Georgia, where logging with rubber-tired skidders was conducted in the riparian area along alternating 60-m stream reaches on the east side of the stream. We monitored temperature above the management unit (reference), at a location within the cut area (within cut), and at a third site 150 m below the cut area (below cut). We measured total suspended solids during base flow and storm flow, taking weekly stream water grab samples above the site and above and below each riparian area, for a total of six sampling locations. We found that stream water temperature following harvest increased within the cut area relative to the reference but decreased at the below sample site back to reference conditions. Overall, total suspended solids responses were minimal or nonexistent during base and storm flows within the cut relative to the reference site, and temperature responses were minimal. Unusually warm and dry weather existed for most of the logging period, which may have minimized the potential for runoff, erosion, and sediment; however, low flows may have contributed to the small increases in water temperature. Hence, we observed only marginal effects of riparian zone cutting on water temperature and total suspended solids in this study.

Keywords: Forest cutting, streamside management zones, stream water temperature, total suspended solids.

Introduction

Researchers have long been interested in the effects of timber-harvesting activities on water quality (Knoepp and Clinton 2009, Lieberman and Hoover 1948, Moore and others 2005, Swank and others 2001, Tebo 1955). For example, early studies at the Coweeta Hydrologic Laboratory focused on the impacts of historical land uses such as exploitive logging practices and mountain farming on stream water quality. The exploitive logging experiment at the Coweeta Hydrologic Laboratory (Lieberman and Hoover 1948) resulted in total suspended solids (TSS) values 20-fold greater than in an adjacent control watershed. Swift and Messer (1971) measured stream water temperature responses to forest removal on six small watersheds and reported no change in maximum summer temperature to as much as a 7 °C increase in streams draining the mountain farm.

One key factor regulating water quality responses to management is how forest management impacts structural and functional processes in the riparian zones. Forested riparian areas mediate a number of terrestrial-aquatic linkages (Karr and Schlosser 1978) by influencing physical, chemical, and biological dimensions of materials that move from the terrestrial system to streams. Many studies have quantified the impacts of riparian zone management on aquatic resources in the Southern Appalachians (Greene 1950, Jones and others 1999, Swift and Messer 1971, Webster and others 1992) with most of the studies focusing on the effects of removing (partially or completely) the vegetation from riparian zones. Results varied but, in general, indicated that manipulation of vegetation in steep mountain watersheds can alter thermal, sediment, and discharge regimes of the affected stream through reduced shading, soil disturbance, and water uptake.

Streamside management zones (SMZs) implement some of the more commonly recommended best management practices (BMPs) for water resource protection (Klapproth 1999). Development of SMZ practices was based primarily on two erosion-related issues: water quality and site productivity (Lakel and others 2006). Even though a wide range in requirements or recommendations exists across jurisdictions (Lee and others 2004), most States provide BMPs for forest-management activities that protect water quality and aquatic habitat. For example, guidelines for Georgia are published in "Georgia's Best Management Practices for Forestry" by the Georgia Forestry Commission (1999). Numerous studies have examined the usefulness of BMPs in a variety of settings. Arthur and others (1998) compared the effectiveness of BMPs used during riparian and upland forest harvest in the Central Appalachians and found that properly implemented BMPs resulted in significantly lower amounts of post-harvest sediment compared with not using BMPs. Similarly, Kochenderfer and others (1997) examined the effectiveness of BMPs at minimizing sediment yield and stream temperature in a West Virginia watershed following timber harvest and, based on observed increases in sediment yield, concluded that sediment generated during the logging operation represented < 5 percent of total stream exports over an estimated 100-year rotation. Further, reducing basal area by 44 percent had a negligible effect on maximum growing season stream water temperature due to adequate shading by residual trees and understory shrubs.

This study examines the cumulative effects of streamside forest management on water quality where forest harvesting was conducted in discrete patches along the stream. Our objectives were to examine the cumulative effects of forest harvesting in patches within the riparian zone on stream water temperature and TSS.

Methods

Study Site Description

This study was conducted on the Chattooga Ranger District of the Chattahoochee-Oconee National Forest, Rabun County, Georgia (35° N, 83° W). The study stream is Flat Branch, a perennial second-order tributary of the Coleman River located in the headwaters of the Tallulah River Watershed (fifth level HUC 0306010207) within the Savannah River Basin (third level HUC 030601) (Seaber and others 1987). Stream grade for the study reach is approximately 4.1 percent, and the total contributing watershed area, including the cut area, is approximately 134 ha. The area receives abundant rainfall distributed evenly throughout the year and averages 1650 mm annually, with < 10 percent falling as snow or ice. Average annual air temperature is 14 °C and ranges from an average monthly minimum in January of -4 °C to an average monthly maximum in August of 25 °C. Elevation at the study site is approximately 900 m, and the topography is relatively flat to gently rolling. Soils in the area are of the Edneyville and Bradson series in the uplands, and Toccoa and Tusquitee series near the stream.

Logging Description and Layout

Logging operations used a ground-based system that included rubber-tired grapple and cable skidders, rubber-tired feller and chainsaw felling, a knuckleboom log loader, and tractor trailer tree-length hauling. In figure 1, areas shown in solid gray were designated for shelterwood harvest, and areas in dark gray cross-hatch are streamside management zones (SMZs). Equipment was not permitted in the SMZ, and chainsaw-felled timber in these areas was removed by cabling to nearby shelterwood areas. Additionally, two 60-m strips along the east side of the stream, separated by 60 m of riparian zone management, were designated to receive shelterwood area timber harvest levels. The objective of this additional treatment was to produce streamside early successional habitat within the SMZ, and to examine potential impacts of this prescription on water quality.

Timber harvesting began in October 2007 and ended in July 2008. A primary objective of the timber-harvesting project was to create habitat for species of wildlife dependent on high-elevation and early-successional (< 20 years old) forest habitat, such as the golden-winged warbler *(Vermivora chrystoptera)* and ruffed grouse *(Bonasa umbellus),* as well as other game and nongame species of wildlife. Secondary project objectives

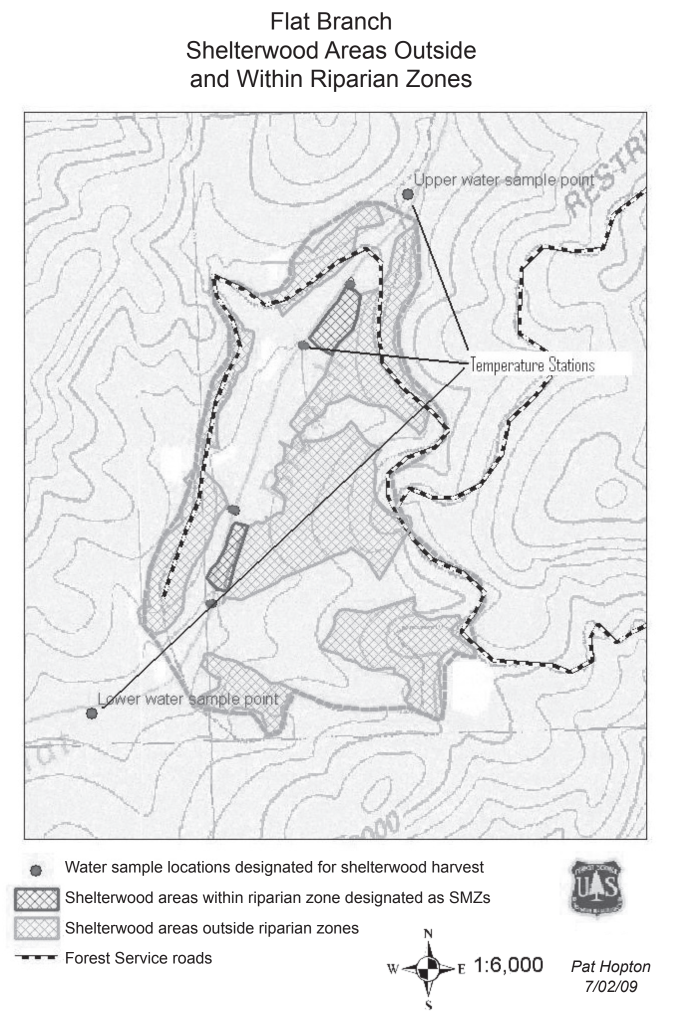

Figure 1—Map of monitoring area showing areas receiving shelterwood cuts within (dark gray cross-hatched) and outside (light gray cross-hatched) the riparian zone. Also shown are stream sample locations above and below the study area.

included improving native brook trout habitat and reducing risk of southern pine beetle *(Dendroctonus frontalis)* attacks.[1]

Stream Water Temperature

Hourly stream water temperature (°C) was measured continuously throughout the spring, summer, and fall of 2006, 2007, and 2008. Hourly measurements were taken by submersible temperature sensors (HOBO® Pro v2 Data Loggers, Onset Computer Corporation) placed above the timber harvest area at the midpoint within the harvest area, and at a location 150 m below the cut. Care was taken to ensure that all temperature sensors remained submerged during the study period.

Suspended Solids

Stream water grab samples were collected weekly adjacent to each water temperature data collection station and at four additional stations along the stream reach within the cut area. Samples were collected with 1-L Nalgene® sample bottles. Sample stations within the cut area included all but the upper and lower stations (fig. 1). To minimize the impacts on TSS that might come from disturbing the stream bottom while walking in the stream, grab samples were taken by beginning each collection at the most downstream sample location and then working upstream, i.e., samples were taken while walking upstream. In addition, care was taken to ensure that no contact was made between the lip of the sample bottle and submerged objects. Bottles were clearly labeled with the sample location (i.e., reference, within cut, below cut) and the collection date. Storm samples were collected using the sampling design above, and as soon after storm initiation as possible. Because of the remote nature of the study site, it was not always known at what point during storm flow (i.e., increasing or decreasing discharge) samples were actually retrieved, and only one sample was taken at each collection station for each storm event. Previous studies in the region suggest that TSS can be higher on the rising limb of the hydrograph versus the recession limb (Riedel and others 2004). Our sampling took about 45 minutes to complete, so it is likely that storm-flow sampling sometimes occurred on the rising limb of the hydrograph and sometimes occurred on the falling limb of the hydrograph (Riedel and others 2004). While this introduces variability into the storm flow TSS data, it does not bias the sampling results, because we averaged across sample collections, thereby including samples collected on both rising and falling limbs of the hydrograph (see Data Analysis section). All weekly sample collections were refrigerated until analyzed. Filtration of stream samples for estimating concentrations of TSS (mg L^{-1}) were conducted at the analytical lab of the Coweeta Hydrologic Laboratory in accordance with established Coweeta QA/QC Laboratory protocols (Coweeta QA/QC Manual, Analytical Laboratory publication[2]).

Data Analysis

Values for TSS within the cut area (all locations excluding the upper and lower locations, see fig. 1) were averaged to determine an overall within-cut value for both base-flow and storm-flow conditions. Comparisons were made among the three sample/monitoring locations (reference, within-cut, below-cut) to test for treatment effects on TSS using a repeated measures analysis given AR(1) covariance structure (PROC MIXED, SAS Institute 2008). TSS data were analyzed for differences between sites before and after harvest for both base-flow and storm-flow conditions. Stream water temperature data were analyzed for treatment effects using PROC GLM (SAS Institute 2008). Where treatment effects were detected for both analyses above, least square means were computed and Tukey's pairwise comparisons were performed using an experiment-wise alpha of 0.05. For temporal responses, water temperature and TSS were analyzed at each sample location independently for changes between pre- and post-harvest conditions at those locations. A graphical analysis of stream water temperature was made by examining the difference between the reference and within-cut and below-cut sites. For this analysis, values greater than zero for within-cut or below-cut sites were interpreted as being greater than the reference. Significant differences were evaluated at the α=0.05 level of significance.

Results and Discussion

Stream Temperature

There was no significant difference in summertime mean or minimum temperature between cut and uncut areas (table 1). A small but statistically significant increase in monthly summer maximum stream water temperature occurred within the cut area following harvest (F=3.69, P=0.05), but water temperatures were not different from reference levels at the below-cut site (table 1). In figure 2 we compare mean water temperature at the within- and below-cut sites to the reference site by subtracting out water temperature at the reference site.

[1] Personal communication. 2008. David Jensen, District Ranger, U.S. Forest Service, Chattooga RD, 9975 Highway 441 South, Lakemont, GA 30552.

[2] U.S. Department of Agriculture Forest Service. [N.d.]. Coweeta QA/QC Manual, Analytical Laboratory Publication. Internal report. On file with: U.S. Department of Agriculture Forest Service, Southern Research Station, Coweeta Hydrologic Laboratory, 3160 Coweeta Lab Road, Otto, NC 28763.

Values above the "zero" line represent water temperatures greater than the reference. In this comparison (fig. 2), there was an increase of approximately 2 °C within the harvest area during the summer of 2008, although this increase was not statistically significant. Comparing that same location within the cut area to a point 150 m below the lower boundary of the cut, the observed increase dissipated and was not different from the reference location.

Monthly maximum stream water temperatures were greatest during the summer within the cut area compared with the reference and below the cut, and the reference and below the

Table 1—Monthly summer (June through September) mean, minimum, and maximum stream water temperature for the three sample locations during pre- and post-harvest periods

	Mean		Minimum		Maximum	
Site	Pre-cut	Post-cut	Pre-cut	Post-cut	Pre-cut	Post-cut
Reference	16.0[a]	15.9[a]	15.7[a]	15.6[a]	16.5[a]	16.2[a]
Within cut	16.4[a]	16.5[a]	16.0[a]	15.9[a]	17.0[a]	17.1[b]
Below cut	15.9[a]	15.9[a]	15.4[a]	15.5[a]	16.4[a]	16.3[a]

Note: values for mean, minimum, and maximum temperatures with the same letter superscript within pre- or post-cut periods are not significantly different at α=0.05.

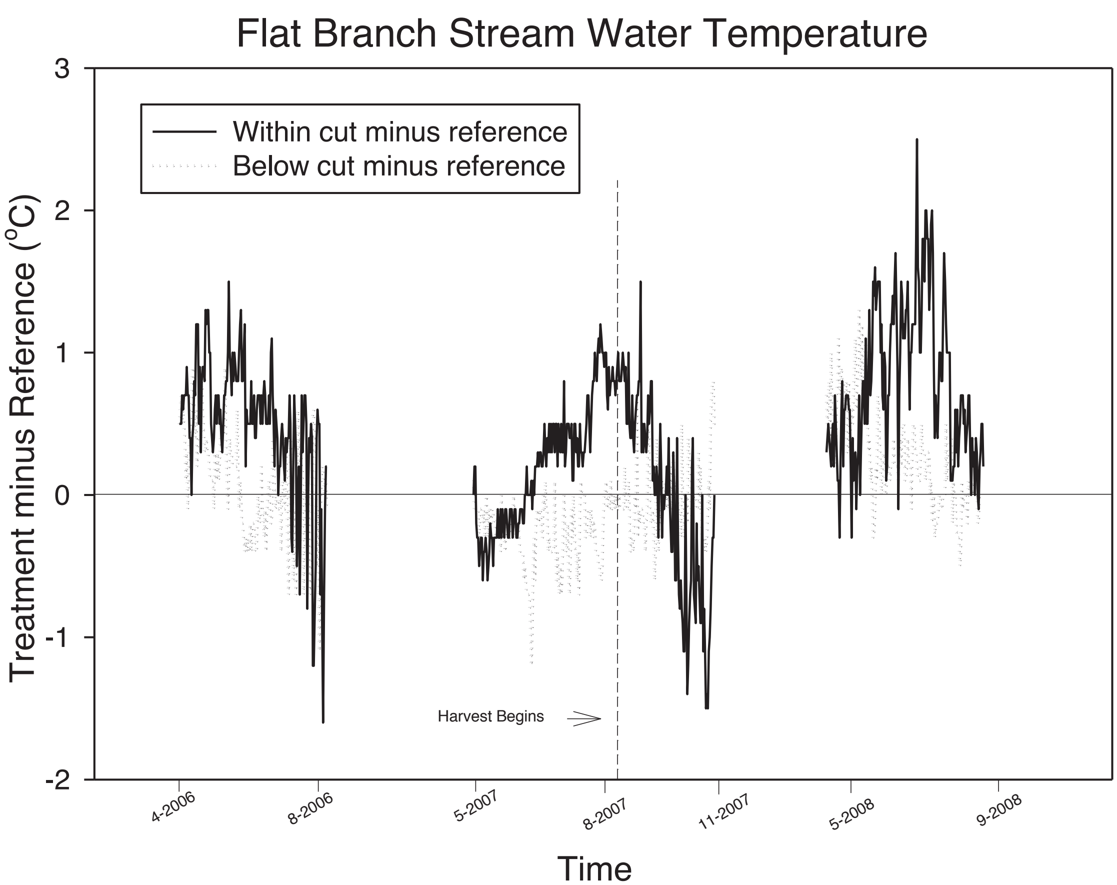

Figure 2—Stream water temperature (°C) at Flat Branch. Values are differences in temperature between sample sites (within cut and below cut) and the reference site. Positive values indicate temperatures greater than the reference and negative values indicate temperatures lower than the reference.

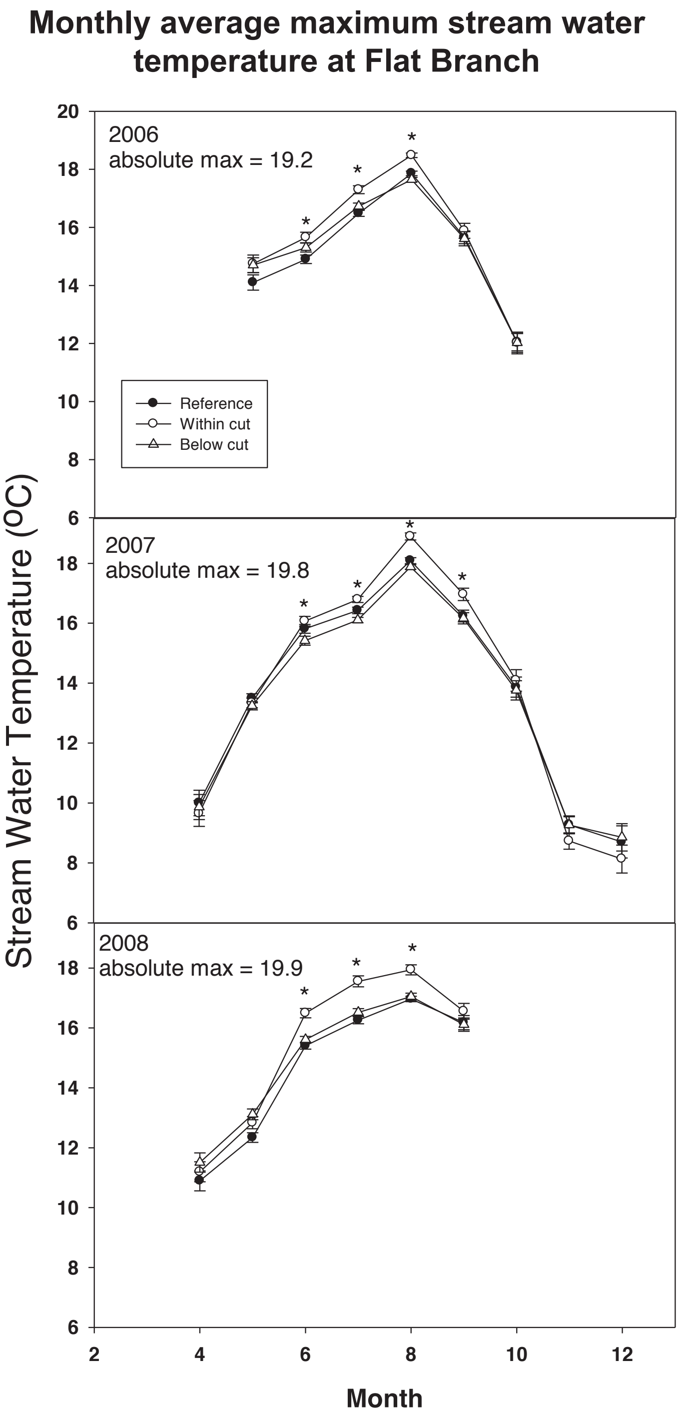

Figure 3—Average monthly maximum stream water temperature (°C) for the reference, within cut, and below cut sites by month for 2006 through 2008. Inset is the absolute maximum temperature each individual year. Means with an asterisk (*) superscript represent significantly greater average maximum water temperature within the cut area compared with the reference and/or below cut for that month at α=0.05.

cut were similar throughout the study period (fig. 3). Although maximum water temperature increased by 2 °C within the cut area, the absolute maximum of 19.9 °C was below the temperature threshold considered detrimental to reproduction and to the establishment of young among all species of trout (e.g., 22.3 °C for brook trout [*Salvelinus frontinalis*], 24.0 °C for rainbow trout [*Oncorhynchus mykiss*], and 24.1 °C for brown trout [*Salma truta*]) found in the region (Eaton and others 1995). Ringler and Hall (1975) reported increases in water temperature after logging in an Oregon watershed, and attributed the increase to reduced forest cover over the stream surface. Similarly, Johnson and Jones (2000) reported increases in stream maximum summertime temperature that remained elevated for 15 years following harvest, and attributed the increase to removal of riparian vegetation. Swift (1983) reported that daily maximum summertime temperatures increased by 3.3 °C for the first 2 years following harvest, including riparian vegetation, on a south-facing watershed, with daily maximum temperature increases falling over the following 3 years to 1.2 °C on average. In that study, over 950 m^2 of stream were exposed on a south-facing slope following logging. In contrast in our study, exposed stream area was approximately 300 m^2. The observed increase in daily maximum temperatures in our study (2 °C) immediately after harvest is consistent with the pattern reported by Swift (1983), but the magnitude of increase is much lower given the smaller exposed stream surface area on our study site.

Total Suspended Solids

Forty sets of base-flow samples and 6 sets of storm-flow samples were taken during the pre-harvest period, and 31 sets of base-flow samples and 4 sets of storm-flow samples were taken after harvest (fig. 4). Storm-flow samples were limited due to unusually dry weather patterns during both pre- and post-harvest periods. No significant differences in TSS were observed among sample locations before harvest and after harvest for base flow and storm flow; however, some differences were observed when comparing pre- and post-harvest within a measurement location. For example, at base flow, TSS at the reference location was significantly lower post-harvest (F = 4.26, P = 0.043) compared to pre-harvest. During storm flow, there was a significant increase in post-harvest TSS within the cut area (F = 5.33, P = 0.027) compared to pre-harvest. Although a large increase in TSS was also observed between pre- and post-harvest at the reference location during storm flow, high variability precluded detection of statistical significance. TSS increased within the cut area post-harvest, but there was no significant difference between pre- and post-harvest TSS during storm flow below the cut.

Increases in TSS observed within the cut area during storm flow were likely a result of increased TSS at the reference site located above the cut area. The source of sediment from this upstream location is unknown, but it could be residual sediment from past land uses that continues to migrate downstream during storm events. For example, Swank and others (2001) reported increased sediment yield from a clearcut watershed compared with pre-harvest conditions for at least 15 years following harvest activity, due primarily to large pulses of sediment input resulting from two storms during road construction on that site. It is unlikely that the elevated TSS in the cut area was due to surface erosion and overland flow caused by the harvest operations, because the riparian zone in the Flat Branch study area is relatively flat. Within the entire harvested area, the maximum difference in elevation is approximately 15 m, and average slope is < 20 percent. Also, during the harvest operation and the year following the operation, the region experienced unusually hot and dry conditions that further reduced the probability of soil erosion and overland flow. The two dominant mechanisms for reductions in sediment delivery to streams are filtering through riparian vegetation (Cooper and Gilliam 1987) and particle size sorting as the overland flow velocity decreases as it passes through riparian vegetation (Cooper and others 1987). Neary and others (1993) report that the effectiveness of these processes is a measure of the adequacy of the riparian buffer for protecting water quality.

Warm and dry weather during and after harvest may have influenced the temperature response in our study. Low rainfall decreases stream water discharge, which often leads to elevated water temperature. Although low stream flow may have contributed to the observed water temperature increase, cooler water below the cut suggests that the observed increase was also due to the removal of forest cover both over the stream and in areas adjacent to the stream. Story and others (2003) attributed downstream cooling below harvested areas to the interaction of subsurface hydrology with surface flow, speculating that the cooler subsurface flow did not interact sufficiently with the warmer surface water within the cut area to buffer localized heating brought on by increased direct solar radiation. Poole and Berman (2001) reported that stream

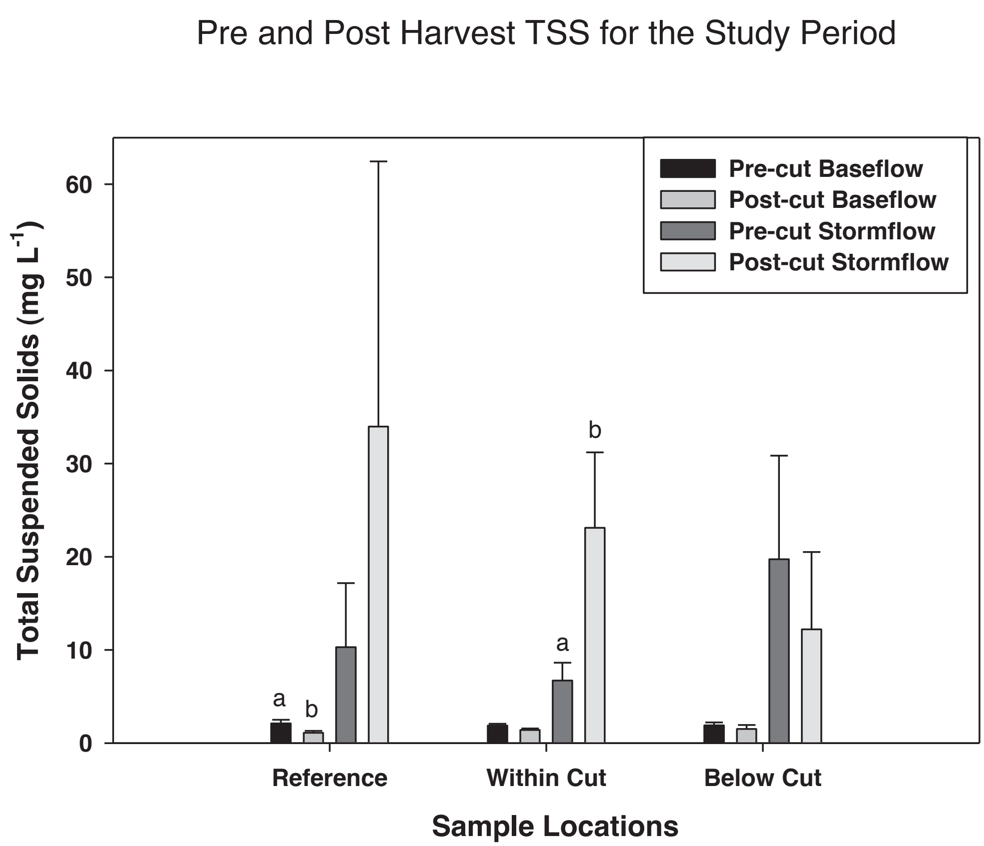

Figure 4—Pre- and post-harvest total suspended solids (mg L^{-1}) for the three sample sites at base flows and storm flows. Means with different letter superscripts are significantly different within sites for pre- and post-harvest values. For means with no superscript, significant differences were not found. There were no significant differences among sites during either base or storm flow. Error bars are one standard error.

water temperature regimes are a function not only of external drivers such as direct solar radiation but also of the internal structure of the stream, which determines how heat and water will be distributed within and exchanged among a stream's components, e.g., channel, alluvial aquifer, and riparian zone/floodplain.

The method of timber harvesting and care, given the resource, play important roles in the outcome of these activities. Other studies testing BMPs in steep terrain have shown only small or no increase in TSS following harvest. For example, Clinton (unpublished data[3]) observed only small and temporary increases in TSS on sites receiving two-age silvicultural treatment and having buffer widths ranging from zero to 30 m. In the Clinton (see footnote 3) study, timber harvesting was conducted using cable-yarding technology that keeps soil disturbance to a minimum and diminishes the effects of erosional processes associated directly with timber extraction.

Summary and Conclusions

Timber-harvesting activities can result in increases in sediment yield where improper timber-extraction methods are used (Lieberman and Hoover 1948). However, with the development and proper implementation of BMPs, negative effects of harvesting timber on water quality can be minimal and short term. In our study, results of post-harvest monitoring indicated no substantial effect of timber harvesting in the riparian zone on water temperature and TSS. Care was taken during the operation to limit access by rubber-tired skidders to managed riparian shelterwood areas, and this limitation likely played a direct role in minimizing sediment delivery to the stream. TSS was highly variable, with no differences among sample locations (i.e., reference, within the harvested area, and below the harvested area) during base flow or storm flow. Some differences were found between pre-cut and post-cut within some sample locations. For example, within the cut area, TSS during storm flow increased significantly when pre-harvest and post-harvest measurements are compared; however, this response was most likely due to an increase in storm flow TSS in the upstream reference area. The low topographic relief on Flat Branch helped mitigate the potential for sediment delivery to the stream. Although a small increase in water temperature was observed, maximum temperatures remained below published maximum thresholds for common trout species in this region. Further, observed increases in water temperature within the harvested area dissipated within a few hundred meters downstream. The results suggest that thoughtful pre-harvest planning and effectively applied BMPs can minimize the negative impacts associated with timber-harvesting activities.

[3] Clinton, B.D. Stream water responses to forest cutting: riparian buffer width effectiveness. Unpublished data. On file with: U.S. Department of Agriculture Forest Service, Southern Research Station, Coweeta Hydrologic Laboratory, 3160 Coweeta Lab Road, Otto, NC 28763.

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