EVALUATING BEST MANAGEMENT PRACTICES FOR EPHEMERAL CHANNEL PROTECTION FOLLOWING FOREST HARVEST IN THE CUMBERLAND PLATEAU – PRELIMINARY FINDINGS

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Abstract.—Most states in the United States have established forestry best management practices to protect water quality and maintain aquatic habitat in streams. However, guidelines are generally focused on minimizing impacts to perennial streams. Ephemeral channels (or streams), which function as important delivery systems for carbon, nutrients, and sediment to perennial streams, are comparatively unprotected. An examination of the effectiveness of three types of streamside management zones around ephemeral channels is under way at the University of Kentucky's Robinson Forest, located in southeastern Kentucky. Treatments include: 1) no equipment limitation with complete overstory removal and unimproved crossings; 2) no equipment limitation with retention of channel bank trees and improved crossings; and 3) equipment restrictions within 7.6 m of the channel with retention of channel bank trees and improved crossings. The following improved crossing types were studied: wooden portable skidder bridges, steel pipe/culverts, and PVC pipe bundles. Water samples were taken during storm flows using automated water samplers and were analyzed for total suspended solids and turbidity. Initial results indicated that harvest operations resulted in increased sediment movement in ephemeral channels over unharvested controls. All improved channel crossings reduced the amount of sediment input over that of an unimproved ford. However, the 7.6-m equipment restriction zone did not provide additional sediment reductions.

INTRODUCTION

Forestry best management practices (BMPs) have been established in most states to protect water quality and aquatic habitat during forest harvests. Frequently, these guidelines vary based on the stream type impacted by the harvesting operation; ephemeral channels receive the least protection.

Ephemeral channels are distinguished from intermittent and perennial streams based on hydrology. Kentucky's Forestry Best Management Practices describe ephemeral channels as those that flow during or directly after precipitation or in response to snow melt and conduct surface water directly or indirectly to perennial streams (Stringer and Perkins 2006). Perennial streams flow continuously except in extreme drought, and intermittent streams flow during the wet season (Fritz and others 2008). Ephemeral channels commonly lack defined banks and generally have large amounts of organic matter in the channel bed (Hansen 2001). Svec and others

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(2005) used channel geometry and watershed characteristics to distinguish among the three stream types in eastern Kentucky.

Ephemeral channels are an important component of the headwater stream system, which encompasses first- to third-order streams draining areas of less than 2 km^2, including perennial, intermittent, and ephemeral flow regimes (Horton 1945, Adams and Spotilia 2005). A majority of a watershed's stream length is located in the headwater system. Studies have found that the headwaters can encompass from 60 percent to 80 percent or more of the entire watershed network (Gomi and others 2002, Benda 2005, Wipfli and others 2007). Headwater streams are able to effectively deliver water, fine sediment, and fine particulate organic matter downstream, as well as store coarse sediment and large woody debris (MacDonald and Coe 2007, Wipfli and others 2007). Additionally, ephemeral channels, as a component of the overall headwater system, provide important habitat to a variety of biota (Meyer and others 2007).

During harvesting operations, ephemeral channels are often crossed by driving directly through the channel rather than crossing with an improved or elevated crossing. This procedure is common because many ephemeral channels are relatively small and running water is frequently absent at the time of harvest. However, these channel crossings can lead to increased sediment movement from the ephemeral channels to downstream reaches (Davies and Nelson 1993). Improved crossings potentially could decrease the amount of sediment delivered downstream.

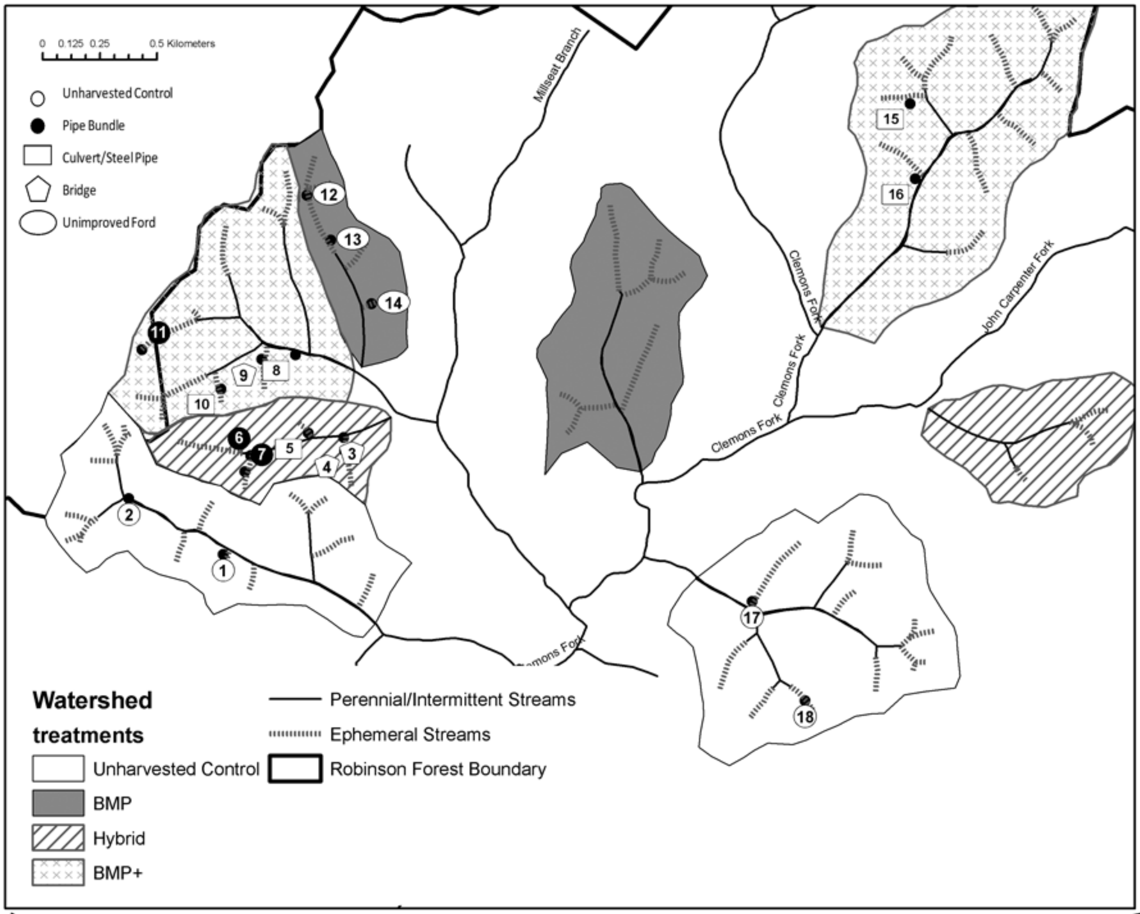
The objective of this study was to determine how alternative forestry BMPs influence ephemeral channel suspended solids and turbidity. We assessed the following three BMPs: 1) no equipment limitation with complete overstory removal and unimproved crossings, 2) no equipment limitation with retention of channel bank trees and improved crossings, and 3) equipment restrictions within 7.6 m of the channel with retention of channel bank trees and improved crossings. In addition, we compared several improved stream crossing techniques to unimproved crossings and unharvested conditions. These treatments were developed in part to help provide information on the effectiveness of Kentucky's Best Management Practices for Water Quality Management (Stringer and Perkins 2001).

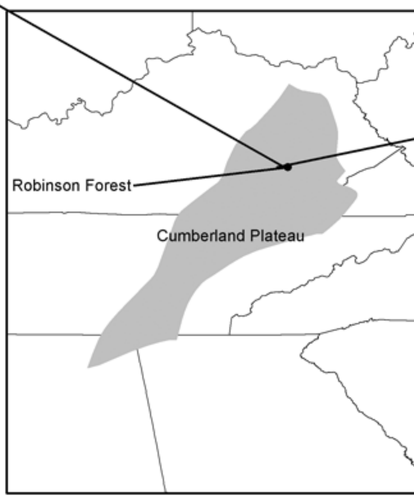
STUDY AREA

Robinson Forest is located in the Cumberland Plateau region of southeastern Kentucky (Fig. 1). Six harvested watersheds (two per BMP treatment) and two unharvested control watersheds were used in the study. Topographically, Robinson Forest is characterized by steep slopes with well drained residuum or colluvial soils formed from sandstone, shale, and siltstone. The forest is classified as mixed-mesophytic forest with oak (*Quercus* spp.), hickory (*Carya* spp.), and yellow-poplar (*Liriodendron tulipifera*) as dominant overstory species. Mean annual precipitation at Robinson Forest is 117.5 cm (Cherry 2006).

Channel slope for the monitored ephemeral channels ranged from 7 to 26 percent with a mean slope of 19 percent. The slope of the skid trails on either side of the crossings ranged from 1 to 23 percent with a mean of 9 percent. The height of the trail relative to the channel ranged from 0 to 2.7 meters, with a mean of 0.97 meters.

Skid trails were constructed along the contour at various intervals from the top to the bottom of the slopes. The majority of channel crossings occurred with either cable or grapple skidders (John Deere models 540





Sampler ID	Approx. Area (ha)	Crossing Type	Treatment Type
1	2.93	Unharvested Control	Unharvested Control
2	8.92	Unharvested Control	Unharvested Control
3	2.80	Bridge	Hybrid
4	2.39	Bridge	Hybrid
5	2.00	Culvert/Steel Pipe	Hybrid
6	2.48	Pipe Bundle	Hybrid
7	1.72	Pipe Bundle	Hybrid
8	1.72	Culvert	BMP+
9	2.25	Bridge	BMP+
10	1.75	Culvert/Steel Pipe	BMP+
11	0.76	Pipe Bundle	BMP+
12	1.45	Unimproved Ford	BMP
13	0.75	Unimproved Ford	BMP
14	2.21	Unimproved Ford	BMP
15	3.92	Culvert/Steel Pipe	BMP+
16	4.36	Culvert/Steel Pipe	BMP+
17	8.03	Unharvested Control	Unharvested Control
18	5.16	Unharvested Control	Unharvested Control

Figure 1.—Location of Robinson Forest and treatment watersheds.

and 648 and Caterpillar models 525 and 545). Additional equipment used during the harvest that crossed ephemeral channels included: Timbco swing-armed feller bunchers (model 445 or 445EXL) and John Deere bulldozers (model 650, 700, or 800). The feller bunchers and bulldozers ran on tracks; the skidders used air-filled rubber tires.

METHODS

TREATMENTS

Three watershed treatments were applied to two watersheds each (Fig. 1). The current regulations in Kentucky for ephemeral channels require that channels be crossed with improved crossings where feasible. Where improved crossings are not feasible, channels should be crossed at right angles with fords. Retention of overstory trees and equipment limitations in or directly adjacent to the channel are not required. Blockage of ephemeral channels with logging debris (soil, root wads, tree tops, or tree sections) is not permitted by Kentucky's mandatory BMP law. This treatment is referred to as the "BMP treatment." The second treatment, referred to as a "Hybrid treatment," requires the use of improved channel crossings, as well as retention of the nearest overstory tree along the channel on both banks (tree stringer). The final treatment is the "BMP-plus treatment," which also requires improved crossings and retention of a tree stringer along both banks, as well as a 7.6-m zone from the channel in which equipment is not permitted (equipment limitation) (Table 1).

The improved crossings tested were portable wooden skidder bridges, steel pipes/culverts, and PVC pipe bundles. Portable wooden skidder bridges consisting of three panels were installed and removed over channels using wheeled grapple skidders. The steel pipe/culvert treatment used either corrugated steel or solid steel pipe placed into channels and backfilled with at least 10 cm of soil. PVC pipe bundles (Mason and Moll 1995) were constructed according to Blinn and others (1998). The PVC pipe bundles were constructed of at least twenty 9-cm diameter PVC pipes threaded together with steel cable (Reeves and others 2008). Pipe bundles were laid in the channel and allowed to conform to the channel bottom, covered with a layer of geo-textile fabric, and overlaid by at least 20 cm of soil. The purpose of the overlain soil was to minimize damage to the pipe bundle during crossing by wheeled skidders, both loaded and unloaded, as part of normal harvesting operations. On average, skid trail crossings were in use for a limited time period, generally 2 to 6 weeks. Crossings were removed after the skid trail was retired. During retirement, structures were removed and in the case of the culvert/pipe and PVC pipe bundle, the majority of the overlain sediment was removed from within the channel using a bulldozer.

Table 1.—Ephemeral channel best management practices applied during treatment. The current Kentucky regulations are implemented in the "BMP" treatment. A "stringer" refers to retention of the nearest overstory tree to the channel along both banks. In addition to the three treatments, ephemeral channels in unharvested areas are monitored as a control treatment.

Treatment	Sreamside management zone width (m)	Overstory retention	Crossing type
BMP	0	0%	Unimproved
Hybrid	0	Stringer	Improved
BMP+	7.6	Stringer	Improved

SAMPLE COLLECTION AND ANALYSIS

Sixteen ephemeral channels in six watersheds were monitored from July 2008 to November 2009. In two of the 16 channels, multiple channel crossings were monitored using two samplers, for a total of 18 sampling points. Estimated catchment areas of the channels measured from the sampling point ranged from 0.75 ha to 8.9 ha, with a mean area of 3.1 ha (Fig. 1, estimated from topographic maps and geographic information systems data).

Measureable precipitation was recorded on approximately 40 percent of the days in the period sampled. Of the 84 total events during the sampling period, 35 (42 percent) had total precipitation of greater than 12.7 mm and 21 (25 percent) had total precipitation of greater than 25.4 mm. The total number of sampled events was 25, with a mean precipitation of 44 mm (range: 9 mm to 240 mm). Partial events (events that did not activate all samplers) were included in the analyses due to differences in sampler deployment dates, precipitation gradients, channel flow, and equipment functioning that made obtaining a complete sample set from a specific event difficult.

ISCO automated pump samplers (Teledyne ISCO, Lincoln, NE) equipped with liquid level actuators were used to collect samples following storm events that resulted in ephemeral channel flow. Actuators were placed directly in the dry channel bed to activate the sampler when flow began in response to a precipitation event. Events that were not of sufficient duration or intensity to result in channel flow were not sampled. One 200-ml sample was collected every 30 minutes beginning at the start of a flow event and ending 24 hours later, resulting in a 9.4-L composite sample. A composite sampling method was chosen due to the time associated with analyzing multiple samples for each event and sampling location. Of the composite sample, a 1.5-L sub-sample was used for analysis.

Samples were analyzed for two parameters: total suspended solids and turbidity. Total suspended solids was determined gravimetrically using a 0.45-μm filter according to American Public Health Association guidelines (Greenberg and others 1992). Turbidity (measured in formazin turbidity units [FTU]) was analyzed using a Hanna portable turbidity meter (model HI 93703, Hanna Instruments, Woonsocket, RI).

Harvesting began in June 2008 and was completed in October 2009. Because monitoring of each channel began as soon as possible following the start of its use as a crossing site, the number of samples for each crossing type and treatment varied.

Data were grouped according to treatment and crossing type. Of the 18 crossings, three were crossed with pipe bundles, five with culverts, and three with bridges; three were forded without improved crossings, and four remained unharvested. Three channels were harvested using the BMP treatment, three used the Hybrid treatment, and six used the BMP-plus treatment. Statistical differences were determined using a protected least significant differences test (one-way ANOVA followed by nonparametric Mann-Whitney tests) (SAS Institute Inc., Cary, NC). Percentage comparisons (increase or decrease) were calculated from mean total suspended solids and turbidity measurements from the ephemeral sampling points.

RESULTS

Preliminary data indicate a pronounced effect on total suspended solids and turbidity when improved crossings are used (Fig. 2). When bridges were used, total suspended solids was reduced by 88 percent

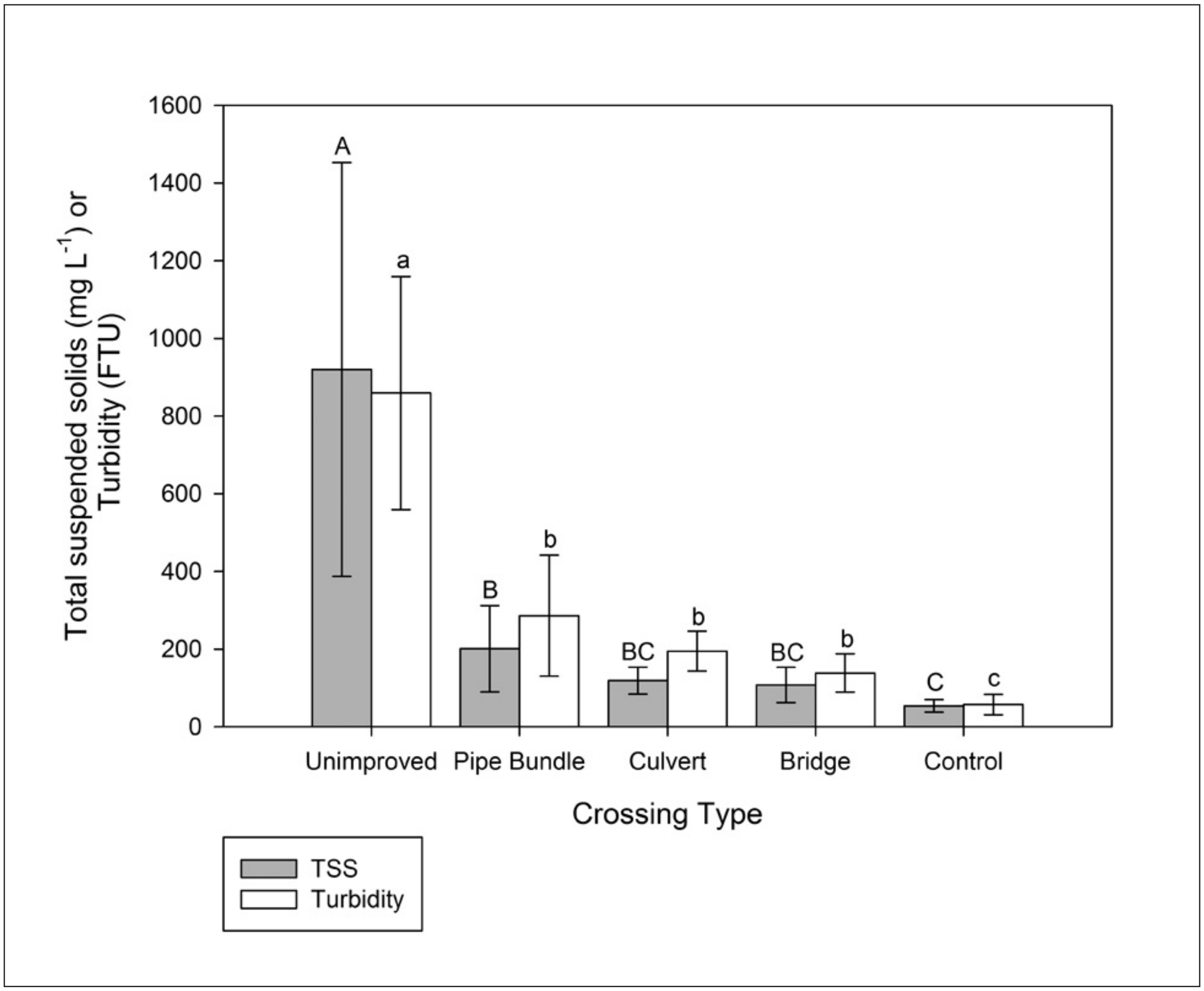


Figure 2.—Effect of crossing type on total suspended sediment and turbidity. Letters indicate significant differences at the α = 0.05 level; capital letters indicate differences in total suspended sediment and lowercase letters indicate differences in turbidity. Formazin turbidity units (FTU) were used to measure turbidity. “Control” refers to data from unharvested ephemeral channels.

compared to unimproved crossings ($p = 0.003$, $n = 26$). Culverts resulted in an 87-percent reduction in total suspended solids ($p = 0.002$, $n = 39$), and pipe bundles reduced total suspended solids concentrations by 78 percent ($p = 0.01$, $n = 24$) compared to unimproved crossings. Similar reductions in turbidity were measured, with bridges resulting in decreases of 84 percent compared to unimproved crossings ($p = 0.004$, $n = 25$), culverts reducing turbidity by 77 percent ($p = 0.008$, $n = 37$), and pipe bundles reducing turbidity by 67 percent ($p = 0.02$, $n = 22$). While all improved crossings showed a significant reduction in suspended solids compared to fords, there was no statistical difference among improved crossings.

Among the improved crossing types, bridges resulted in the smallest increase in suspended solids (100 percent) compared to unharvested channels ($p = 0.11$, $n = 53$). Suspended solids in channels using culvert/pipes was 120 percent higher than in unharvested channels ($p = 0.08$, $n = 66$) and in those using PVC pipe bundles was significantly higher (275 percent) than in unharvested channels ($p = 0.004$, $n = 51$). Significant increases in turbidity were measured between the unharvested control and bridge (140-percent increase; $p = 0.0001$, $n = 46$), unharvested control and culvert (240-percent increase; $p < 0.0001$, $n = 58$), and unharvested control and pipe bundle (400-percent increase; $p = 0.0001$, $n = 43$).

Differences were also measured in total suspended solids ($p < 0.0001$, n = 107) and turbidity ($p < 0.0001$, n = 97) when the cumulative treatment impacts were considered (Fig. 3). In the BMP treatment, total suspended solids was 500 percent higher than in the Hybrid treatment (p = 0.004, n = 34) and was 655 percent higher than in the BMP-plus treatment (p = 0.001, n = 47). In addition, significant increases in turbidity were measured between the BMP and Hybrid treatments (260-percent increase; p = 0.007, n = 31), as well as between the BMP and BMP-plus treatments (390-percent increase, p = 0.004, n = 43).

Compared to the unharvested control, total suspended solids concentrations in the Hybrid treatment were 185 percent higher (p = 0.006, n = 61) and turbidity was 320 percent higher ($p < 0.0001$, n = 52). Total suspended solids concentrations in the BMP-plus treatment were nearly 130 percent higher than in the unharvested control (p = 0.047, n = 74), with a 210-percent increase in turbidity (p = < 0.0001, n = 56).

Total suspended solids concentrations at the ephemeral channel crossings were 17 times higher in the BMP treatment compared to the unharvested control (p = 0.0001, n = 45). Turbidity was 15 times higher in the BMP treatment compared to the unharvested control (p = 0.0001, n = 37).

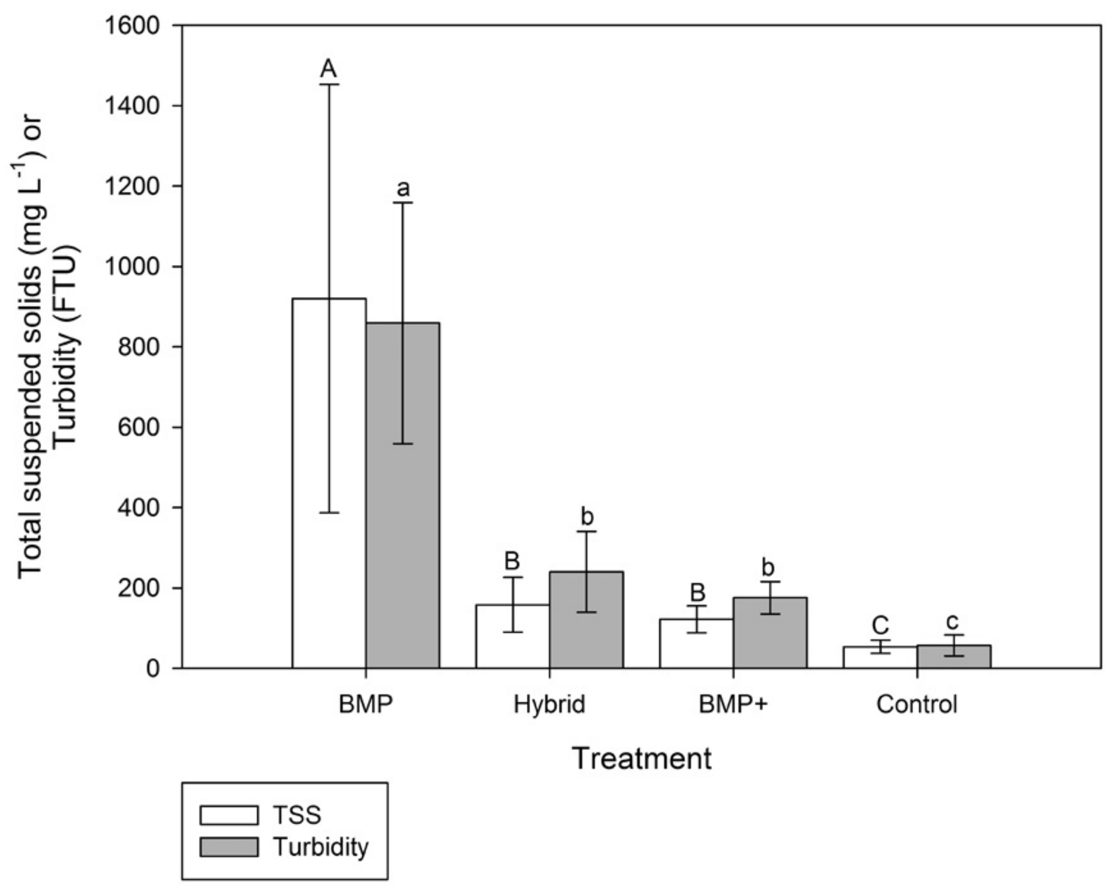


Figure 3.—Effect of treatment on total suspended sediment and turbidity. Letters indicate significant differences at the α = 0.05 level; capital letters indicate differences in total suspended sediment and lowercase letters indicate differences in turbidity. “Control” refers to data from unharvested ephemeral channels.

DISCUSSION

A prolonged drought in summer and fall 2008 during harvest operations may have influenced differences among the crossing types. Due to the lack of precipitation and subsequent flow in ephemeral channels, all of the samples were taken after crossings were retired. Therefore, data from this study measured the impacts of harvesting and improved crossing use on ephemeral channel sediment dynamics following retirement of crossings, rather than determining the ability of improved crossings to protect channels during harvesting activities.

Comparisons among the crossing types showed that any improved crossing type decreased suspended solids and turbidity when compared to unimproved crossings. Additionally, the use of bridges and culverts in ephemeral channel crossings resulted in total suspended solids concentrations that were not statistically different from concentrations measured in unharvested ephemeral channels. These results clearly indicate that either a bridge or a culvert used in ephemeral channels minimizes sediment introduction to these channels following forest harvest.

Pipe bundles were able to significantly decrease total suspended solids concentrations and turbidity compared to the unimproved crossings. However, suspended solids concentrations from channels crossed using pipe bundles were nearly 90 percent higher than from channels crossed with bridges and 70 percent higher than from channels crossed with culverts. While not statistically different, the higher suspended solids concentrations measured in channels crossed using pipe bundles may result from the difficulties associated with controlling sediment introduction to the channel during installation and removal of pipe bundles on such steep slopes. The complication encountered while using pipe bundles in this study resulted from the soil fill depth required on the downstream side of the crossing to make the skid trail level. Removal of this fill using a bulldozer was difficult, and given that much less fill would be required when using a pipe bundle on a gentler slope, these ephemeral channels may simply be too steep for pipe bundles to be as effective an option as bridges or culverts as an improved crossing. Reeves and others (2008) found that suspended solids production from PVC pipe bundles used for similar crossings on a relatively flat stream gradient did not differ significantly from values from portable skidder bridges or culverts. The difference in findings indicates that the topographic condition and stream or channel gradient must be taken into account when crossing recommendations are developed.

No significant differences in total suspended solids were detected between the Hybrid and BMP-plus treatments. This result could indicate that sediment originating from areas adjacent to the channel is negligible compared to the sediment introduced from the channel crossings.

CONCLUSION

Preliminary data suggest the use of improved crossings significantly decreases sediment production and transport in ephemeral channels impacted by forest harvesting operations. Although the 7.6-m equipment limitation zone did not provide additional sediment reductions over that of the improved crossing and tree stringer alone, its influence on thermal protection, as well as on carbon and nitrogen dynamics, warrants further study and will be evaluated. Ephemeral channel monitoring is ongoing, including measurements of discharge. The final dataset will include sediment load data and particle size analysis.

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