FORESTRY BEST MANAGEMENT PRACTICES AND SEDIMENT CONTROL AT SKIDDER STREAM CROSSINGS

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Abstract--Stream crossings for skid trails have high sediment delivery ratios. Forestry Best Management Practices (BMPs) have proven to be effective for erosion control, but few studies have quantified the impact of various levels of BMPs on sedimentation. In this study, three skid-trail stream-crossing BMP treatments were installed on nine operational stream crossings (three replications) to evaluate the degree of sediment control associated with the different treatments. Treatments were: (1) slash, (2) mulch, and (3) mulch plus silt fence. Upstream and downstream water samples were collected daily at the stream crossings for 1 year following BMP installation. Samples were evaluated for total suspended solids. Both slash and mulch treatments applied to the stream-crossing approaches after removal of temporary skidder bridges were effective at reducing the amount of sediment entering the stream after harvest. The mulch plus silt-fence treatment was the most expensive treatment, yet it allowed more sediment to enter the stream at the approach due to silt-fence installation disturbances. Thus BMP related disturbances should be minimized adjacent to a stream bank.

INTRODUCTION

Forest roads and skid trails can cause significant increases in erosion and sedimentation (McBroom and others 2008, Patric 1976, Swift and Burns 1999). Therefore most forestry best management practices (BMPs) were developed with a focus on erosion associated with silvicultural transportation networks, including roads, decks, skid trails, and stream crossings (Anderson and Lockaby 2011, Aust and Blinn 2004). Typical BMPs for roads, skid trails, and logging decks include proper planning and location, use of streamside management zones (SMZs) or buffer strips, control of grade, control of water, surfacing, road or trail closure to minimize soil disturbance, and revegetation following harvesting (Aust and Blinn 2004, Ice and others 2010, Shepard 2006, Swift 1985).

Stream crossings are a particularly important potential source of sediment because stream crossings interrupt SMZs and may serve as channels for sediment to enter streams (Aust and others 2011, Litschert and MacDonald 2009, MacDonald and Coe 2007, Swift 1985, Witmer and others 2009). Therefore, sediment concentrations are often increased below stream crossings (Croke and others 2005, Lane and Sheridan 2002). Sediment contributions from stream crossings have been associated with road densities (Schoenholtz 2004), time since road construction (Luce and Black 1999, Schoenholtz 2004), stream-crossing types, and adequacy of approach BMPs (Aust and others 2011).

During annual BMP audits, the Virginia Department of Forestry (VDOF) has repeatedly identified stream crossings as an area where BMP compliance could be improved (VDOF 2008). However, methods of stabilization are not explained in the Virginia BMP manual, and closure techniques are not specified for stream crossings in many of the state BMP manuals in the South.

Additionally, forest stream crossings and associated BMPs have been the central issues in court cases appearing before the U.S. Ninth Circuit Court of Appeals and the U.S. Supreme Court (Boston 2012). The issue is not resolved, yet it does emphasize the need for additional research regarding the effects of forest-road stream-crossing BMPs on sediment (Anderson and Lockaby 2011). The objectives of this research were to evaluate three levels of skid-trail stream-crossing closure BMPs (slash, mulch, and mulch + silt fence) on stream sediment levels and to quantify the costs of the BMP treatments.

MATERIALS AND METHODS

Study Sites

Nine operational skidder stream crossings that used steel-panel skidder bridges to span Piedmont streams were evaluated for 1 year

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after the temporary crossings were closed. Stands were MeadWestvaco-managed 18- to 25-year-old loblolly pine (*Pinus taeda* L.) plantations that were clearcut between fall 2010 and spring 2011. All stream-crossing locations were specified before harvesting by a professional forester in order to minimize the number of crossings needed. The steel-paneled bridges ranged from 7.3 to 9.7 m in length, and three 1-m-wide panels (3-m wide total) were used on each crossing. Panels were installed and removed with rubber-tired grapple skidders, as is common operationally. Standard 15-m SMZs were flagged for each side of the streams, but actual SMZs ranged from 13 to 45 m in width.

Mean annual precipitation values ranged from 1070 to 1140 mm year^{-1} (NRCS 2013). Rolling topography had average side slopes of 15 percent ranging up to 30 percent. Stream crossings were on first- and second-order intermittent streams having watershed sizes from 3 to 39 ha above the crossing points. Sites had similar soils, Hapudults and ultic Hapludalfs (NRCS 2013). All sites had a history of prior agricultural disturbance as is typical of the region (Jackson and others 2005, Nutter and Douglass 1978).

Treatments

After harvesting, skidder bridges were removed, and three BMP closure treatments were replicated three times, for a total of nine stream crossings having 18 approaches; i.e., BMP treatments were the same on each side of the stream. All stream crossings had waterbars, which is the minimal recommended BMP level in Virginia (VDOF 2011). The stream-crossing closure treatments were: (1) Slash: a rubber-tired grapple skidder placed logging slash (tree limbs and tops) from slash piles on skid trail approaches to a depth of 0.25 to 1 m; (2) Mulch: fescue seed, fertilizer, lime, and straw mulch were spread on the approaches (not in the stream), with the mulch providing 100 percent coverage of bare soil. Each approach was covered with 10 bales of straw mulch, equating to 20 bales per crossing; and (3) Mulch + silt fence: silt fences were installed in trenches < 1 m from the stream bank on both sides of the stream channel. Fescue seed, fertilizer, lime, and straw mulch were spread on the approaches with the mulch providing 100 percent coverage of bare soil. Each approach was covered with 10 bales of mulch, equating to 20 bales per crossing.

Sediment Sampling

At each stream crossing, two automated water samplers, either ISCO 3700 (Teledyne Isco, Inc., Lincoln, NE) or Sigma 900MAX (Hach Company, Loveland, CO) were installed. One automated sampler was positioned approximately 10 m upstream, and the second was positioned 10 m downstream from the crossing. Equipment safety and logistics required that water samplers were installed after harvesting but before the BMP closure treatments were applied (which ranged from a period of 1 to 10 days depending on the location). All automated water samplers collected one 500-mL sample per day. Samples were retrieved every 3 weeks and analyzed for total suspended solids (TSS) using the method outlined by Eaton and others (2005). Data collection continued for 1 year following harvesting. Daily precipitation data were collected from National Oceanic and Atmospheric Administration (NOAA) weather stations near each tract.

Treatment costs were recorded and reported by the MeadWestvaco forester responsible for overseeing the BMP installation. Costs included both materials and labor. The slash treatment did not require a material cost, so costs were based on labor and machine time only. Costs were reported as averages for each treatment.

Statistical Analysis

Statistical analyses used rain events as statistical blocks in order to control TSS variation at different rainfall intensities as suggested by Clinton and Vose (2003) in a similar forest road study. Four rainfall categories were established by dividing the daily rainfall data into quartiles above zero and then combining the lowest category with the days with no rain. The categories were: low = 0.00-1.0 mm; medium = 1.1-4.0 mm; high = 4.1-10.00 mm; and maximum > 10.0 mm. A daily TSS percent change value was calculated for analysis using the following equation:

Daily TSS percent change = [(Downstream TSS – Upstream TSS)/Upstream TSS] x 100 (1)

Data were analyzed for statistical significance using JMP Statistical Discovery Software (JMP Version 9, SAS Institute, Cary, NC). Data were not normally distributed; thus, non-parametric tests were used. Both the Kruskal-Wallis test (Ott and Longnecker 2010a) and the Wilcoxon test (Ott and Longnecker 2010b) were used to detect treatment differences. Physical features of the stream-crossing approaches were also measured and analyzed for significance with a Pearson's correlation matrix.

RESULTS AND DISCUSSION

Total Suspended Solids

Treatment performance rank is indicated by the Kruskal-Wallis statistical test (table 1). Higher scores (score mean values) indicate higher sediment values downstream relative to upstream values. The Wilcoxon tests indicate treatment differences between each paired treatment at each rainfall category (table 2). The rainfall categories that displayed significant differences between treatments were low, medium, and high (in the Kruskal-Wallis test). Slash performed better than the other two treatments with regard to sediment reduction at the low rainfall category. However, the medium, high, and maximum rainfall categories indicated that the slash and mulch treatments were statistically the same, while they both were different than the mulch + silt-fence treatment. These results indicate that the slash and mulch treatments performed better than the mulch + silt-fence treatment. Although silt-fence installation is a proven BMP for reducing silt-sized and larger sediment (Robichaud and Brown 2002), its installation requires disturbance. Silt fences were installed adjacent to streams, and the installation disturbances apparently introduced sediment. It should also be noted that silt-fence failure could be related to the high clay content commonly found in the Piedmont of Virginia. Clay soil particles are smaller than silt particles and therefore have the ability to pass through silt fence. These results indicate the need to minimize disturbances within the SMZs even while installing BMPs.

BMP Treatment Costs

BMP treatment costs were reported by the forester responsible for overseeing the BMP treatment installation (table 3). The slash treatment average costs were $120 per stream crossing. This assumes that logging slash is available on site, and that it is moved after harvest has been completed. The costs are based on 2 hours of operator and machine time for slash application. This cost could be reduced if slash was spread on stream-crossing approaches during normal logging operations. The mulch treatment average costs, including material and labor, were $280 per stream crossing. Mulch + silt-fence applications were the most expensive treatment, costing an average of $345 per stream crossing, including materials and labor. These costs are lower but in the same order of magnitude as those reported recently by McKee and others (2012), who surveyed 70 logging contractors and reported the costs of stream-crossing BMPs ranged from $533 to $655 across Virginia.

CONCLUSIONS

Practically all forestry BMP recommendations recognize that stream-crossing portions of skid trails are where sediment delivery has the greatest potential to occur. However, few studies have specifically addressed BMP efficacy for closing stream crossings (Anderson and Lockaby 2011). Our results indicate that sedimentation is reduced by applications of the slash or seed and mulch treatment to temporary skidder stream-crossing approaches. On these sites, slash treatments cost less and would be more desirable. Mulch and seed is another viable option where slash is less readily available, but it can cost more. Either slash or mulch provided immediate coverage and erosion control at the stream-crossing approach. This study indicates that the nearly 100 percent soil coverage provided by the slash or mulch treatments were more important for erosion control than the slope of the approach (up to 18 percent). Slash was the most cost-effective option. These results correspond well to the bladed skid trail and overland skid trail closure results found by Wade and others (2012) and Sawyers and others (2012).

Table 1--Results of the Kruskal-Wallis Test. The score mean values show the rank in which the treatments performed. Higher scores (score mean values) indicate a higher percentage of sediment downstream, compared to other treatments. The asterisk (*) in the P-value column denotes significant differences between treatments at the respective rainfall category, at α = 0.05. Score means not connected by the same letter are significantly different

Daily rainfall category	Chi square	P-value	Treatment	N	Score mean
Low 0.0-1.0 mm	14.9433	0.0006*	Slash	245	193.27 a
			Mulch	96	231.95 b
			Mulch + silt fence	83	246.77 b
Medium 1.11- 4.0 mm	9.0407	0.0109*	Slash	27	24.14 a
			Mulch	16	26.25 a
			Mulch + silt fence	13	40.30 b
High 4.1-10.0 mm	11.7111	0.0029*	Slash	37	38.00 a
			Mulch	31	43.90 a
			Mulch + silt fence	23	61.69 b
Maximum > 10 mm	4.2202	0.1212	Slash	43	42.25 a
			Mulch	24	40.95 a
			Mulch + silt fence	22	54.77 a

Table 2-- Results of the Wilcoxon test. Each treatment was compared with all other treatments within each rainfall category. The asterisk (*) in the P-value column denotes significant differences between the two treatments being compared at α = 0.10. Score mean difference is the difference between the score means from the Kruskal-Wallis test

Daily rainfall category	Treatment	vs.	Treatment	Score mean difference	Standard error difference	Z	P-value
Low 0.00 – 1.0 mm	Mulch		Slash	30.567	11.870	2.575	0.0100*
	Mulch + silt fence		Slash	41.969	12.044	3.485	0.0005*
	Mulch + silt fence		Mulch	5.425	7.766	0.699	0.4848
Medium 1.1 – 4.0 mm	Mulch + silt fence		Slash	10.826	3.946	2.743	0.0061*
	Mulch + silt fence		Mulch	8.016	3.179	2.521	0.0117*
	Mulch		Slash	2.140	3.961	0.540	0.5891
High 4.1 – 10.0 mm	Mulch + silt fence		Slash	15.440	4.637	3.329	0.0009*
	Mulch + silt fence		Mulch	10.678	4.329	2.466	0.0136*
	Mulch		Slash	4.505	4.814	0.935	0.3494
Maximum > 10.0 mm	Mulch + silt fence		Slash	9.378	4.956	1.892	0.0584*
	Mulch + silt fence		Mulch	6.751	3.961	1.704	0.0883*
	Mulch		Slash	-1.201	4.964	-0.241	0.8088

Table 3-- Treatment costs per stream crossing as reported by the logging contractors

Treatment	Materials	Material cost	Labor	Labor Cost	Total cost per stream crossing
		$		*$*	*$*
Slash	Logging slash	n/a	Skidder machine time (2 hours)	120	120
Mulch	Straw mulch (20 bales)	100	Dozer machine time	90	
	Lime	5	Manual labor (2 hours)	80	
	Fertilizer and seed	5			280
Mulch + silt fence	Straw mulch (20 bales)	100	Dozer machine time	90	
	Lime	5	Manual labor (3 hours)	120	
	Fertilizer and seed	5			
	Silt fence	25			345

Applying either slash or mulch with seed to the stream-crossing approaches during harvest closure will reduce the amount of sediment that could otherwise enter the stream at these sensitive areas. Skidder stream crossings can be effectively closed, as long as coverage of bare soil is completed immediately following (or during) harvest. Minimal stream sedimentation can be achieved with the appropriate combination of stream-crossing BMPs.

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