EVALUATION OF EROSION CONTROL BMPS ON DITCHED HAUL ROAD STREAM CROSSING APPROACHES FOLLOWING RECONSTRUCTION

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Abstract—Ditched forest roads leading to stream crossings and used for log transportation have recently been a topic of water quality concern and legal controversy. Best management practices (BMPs) can reduce potential water quality issues, yet few research studies have quantified BMP costs and reductions in sediment from implementing specific ditch BMPs. Researchers reconstructed fifty 15.2 m sections of ditches at stream crossings or cross drains and applied one of five treatments. Treatments were replicated 10 times and split by two slope classes in a completely randomized design. Silt fence traps were placed at the end of each ditch section prior to stream crossings or culvert inlets. Sediment pins were installed adjacent to the silt fence and sediment deposit depths were measured 42 days following ditch re-construction. Field based results show that median erosion rates were greatest for the Bare (48.0 Mg ha^{-1} yr^{-1}), followed by Seeded (25.0 Mg ha^{-1} yr^{-1}), Check Dams (22.2 Mg ha^{-1} yr^{-1}), Completely Rocked (2.6 Mg ha^{-1} yr^{-1}), and Seeded with Erosion Mat (2.1 Mg ha^{-1} yr^{-1}). Results from the Kruskal-Wallis statistical test showed that the Bare treatments had significantly greater erosion rates from Completely Rocked and Seeded with Erosion Mat treatments. Cost of BMP treatment was cheapest for Seeded ($9), followed by Seeded with Erosion Mat ($24), Check Dams ($45.40), and Completely Rocked ($119.50). Study results suggest that re-constructed ditches should drain short sections of road and should contain some erosion control BMP in order to reduce erosion and sediment delivery.

INTRODUCTION

Forest roads are an essential, yet expensive component of forest management. They are inherently prone to surface runoff and erosion issues as they often lack surface roughness, expose compacted bare mineral soils, and concentrate overland flow via ditches or rutted road surfaces (Grace 2005). Runoff from road and ditch networks can degrade water quality if not properly dispersed and controlled (Brown and others 2013). High sediment levels have been shown to be detrimental to many aquatic wildlife species (Henley and others 2000; Gibson and others 2005) and can lead to increased water treatment costs (Bridges and others 2010). Road and ditch networks sloping towards stream crossings (approaches) pose one of the greatest risks of sediment delivery from forest operations because of their juxtaposition to waterways (Aust and Blinn 2004). These areas are especially vulnerable to erosion immediately following construction or maintenance (Croke and others 2001). Subsequently, forestry best management practices (BMPs) have been developed for these areas to comply with the Federal Water Pollution Control Act of 1972 (Clean Water Act). Forest managers are continually challenged to implement cost-effective BMPs to ensure maximum financial benefits and minimize environment degradation. Therefore research that quantifies cost-efficacy of BMPs is highly desirable, especially for sensitive areas such as stream crossing approaches.

Many ditched forest road stream crossings are exempt from point source permitting under the Clean Water Act (Section 404) when they are considered normal ongoing silviculture operations that follow federal and state BMPs, do not alter hydrology, and do not introduce toxins into water sources. Environmental concerns regarding this exemption for ditched forest roads have sparked numerous debates and lawsuits (Boston and Thompson 2009). Of the most notable was the Ninth Circuit Court and later US Supreme Court ruling initiated by *National Environmental Defense Center v. Brown*. The Ninth Circuit Court ruled that runoff collected by ditches and conveyed into the nations waters constituted as an industrial point source pollutant and required a National Pollution Discharge Elimination System (NPDES) permit (Boston 2012). In response to the ruling, the Environmental Protection Agency (EPA) elicited and reviewed comments from professionals and the general public regarding the exemption (EPA 2012). The US Supreme Court later reversed the Ninth Circuit Court ruling in March of 2013 retaining that the EPA was given authority through

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legislation to determine what activities may or may not be exempt from NPDES permitting. The EPA announced that they would not change how the exemption would be enforced in July of 2014 (EPA 2014), yet further litigation is likely to ensue (MacCurdy and Timmons 2013). This highly controversial matter only further highlights the need for research to quantify forest road and ditch sediment rates. The objective of this paper was to quantify erosion rates following re-construction of ditches leading to stream crossings implementing four operational ditch BMP treatments. We also discuss the comparison of erosion rates to associated treatment costs.

MATERIALS AND METHODS

Study Sites

Three primarily insloped forest roads that would serve as class II haul roads for logging (Walbridge, 1990) were selected for this study. All road segments are located near Blacksburg, Virginia within the Ridge and Valley physiographic region. Blacksburg receives a mean annual rainfall total of 1041 mm, which is commonly well distributed throughout the year (NOAA 2015). Two of the road segments are managed by Virginia Tech and the third road segment by US Forest Service. Mean road grades are below 12 percent, with maximum slopes of 16 percent. All road sections are gated and restrict public vehicle use. However, the US Forest Service road provides firewood cutting permits, which allow occasional light truck use. Virginia Tech school forest roads serve access to a municipal water tower and cell phone tower. These roads also received light vehicle use during this study.

Study Design and Treatments

Fifty ditched stream crossing approaches from the three road segments were selected in June 2014 for ditch re-construction. A John Deere 450 bulldozer was used to remove soils and organic debris away from streams (upslope) within the ditch to improve ditch function, road drainage, and trafficability. Ditches were reconstructed according to site specific situations, but all were cleared to a minimum of approximately 15.2 m past each stream crossing. Where applicable, a rolling dip was installed at the end of treatments to minimize drainage area. A New Holland TN650 Farm tractor was used to smooth the road to ditch transition using a rhino blade. Road surfaces were not re-graveled following re-construction. Silt fence catchment areas were placed within each ditch section prior to the stream crossings (Robichaud and Brown 2002). A network of sediment pins were installed adjacent to the silt fence to allow for periodic measurement of sediment deposit depths. Treatments were applied to the nearest 15.2 m to the sediment catchment areas. Seed treatments were applied by hand spreading a Forest Service recommended seed and lime mixture of orchard grass (65 pls lbs ac^{-1}), annual rye (25 pls lbs ac^{-1}), white clover (2 pls lbs ac^{-1}), and pelletized lime. Seed and erosion mat treatments received the same seed mixture and were covered with an erosion mat interlaced with straw. Erosion mats were secured within the ditch by landscape staples. Number 1 surge (8.9 – 10.2 cm) was used for check dam and rock treatments. The number 1 surge was purchased from a local quarry and delivered on site. Rock treatments were applied using the frontend loading bucket of the farm tractor. Two rock check dams (~1.5 m length) were applied at ¼ and ¾ distances from catchment area in check dam treatments. Randomization of treatments was split by ditch slope (table 1). One of five treatments (bare, seeded, seeded and erosion mat, check dams, and completely rocked) was randomly assigned to each ditch section. Each treatment was replicated 10 times for a total of 50 experimental units, but was not balanced within slope classes (table 1). This study was analyzed as a completely randomized design. Data were analyzed for statistical significance using JMP statistical software. Due to unequal variance and non-normally distributed data, the Kruskal-Wallis test was used to detect treatment differences in median sediment delivery rates.

Table 1—Number of randomly assigned BMP treatments by slope class

	Number of Replications by Slope Class		
Treatments	0 – 6.99 percent	7.00 – 16 percent	Total
Bare	5	5	10
Seed	4	6	10
Seed and Erosion Mat	6	4	10
Check Dam	3	7	10
Rock	5	5	10
Total	23	27	50

Measurements

Sediment pin heights were measured 42 days following construction using a standard 1/16th inch increment measuring tape. Bulk densities were collected from each catchment area containing sediment deposits following the core method (Blake and Hartge 1986). Sediment volumes (m^{-3}) were calculated by multiplying depositional area (m^{-2}) by elevation gain (m). Sediment volumes were converted to a sediment load (Mg) by multiplying bulk density (Mg m^{-3}) of the trapped sediment by sediment volumes (m^{-3}) (Brown and others, 2013). Sediment loads were then divided by the drainage area and time (42 day) in order to obtain an annual erosion rate (Mg ha^{-1} yr^{-1}). Daily rainfall data were obtained from Virginia Tech airport weather station (software, VWS V14.00), which is located less than 11 km from all study areas. Ditch and road dimensions were measured using a total station (Sokkia total station model SET-520, Tokyo, Japan). Additional road characteristics measured included: surface roughness (Saleh 1993), soil particle size (Gee and Or 2002), road shape, percent canopy cover, and percent bare soil (Brown and others 2013).

RESULTS AND DISCUSSION

Field based results show that median erosion rates were greatest for the Bare (48.0 Mg ha^{-1} yr^{-1}), followed by Seeded (25.0 Mg ha^{-1} yr^{-1}), Check Dams (22.2 Mg ha^{-1} yr^{-1}), Completely Rocked (2.6 Mg ha^{-1} yr^{-1}), and Seeded with Erosion Mat (2.1 Mg ha^{-1} yr^{-1}). Results from the Kruskal-Wallis test showed the rank in which treatments performed (table 2). Higher score mean values indicate greater erosion rates. Bare treatments were significantly different from Completely Rocked and Seeded with Erosion Mat (p = 0.0957). Cost of BMP treatments was cheapest for Seeded ($9), followed by Seeded with Erosion Mat ($24), Check Dams ($45.40), and Completely Rocked ($119.50) treatments. Cost estimates were based on material, labor, and machine time per 15.2 m ditch section (table 3). Manual labor and machine time pay rates, typically of the area, were $20 and $60 hr^{-1}, respectively. Treatments that implemented

Table 2—Results of the Kruskal-Wallis statistical test. The score mean values show the rank in which treatments performed. Higher score means indicate greater erosion rates. Significant differences between treatments exist at α = 0.1

Treatment	Score Mean	P-value	Chi Square
Bare	34.8a		
Seeded Only	28.4ab		
Check Dams	25.2ab	0.0957	7.89
Completely Rocked	20.5b		
Seeded with Erosion Mat	18.6b		

Table 3—Cost of BMP treatment per 15.2 m ditch section

Treatment	Materials	Cost	Time	Cost	Total
Bare	n/a	n/a	n/a	n/a	$0
Seeded Only	Seed	$3	Manual labor (0.25 hrs)	$5	$9
	Lime	$1			
Seeded Mat	Seed	$3	Manual labor (0.5 hrs)	$10	$24
	Lime	$1			
	Straw mat	$10			
Check dams	#1 surge stone	$5.40	Manual labor (0.5 hrs)	$10	$45.40
			Tractor machine time (0.5 hrs)	$30	
Rocked	#1 surge stone	$44.50	Manual labor (0.75 hrs)	$15	$119.50
			Tractor machine time (1 hrs)	$60	

rock were most expensive, yet did not yield the lowest mean erosion estimates. Seeded treatments were less costly, but seeded only provided less initial soil cover (mean coverage of 50 percent) than Seeded with Erosion Mat (mean coverage of 75 percent) 42 days after ditch re-construction. The least costly and most effective sediment reductive BMP was Seeded with Erosion Mat.

Twenty-four rain events occurred over the 42 day period, totaling 12.2 cm of rainfall. The two largest rain events were approximately 1.5 cm, while most other events were less than 0.33 cm. Measured erosion rates were highly variable within treatments (table 4). All treatments had at least one replication where measured soil erosion rates within the ditch were equal to or less than a undisturbed mixed forest (0.72 Mg ha^{-1} yr^{-1}) (Yoho 1980). However, three bare ditch sections had similar erosion rates to gully type erosion (188-895 Mg ha^{-1} yr^{-1}) (Yoho 1980). Each of these three bare ditch sections had unique circumstances, which may have led to excessive erosion. First, the greatest measured erosion rate (3,279 Mg ha^{-1} yr^{-1}) was located on a 10 percent slope with 65 percent bare soil within the ditch (loose bedrock fragments provided cover) and a road drainage area ~560 m^2. This ditch section lacked adequate water control due to depth to bedrock. At the time of sediment measurement, an obvious concentrated flow path (150 m) starting from the travel surface and leading to the ditch was observed. The second greatest measured erosion rate (900 Mg ha^{-1} yr^{-1}) was located on a 6.6 percent slope with 95 percent bare soil within the ditch. In this circumstance, re-construction of the ditch revealed a seep stemming from a 90 percent bare soil cutslope. Increased moisture conditions and exposed soils may have led to excessive erosion. The third greatest erosion rate (389 Mg ha^{-1} yr^{-1}) had similar characteristic to the greatest measure. This ditch section has a 12 percent slope with 45 percent bare soil within the ditch (loose bedrock fragments provided cover). Additionally, the crown slope (slope from road edge to bottom of the ditch) was 33 percent. These finding demonstrate the highly variable nature of soil erosion, but also exemplify the importance of ditch BMPs and water control to minimize sediment delivery at stream crossings.

CONCLUSIONS

Ditched roads leading to stream crossings have the potential to deliver large quantities of sediment to streams under unique circumstances such as large bare soil contributing areas with steep slopes, bare cutslopes with active seeps, and rutted road surfaces that allow runoff to become concentrated. Findings from this study suggest Completely Rock and Seeded with Erosion Mat treatments were the best at reducing erosion following construction. However, the authors suspect to see greater treatment differences with time. Therefore our findings suggest that re-constructed ditches should drain short sections of road and contain some erosion control BMP in order to reduce erosion and sediment delivery. Some site conditions may merit additional BMP efforts and should be planned for.

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Table 4—Measured erosion rates (Mg ha-1 yr-1) for each ditch section by treatment 42 day after ditch re-construction

Bare	Seeded	Check	Rocked	Mat
0.3	0.1	0.0	0.0	0.0
5.1	0.1	0.0	0.1	0.0
5.5	0.9	0.1	0.2	0.2
11.1	1.2	6.6	0.4	0.4
18.5	5.8	11.9	1.1	1.3
77.5	44.2	32.6	4.1	2.8
173.9	51.5	33.2	10.9	6.3
389.2	91.1	37.5	11.7	7.6
900.4	104.0	77.2	24.4	9.7
3279.5	114.0	101.5	72.4	32.6

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