Evaluation of Bladed Skid Trail Closure Methods in the Ridge and Valley Region

J. Andrew Vinson, Scott M. Barrett, W. Michael Aust, and M. Chad Bolding

Forest roads and skid trails with inadequate best management practices (BMPs) often contribute the majority of erosion produced from forest harvesting operations. We evaluated soil erosion rates from bladed skid trails in the mountains of Virginia after a timber harvest. The randomized complete block design included six blocks, each containing four skid trail closure BMP treatments (waterbar only [Control], slash-covered [Slash], seeded [Seed], and seeded with fertilizer and mulch [Mulch]). Control treatments resulted in an average erosion rate of 6.8 tons $\text{ac}^{-1} \text{yr}^{-1}$ (15.1 tonnes ha$^{-1}$ yr$^{-1}$) following installation. Seed treatments resulted in an average erosion rate of 2.6 tons $\text{ac}^{-1} \text{yr}^{-1}$ (5.9 tonnes ha$^{-1}$ yr$^{-1}$). Mulch treatments averaged 0.5 ton $\text{ac}^{-1} \text{yr}^{-1}$ (1.1 tonnes ha$^{-1}$ yr$^{-1}$), and Slash treatments averaged 0.4 ton $\text{ac}^{-1} \text{yr}^{-1}$ (0.8 tonnes ha$^{-1}$ yr$^{-1}$). Seed, Mulch, and Slash treatments significantly reduced soil erosion rates in comparison to Control treatments ($P = 0.0315$), with Mulch and Slash treatments being most effective ($P < 0.0001$). Results indicate that ground cover treatments are beneficial in addition to waterbars for effective erosion control. A cost analysis indicates that Seed treatments are the most cost-effective ($2771.89 / \text{mi}$); however, on a basis of erosion prevented, Slash treatments were the most cost-effective ($73.65 / \text{ton}$).

Keywords: soil erosion, forest harvesting, best management practices (BMPs), BMP costs

Sediment is the most common nonpoint source pollutant from forest operations (Yoho 1980, US Environmental Protection Agency 2003). The forest operations generally creating the most sediment are haul roads, logging decks, skid trails, and stream crossings (Lakel et al. 2010). Christopher and Visser (2007) determined that haul roads and skid trails remained the primary source of sediment pollution from forest harvests, even 2–8 years after their closure. Bladed skid trails are often used in steep terrain to facilitate operator safety and skidding productivity. Kochenderfer (1977) determined that 5–11% of an Appalachian Mountain harvest is composed of skid trails, depending on terrain. It was also estimated on a more recent harvest on steep terrain within the region that approximately 7.7% consisted of bladed skid trails (Worrell et al. 2011). Worrell et al. (2011) estimated that erosion rates on bladed skid trails in the mountains can average 17.2 tons $\text{ac}^{-1} \text{yr}^{-1}$ (38.6 tonnes ha$^{-1}$ yr$^{-1}$). Wade et al. (2012) measured erosion from bladed skid trails in the Piedmont that produced 1.3–61.2 tons $\text{ac}^{-1} \text{yr}^{-1}$ (3.0–137.1 tonnes ha$^{-1}$ yr$^{-1}$), depending on ground cover and slope. Skid trails are highly erosive because of bare soil exposure, slope steepness, and low road drainage standards (Grace 2002, Anderson and Lockaby 2011). These problems are compounded by continued use or heavy traffic (Lang et al. 2015). The combination of these factors is known to increase erosion, therefore, increasing the possibility of stream sedimentation and degradation (Swift 1985, Grace 2005).

Forestry best management practices (BMPs) are guidelines developed by individual states as a means to reduce nonpoint source pollutants such as sediment from forest operations. Most states’ BMPs recommend that forest managers close out skid trails after harvesting operations. Eroded soil from skid trails can be delivered to streams, thus reducing stream water quality. Sediment in streams can increase water temperatures, abrade the gills of fish, and alter the stream channel morphology to reduce habitat and affect the feeding habits of aquatic wildlife (Douglass and Swank 1972, Henley et al. 2000, Croke and Hair-sine 2006). Unless rehabilitated, skid trails can have negative impacts on future productivity and vegetative growth because soils can be compacted, removed or displaced, or possess altered drainage (Aust and Bliin 2004). In addition to this, soil erosion reduces topsoil depth and removes nutrients from the skid trail, further degrading the site.

Erosion problems can be minimized with appropriate skid trail planning and design prior to harvesting (Arthur et al. 1998). However, additional erosion control practices are recommended after construction and/or harvest operations. Waterbars and wing ditches channel the flow of water away from trails and into
the harvest area, where slash or leaf litter dissipate the concentrated flow (Keller and Sherar 2003). Logging residues from the harvest, often referred to as slash, can be used to provide ground cover for skid trails. McGreer (1981) examined bladed skid trails on volcanic soils and found that slash can reduce soil erosion by up to 99%. The Virginia Department of Forestry and other state forestry agencies across the southeast recommend the use of slash to close out skid trails (North Carolina Division of Forest Resources 2006, Georgia Forestry Commission 2009, West Virginia Division of Forestry 2009, Virginia Department of Forestry 2011). The use of slash has the potential benefit of improving the chemical and physical properties of soil as it decays (Barber and Van Lear 1984). Slash is also beneficial on steep slopes, fill slopes, or stream crossing approaches where immediate ground cover is needed. Slash may also reduce undesirable ATV traffic on such sites. Seeding exposed soil with grass seed is another common method of reducing soil erosion (Maynard and Hill 1992, Grace 2002). However, grass seed requires time to germinate after being applied to the skid trail, and there can be issues with grass survival. These issues can be mitigated through the use of lime, fertilizer, or mulch to improve soil chemical and physical properties and to reduce removal or movement of seeds (Lyons and Day 2009, Foltz 2012). Current literature reports indicate that there are gaps in knowledge regarding the effectiveness of specific skid trail BMPs and their associated costs in the Ridge and Valley physiographic province. Sawyers et al. (2012) and Wade et al. (2012) were both able to quantify skid trail erosion rates on Piedmont soils and topography; however, no studies comparing skid trail closure methods have been conducted in more mountainous terrain in the region. This study was designed to reduce that gap in regards to steep mountain terrain in the Ridge and Valley physiographic province.

Study Objectives

The primary objective of this study was to evaluate the effectiveness of different bladed skid trail closure BMPs by quantifying soil erosion after closure with different BMP practices. The secondary objective was to assess the costs of each studied skid trail closure BMP treatment relative to the erosion reduction efficacy of the treatment.

Methods

Study Area

The study site was located in the Ridge and Valley physiographic province on Virginia Tech’s Fishburn Forest, located in Montgomery County, Virginia (Figure 1). The site was logged in late 2014–early 2015 in a 35-ac (14.16-ha) shelterwood overstory removal of upland hardwoods and mixed pine-hardwood. The average high and low temperatures for this location in January are 41.5° F (5.3° C) and 21.4° F (−5.9° C). The average high and low temperatures in July are 82.2° F (27.9° C) and 60.1° F (15.6° C). Average yearly precipitation is 40.89 in. (103.86 cm) (National Oceanographic and Atmospheric Administration [NOAA] 2010). The soils are typically very shallow, well-drained silt loams, being derived mostly from shale, siltstone, and sandstone residuum and dominated by Berks-Weikert complex soil series (US Department of Agriculture [USDA] Natural Resources Conservation Service [NRCS] 2015). The erodibility factor for these soils is estimated to be 0.43 (USDA NRCS 2015). Common species on the site primarily consisted of chestnut oak (Quercus montana), northern red oak (Quercus rubra), scarlet oak (Quercus coccinea), eastern white pine (Pinus strobus), white oak (Quercus alba), black oak (Quercus velutina), yellow-poplar (Liriodendron tulipifera), pignut hickory (Carya glabra), and Virginia pine (Pinus virginiana). Skid trails featured slopes from 0 to 35%, with an average slope of 16%. Skid trail side-slopes ranged from 5 to 45%.

Treatments

This study was arranged as a randomized complete block design with repeated measures. Waterbars and closure treatments were installed on existing bladed skid trails using a John Deere 450 bull-dozer in April 2015. Blocks were assigned based on slope class: gentle (0–10% slope), moderate (11−20% slope), and steep (>20% slope). Six blocks (two in each slope class) each contained four treatments: (1) waterbars with bare soil in between (Control), (2) waterbars and planted with grass seed (Seed), (3) waterbars, fertilized, planted with grass seed, and mulched with straw (Mulch), and (4) waterbars with slash used as ground cover (Slash). Treatment sections had a slope distance of approximately 50 ft (15.2 m) long, and 10 ft (2 m) wide. On steeper slopes (>20%), treatments lengths were reduced to 40 ft (12.2 m) in length to comply with BMP guidelines (Virginia Department of Forestry [VDOF] 2011). The four treatments were randomly assigned within each block using a random number generator, thus providing 24 experimental units. Earthen berms were constructed on both sides of the skid trail to restrict overland flow and sediment from lateral movement from the trail and funnel sediments toward traps. The uphill section of each treatment contained a waterbar to channel flow from uphill areas away from the treatment, thus isolating treatments and defining contributing areas. The lower end of each treatment was similarly defined with another waterbar that channeled water flow off of the trail and into a sediment trapping area encircled by a silt fence (Figure 2). Each waterbar was constructed at a 30–45° angle to the centerline of the road and to a height of 2−3 ft (0.6−0.9 m) to ensure effectiveness in channeling water flow. A total station was used to measure the total contributing area of each treatment, as well as exact length, slope, and slope profile.

The Control treatment contained waterbars with no ground cover to represent a minimum acceptable level of BMP implementation. Seed, mulch, and fertilizer applications were based on recommended rates from the VDOF BMP manual (VDOF 2011). For the Seed treatment, grass seed was applied at the time of skid trail closeout (April 2015) using a mix of approximately 50% perennial ryegrass (Lolium perenne) and 50% KY-31 fescue (Festuca arundinacea). Seed was applied at a rate of approximately 150 lb/ac (168 kg/ha). For the Mulch treatment, the same grass seed mixture was applied, along with fertilizer and straw mulch. Straw mulch was spread by hand at a rate of approximately 2 square bales per unit to

Figure 1. Location map of harvest site within Montgomery County, Virginia.
ensure 100% ground coverage of the trail, ± 3 in. (7.62 cm) in depth. Fertilizer was applied at a rate of approximately 300 lb/ac (336 kg/ha) of 10-10-10. Slash treatments were applied by hand onto skid trails to ensure uniform coverage and then compacted with the bulldozer to make contact with the ground. After compaction, slash was at a depth of approximately 1–2 ft (0.3–0.6 m) (Figure 3).

**Figure 2.** Layout of each 50 ft (15.2 m) experimental unit.

**Figure 3.** Comparison photographs of each BMP treatment after installation. Note the downslope waterbar with sediment trap in each photo.

**Sediment Trap Efficiency**

Sediment traps and silt fences are not 100% effective in collecting sediment (Robichaud and Brown 2002). Sediment trapping efficiency was calculated to determine the amount of eroded material that was captured by the silt fences by conducting a soil particle size analysis on both the collected sediment and the trail surface. Analysis was performed using the hydrometer method (Gee et al.


Table 1. Results of soil particle size analysis comparing the trail surface with the trapped sediment.

<table>
<thead>
<tr>
<th>Material analyzed</th>
<th>% sand</th>
<th>% silt</th>
<th>% clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trail surface</td>
<td>43</td>
<td>39</td>
<td>18</td>
</tr>
<tr>
<td>Collected sediment</td>
<td>48</td>
<td>42</td>
<td>10</td>
</tr>
<tr>
<td>Change</td>
<td>+ 5</td>
<td>+ 3</td>
<td>−8</td>
</tr>
</tbody>
</table>

Figure 4. Sediment trap with erosion pins in place.

1986). It was assumed that smaller clay particles can more easily pass through the silt fence material (Wishowski et al. 1998). When the soil from the trail surface was compared to the eroded material through the aforementioned particle size analysis, it was determined that sand and silt percentages increased, whereas the percentage of clay particles decreased (Table 1). This result reinforces the assumption that the silt fences are not 100% efficient at trapping clay particles. Because approximately 8% of the soil particles were lost, we assumed a trapping efficiency of 92%, which is very similar to what others have found using different methods (Barrett et al. 1998, Robichaud et al. 2001). Therefore, all collected data were adjusted by 8%.

Data Collection

Silt fences were installed using the guidelines set by Robichaud and Brown (2002). Ten ¾-in (1.59-cm) diameter rebar pins measuring approximately 14 in. (35.56 cm) long were driven into the ground in a grid pattern (Figure 4) within the area of sediment collection of each silt trap (Aust et al. 1991). A washer was placed loosely over the shaft of the rebar to lie on the ground surface, which allowed data collection to be more easily and accurately conducted by separating the surface of the ground from the collected sediment (Figure 5). The depth of collected sediment was measured using a pin flag and ruler as it accumulated above the washer. The grid pattern of the erosion pins provided a method of establishing an area of sedimentation for each trap. The sediment depths and areas were combined to obtain an estimate of sediment volume for each trap. Measurement of sediment volume occurred on a monthly basis for 12 months. Sediment volumes were converted to mass using the bulk density of the sediment which was obtained using standard laboratory procedures (Blake and Hartge 1986).

Bare soil was measured quarterly along three transects across the entire length of each treatment area to provide seasonal ground cover percentages. Each of these transects was walked, and a point was taken at each step, counting the number of footsteps where the toe of the boot fell on covered or bare soil [i.e., (“covered” steps/total steps) × 100 = percent surface cover]. Cover was considered to be

![Figure 5. Pins in silt fence sediment trap.](https://example.com/figure5.png)

Table 2. Erosion rates for each treatment after the 1-year study period.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average erosion rate</th>
<th>Minimum erosion rate</th>
<th>Maximum erosion rate</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>6.8a</td>
<td>2.5</td>
<td>15.3</td>
<td>12.9</td>
</tr>
<tr>
<td>Seed</td>
<td>2.6b</td>
<td>0.3</td>
<td>6.4</td>
<td>4.67</td>
</tr>
<tr>
<td>Mulch</td>
<td>0.5c</td>
<td>0.01</td>
<td>1.1</td>
<td>0.75</td>
</tr>
<tr>
<td>Slash</td>
<td>0.4c</td>
<td>0.01</td>
<td>0.6</td>
<td>0.41</td>
</tr>
</tbody>
</table>

Treatments with the same letter are not significantly different based on α = 0.05 as determined by Steel-Dwass multiple comparisons testing.

Vegetation, straw, woody material, rocks, or anything else not composed of mineral soil. Soil rock content was determined gravimetrically using standard laboratory procedures (Blake and Hartge 1986). Soil rock content samples were taken 0–2 in. (0–5.08 cm) from the surface. Precipitation data were recorded in daily inches from an airport weather station affiliated with Weather Underground approximately 5 mi (8 km) from the site (Weather Underground Service 2016). Data were collected beginning on the date of installation and continuing throughout the experiment (12 months).

Statistical Analysis Methods

Monthly sediment trap measurements were converted to tons ac⁻¹ yr⁻¹ (tonnes ha⁻¹ yr⁻¹) and analyzed using JMP, version 11.0, statistical software (SAS Institute, Inc. 2015). A Levene normality test indicated that data were not normally distributed; thus, nonparametric tests were used. Differences between BMP treatments were determined using a nonparametric Wilcoxon test and a Steel-Dwass multiple comparisons test at α = 0.05 (Zar 2010). The effects of slope steepness and rock content were also analyzed using nonparametric Wilcoxon and Steel-Dwass multiple comparisons tests.

Results and Discussion

Erosion Rates by Treatment

Control treatments had erosion rates averaging 6.8 tons ac⁻¹ yr⁻¹ (15.1 tonnes ha⁻¹ yr⁻¹), whereas Seed treatment rates were 2.6 tons ac⁻¹ yr⁻¹ (5.9 tonnes ha⁻¹ yr⁻¹), Mulch treatment rates were 0.5 tons ac⁻¹ yr⁻¹ (1.1 tonnes ha⁻¹ yr⁻¹), and Slash treatment rates averaged 0.35 tons ac⁻¹ yr⁻¹ (0.78 tonnes ha⁻¹ yr⁻¹) (Table 2). The Control treatment was significantly different from all other treatments (P = 0.0315) (Table 2), indicating that overall, the BMPs compared in this study were more effective for skid trail
closure than simply waterbars alone. Mulch and Slash treatments reduced erosion significantly more than just Seed treatments alone ($P < 0.0001$) (Table 2). Erosion rates varied over time (Figure 6). This temporal variation was probably a result of seasonal rainfall differences and vegetation growth on the treatment sites. However, variability in the Seed treatments was substantially higher than those of the Slash or Mulch treatments (Table 2). Overall, using BMP methods beyond the Control significantly reduced erosion. However, the application of Slash or Mulch treatments resulted in less erosion than Seed treatments. These findings support what was found in the past by Sawyers et al. (2012) and Wade et al. (2012) in the Piedmont region of Virginia. Their findings also suggest that Slash and Mulch treatments are among the most effective at reducing erosion. However, both found substantially higher rates of erosion from Control treatments (10–12 tons ac$^{-1}$ yr$^{-1}$). This is possibly due to this study having a wider range of slope gradients that were averaged together.

Erosion rates varied throughout the year with precipitation changes (Figure 6). Erosion rates started at a lower rate as on-site storage (bulldozer cleat tracks, small holes, and soil settling) filled and then increased after approximately 3 months. After this increase, the erosion rate diminished every monthly period, with the exception of period 6 (Sept. 4–Oct. 9, 2015) because of an extreme weather event that occurred on Sept. 29, 2015 (Figure 7). On this day the area received the highest rainfall amount ever recorded for this location in one day, 4.39 in. (11.15 cm) (NOAA 2015), resulting in the spike in erosion rates over that period (Figure 6). After this period, the erosion rates continued their trend of diminishing with every month as rainfall amounts decreased and ground cover increased. There also appeared to be an increased rate of erosion during the period from December through January; however, it was later determined that this was probably an effect of frost heave on the sediment surrounding the pins. This was taken into consideration when yearly erosion rates were calculated.

**Changes in Ground Cover**

Quarterly ground cover assessments indicated a generally increasing trend over time (Figure 8). The only exception to this trend were the Mulch treatments; all units of this treatment exhibited decreasing ground cover over the course of the study. This is most likely due to the initially high ground cover that over time decomposed or was removed by wildlife, wind, or the scouring of concentrated flow paths. Control, Seed, and Slash treatments all resulted in increased ground cover over time (Figure 8). Control treatments retained the lowest percentage of ground cover that gradually increased with time as bare soil eroded away to reveal rock fragments and roots, which acted as ground cover, and as natural vegetation and leaf litter accumulated on the trail surface. Ground cover in Seed treatments increased rapidly over the first season, as grass seeds germinated. The increased temperature and decreased rainfall during the summer led to some mortality of grass in the Seed treatments; however, germination of natural vegetation, as well as the

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**Figure 6.** A comparison of average erosion rates from skid trail treatments over the period of data collection (Apr. 7, 2015–Apr. 8, 2016) compared with rainfall amounts.

**Figure 7.** Daily rainfall intensity rates over the course of 1 year of data collection. The largest historic 1-day rainfall event for Blacksburg, VA, was recorded on Sept. 29, 2015.
exposure of rock fragments and accumulation of leaf litter continued to increase the amount of ground cover. Slash treatments initially had higher rates of ground cover that slowly increased as a result of the exposure of rock fragments and germination of natural vegetation.

Effects of Slope Steepness and Soil Rock Content

The topography of the study site played an important role in erosion. Past studies have found that as slope increases, erosion rates also increase (Haupt 1959). However, the results of this study did not follow this trend. Gentle slopes produced the least amount of sediment, followed by the steep slopes, with moderate slopes producing the highest rates of erosion (Figure 9). This was probably due to higher volumetric rock content in the soils on the steeper slopes (Table 3) but could also be attributed to the shorter distance between waterbars (40 versus 50 ft) that was used on steeper slopes to follow recommended BMP guidelines. As the soil on the ground surface eroded, rock fragments were left behind on the surface. Rock fragments acted as a ground cover, increasing the percentage of ground cover and thus reducing erosion rates (Kochenderfer and Helvey 1987). Nonparametric Wilcoxon testing determined that erosion rates were not significantly correlated to slope steepness ($P = 0.3083$). However, there was a negative relationship between rock fragment cover and erosion rates ($P < 0.0001$). This is supported by other findings by Simanton et al. (1984) and Wilcox and Wood (1989).

BMP Costs

The final study objective was to determine how costs of closure methods vary relative to the amount of erosion prevented. Factors

<table>
<thead>
<tr>
<th>Slope class</th>
<th>Samples taken</th>
<th>Mean rock content (%)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gentle</td>
<td>24</td>
<td>16.1a</td>
<td>3.8</td>
</tr>
<tr>
<td>Moderate</td>
<td>24</td>
<td>16.3a</td>
<td>5.5</td>
</tr>
<tr>
<td>Steep</td>
<td>24</td>
<td>31.2b</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Treatments with the same letter are not significantly different based on $\alpha = 0.05$ as determined by Steel-Dwass multiple comparisons testing.
that were considered when costs were determined include the cost of materials, labor, and machine hours. Costs were based on purchase prices for seed, fertilizer, and straw, as well as literature on machine rates and current labor costs (Conrad et al. 2012, Sawyers et al. 2012). A rate of $17.52/hr was used for labor costs and $75/hr for machine rate. Costs of materials were as follows: $4.99/straw bale, $119.99/50-lb bag of perennial ryegrass (applied at a rate of 75 lb/ac), $59.99/50-lb bag of KY-31 Fescue (applied at a rate of 75 lb/ac), and $119.99/40-lb bag of 10-10-10 fertilizer (applied at a rate of 300 lb/ac). Costs were then applied to each treatment based on a 50 ft (15.2 m) section of skid trail, and the total cost of skid trail closure for the harvest was determined, as well as cost per mile (1.6 km) of skid trail closure (Table 4). It is important to note that the costs of Slash treatments were calculated for the methods that were used for their installation during this project. Slash treatments were applied by hand and tracked in with a bulldozer. Although calculation of costs in this manner may not be representative of operationally applied slash, it is the best estimate that we can provide, and we can predict that operationally applied slash can cost substantially less than what was determined by this cost analysis. This was also reported by Sawyers et al. (2012) in their analysis of overland skid trail (assuming 50 ft [15.2 m] waterbar spacing), and the cost of erosion prevented.

Figure 10. Relationship between soil rock content and slope gradient for all treatments. A line of best fit represents the positive relationship. This expression is expressed with an R² value of 0.54 (P < 0.001).

Table 4. Cost analysis of each BMP closeout method on a basis of 50 ft (15.2 m) treatment, the entire harvest on which study was conducted (if closed out with single method), 1 mi (1.6 km) of skid trail (assuming 50 ft [15.2 m] waterbar spacing), and the cost of erosion prevented.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cost for 50 ft (15.2 m) treatment (US$)</th>
<th>Cost for entire harvest (US$)</th>
<th>Cost for 1 mi (1.6 km) of skid trail (US$)</th>
<th>Costs of erosion prevented (US$/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>18.75</td>
<td>1,667.00</td>
<td>1,980.00</td>
<td>NA</td>
</tr>
<tr>
<td>Seed</td>
<td>26.25</td>
<td>2,353.82</td>
<td>2,771.89</td>
<td>88.85</td>
</tr>
<tr>
<td>Mulch</td>
<td>41.64</td>
<td>3,702.51</td>
<td>4,397.50</td>
<td>182.67</td>
</tr>
<tr>
<td>Slash</td>
<td>28.13</td>
<td>2,500.62</td>
<td>2,970.00</td>
<td>73.65</td>
</tr>
</tbody>
</table>

NA, not applicable.

Conclusions

The erosion rates of Control treatments were significantly higher and were far more variable than those of any of the other treatments. The Slash treatment was the most effective in reducing erosion as it provided immediate ground cover (no wait for germination). Over time, the decomposition of slash may also have additional positive effects on the chemical properties of the soil. On a per ton basis, it was also the most cost-efficient in reducing erosion. In addition, slash has the added benefit of preventing ATV traffic from using the closed trails. However, for this reason, slash may not be suitable for use if the trail is to remain open for traffic. It may also be unsuitable if the skid trail is to serve as a fireline, as the slash serves as fuel on the ground. The Mulch treatment was also very effective in reducing erosion, as it was effective immediately, and the added benefits of the mulch and fertilizer aid the grass in germination and survival. This treatment was the most costly of the BMPs, compared in both per area of treatment cost and cost of erosion prevented. However, the Mulch treatment may be the best option under certain conditions when slash is not readily available or can be difficult to apply such as on manual felling and cable skidding operations where stems are topped at the stump, as is commonly found in the Ridge and Valley physiographic province. Seed treatments proved effective in reducing erosion for the lowest per area cost; however, once seeds have germinated, the ground cover may prove to be difficult to maintain for an extended time period due to mortality. Seed treatment was also the least effective of the additional BMPs tested. Overall erosion rates were highest shortly after skid trail closeout and gradually declined over the course of the study. Skid trail closeout should be completed immediately after harvest to minimize erosion.

These findings are important, as in 2015 approximately 246,000 ac of forestland were harvested in Virginia (VDVF 2015). According to VDOF records, approximately 25,000 ac of forestland were harvested in the mountain region alone. Kochenderfer (1977) has proposed that 5–11% of an Appalachian harvest lies in skid trails, with higher percentages on steeper slopes. This amounts to 1,250–2,750 ac of land in skid trails across the Ridge and Valley per year. Following closure with waterbars, we can predict a mean erosion rate of 6.8 tons ac⁻¹ yr⁻¹ in the first year after harvest and can therefore estimate a soil loss of 8,500 to 18,700 tons/yr from the region. By addition of slash or mulch to all of these skid trails, potential erosion could be reduced to approximately 625–1,375 tons/yr. Road and skid trail construction and closeout are major costs incurred by loggers when forest harvests are conducted (Conrad et al. 2012). This cost analysis of bladed skid trail closure could assist with logging cost estimates for land managers and logging industry professionals.

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