Comparison of Three Methods to Estimate Forest Stream Crossing Erosion in the Virginia Piedmont

Albert J. Lang¹, M. Chad Bolding², W. Michael Aust³

Abstract

Controlling erosion from lower standard forest road stream crossings is a common issue in forest operations. Recent disputes and litigation in the Pacific Northwest have emphasized the need for quantification of sediment and effectiveness of best management practices (BMPs) for ditched forest roads. Implementing forestry BMPs for stream crossings can reduce erosion near streams, yet few studies have quantified erosion relative to common approach characteristics implemented in forest management. In this study, ten haul road stream crossing approaches in the Piedmont region of Virginia will be compared using three sediment delivery estimation techniques: 1) a direct measure, 2) two common erosion models (Water Erosion Prediction Project (WEPP) and Universal Soil Loss Equation (USLE)) with actual approach characteristics, and 3) USLE using only aerial photographs and topographic maps. For the direct measure, a rubber waterbar was installed at the base of the crossing to direct water and sediment into silt fence catchment areas. Sites were then periodically measured for sediment deposition using differential leveling for one year. Stream crossing approaches for the first two methods were characteristics using common forestry equipment (e.g. clinometer, loggers tape, and densitometer). The mapping method will be completed using only InFOREST software. InFOREST is a geographic information system software program catered to natural resource management. Erosion estimates will then be compared to actual sediment collection and discussed in terms of advantages and disadvantages of each method. Additionally, this paper will review relevant literature on studies related to sediment delivery from operational forest stream crossings.

Keywords: Best management practices, forest planning, sediment, water quality, silviculture

Introduction

Erosion from low standard silvicultural roads and their nexus to streams has raised concern over the effects of logging operations on water quality (Boston and Thompson, 2009). Specifically, ditched forest roads have been a topic of much debate around the extent of power the Federal Pollution Control Act of 1972 (Clean Water Act) covers. This issue has received national attention and clearly emphasizes the need for research to improve the understanding of road sediment delivery. Additionally, forestry literature continually identifies sediment from roads

¹ Graduate Research Assistant, Virginia Tech Department of Forest Resources and Environmental Conservation, Blacksburg, Virginia. Lan0893@vt.edu.
² Associate Professor of Forest Operations and Engineering, Virginia Tech Department of Forest Resources and Environmental Conservation, Blacksburg, Virginia. bolding@vt.edu.
³ Professor of Forest Hydrology, Virginia Tech Department of Forest Resources and Environmental Conservation, Blacksburg, Virginia. waust@vt.edu.

and skid trails to be one of the foremost water quality concerns with forest management (McBroom et al., 2008).

Budget constraints commonly force managers to focus BMPs on erosion prone areas that could easily lead to sedimentation (Aust and Blinn, 2004). Detailed sediment research can be expensive and time consuming; therefore evaluating other methods to target and rank problem areas is desirable. One such method may be through the use of soil erosion models. Soil erosion models used in research, such as Universal Soil Loss Equation (USLE) and Water Erosion Prediction Project (WEPP) have been shown to adequately rank erosion rates on skid trails with varying levels of BMPs (Sawyers et al., 2012; Wade et al., 2012).

In this study, erosion rates from ten stream crossing approaches located on forest haul roads in the Piedmont region of Virginia were compared using three sediment delivery estimation techniques: 1) a direct measure, 2) two erosion models WEPP and USLE with actual approach characteristics, and 3) USLE using only aerial photographs and topographic maps available in InFOREST software. Additionally, sediment delivery estimation methods 2 and 3 were further subcategorized by defining two contributing areas: 1) the area between the stream and nearest water control structure (WCS); and 2) the area between the stream and topographic break (TB). We defined the TB as the maximum elevation position along the road where water from the road surface could extend to the stream crossing. We used these measures as potential minimum and maximum runoff contributing areas.

USLE and WEPP models were chosen because of their abundant frequency within recent forestry literature (Christie et al., 2013; Wade et al., 2013). InFOREST software, a geographic information system developed by the Virginia Department of Forestry, allows for enhanced access to natural resources information. We chose to use InFOREST because of its user friendliness, accessibility, and ability to readily measure distances and areas on aerial and topographic maps. The objectives of this study were to compare modeling methods to actual collected sediment data and discuss the advantages and disadvantages of each modeling approach.

**Methods**

Ten forest haul road stream crossing approaches used for access to log landings were located on six intensively managed loblolly pine (*Pinus taeda*) plantations in the Piedmont region of Virginia. Roads and stream crossings were built and designed by the landowners between 5 and 25 years ago to serve as permanent crossings for continued timber management. All stream crossings were constructed over intermittent or perennial streams and recommended streamside management zones of mixed hardwood species were left adjacent to stream crossings. The landowners currently manage stands for 18- to 25-year rotations, and repair and improve roads as needed to meet management objectives. A number of hunt clubs lease the land between harvest periods. Low traffic volumes from the hunt clubs was the primary use of the roads during this study.

Rubber conveyor belts acting as a water control structure were installed across the road surface in June 2012. Sediment laden runoff from road approaches were diverted by these belts into silt fence catchment areas (Robichaud and Brown, 2002). The trapped sediment was used as an estimate of actual sediment delivery. These rubber conveyor belts allowed unimpeded access
while serving its purpose as a water control structure. A minimum of ten sediment pins were placed in the silt fence catchment area (Lakel et al., 2010) and periodically measured for sediment deposition using differential leveling for a one year period. Bulk density samples were collected within each catchment area after one year to calculate sediment volume. Composite soils samples from the road surfaces and silt fence catchment areas were also analyzed for soil particle size (Gee and Or, 2002). The difference between soil particle size on the road and in the catchment area was used as a measure of silt fences efficiencies.

The second method of estimating sediment delivery utilized actual road characteristics as inputs into both USLE (Dissmeyer and Foster, 1984) and WEPP models. Actual road dimensions and characteristics were measured during belt installation. Percent bare soil and canopy covering the approaches were measured seasonally (four measurements) to capture the varying erosion rates associated with senescence. The USLE was partially completed in the field then the soil component (k-value) computed in office using the lab determined soil particle sizes. The four USLE estimates were averaged for comparison in this study. Precipitation data was gathered from a privately owned and publicly shared (www.wunderground.com) weather station nearest the stream crossings. The weather station’s ID was KVAAPPOM4 and utilized VWS V14.00 weather monitoring software.

The third method was chosen to emulate a minimal planning effort approach. None of the field data neither used nor was a site visit necessary. We used InFOREST software to gather slopes and distances to nearest WCS and TB for each road approach. The nearest WCS were identified in aerial photographs. TBs were identified by drawing a line following the road on aerial photos then measuring the appropriate distance on topographic maps. Road widths were assumed to be 3.66 m. Elevation changes were then estimated using 40 foot contour lines from topographic maps. Soil information was gathered from the web soil survey (USDA NRCS, 2014). The gathered information was then applied to USLE to estimate erosion.

**Results and Discussion**

Each of the ten approaches was categorized into one of four road classes (1-4), with class 1 roads having the greatest standards. This study was comprised of one class 2, five class 3, and four class 4 road approaches. Thirteen rainstorms exceeding 2.54 cm/day occurred in the one year data collection period. Nearly all catchment areas had greater clay and lesser sand content than road surfaces. Silt fence efficiency of clay was much greater than anticipated (most were 100%), while sand efficiency was much less (most less than 60%). This discrepancy may be explained by the type of runoff occurring on approaches, which likely would have been sheetflow. The erosion power associated with sheetflow may not have had the shearing force needed to carry larger sized particles causing sand to settle out of suspension prior to reaching catchment areas. Nevertheless, both models have been designed to measure sheetflow erosion processes.

Measured and modeled erosion amounts from the three techniques are shown in Table 1. All of the closest modeled estimates stemmed from onsite data collection used in method 2. However, neither WEPP nor USLE consistently predicted closer to the measured amounts of sediment, with each most closely predicting five different sites. Measured sediment exceeded 1 tonne on two class 4 approaches, while each of the other approaches trapped less than 0.2 tonne. Three approaches did not have water control structures, thus modeled erosion predictions were
identical for both estimated contributing areas. WCS estimates were always lower than TB estimates. WEPP, in the majority of the sites, proved to be less affected by WCS versus TB, while USLE showed a greater discrepancy based on which value was input.

Table 1. Measured and modeled estimates in tonnes of sediment delivery using three estimation techniques. † Nearest water control structure used in slope length estimation; * Topographic break used in slope length estimation; ‡ Closest modeled estimate.

<table>
<thead>
<tr>
<th>Road Class</th>
<th>Method 1</th>
<th>Method 2</th>
<th>Method 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured (tonnes)</td>
<td>WEPP (tonnes)†</td>
<td>WEPP (tonnes)*</td>
</tr>
<tr>
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<td>0.016</td>
<td>0.001</td>
<td>0.002†</td>
</tr>
<tr>
<td>3</td>
<td>0.044</td>
<td>0.001†</td>
<td>0.001†</td>
</tr>
<tr>
<td>3</td>
<td>0.047</td>
<td>0.003</td>
<td>0.008</td>
</tr>
<tr>
<td>3</td>
<td>0.150</td>
<td>0.196†</td>
<td>0.196†</td>
</tr>
<tr>
<td>3</td>
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<td>0.065</td>
<td>0.065</td>
</tr>
<tr>
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<td>0.003</td>
<td>0.274†</td>
<td>0.274†</td>
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</table>

Eight of nine WEPP modeled estimates were able to accurately predict erosion to be less than 1 tonne when the measured was less than 1 tonne. However, six of the eight WEPP estimates were an order of magnitude less than the measured (Figure 1). When measured sediment exceeded 1 tonne, WEPP overestimated by an order of magnitude in one case (2nd class 4 estimate) and well underestimated sediment in the other (4th class 4 estimate). In general, using the TB as the length factor input into WEPP yielded more accurate predictions. This likely occurred because larger approach areas cause larger estimated sediment delivery given the small sediment scale. However, since WEPP has numerous adjustable parameters, we believe that one or several of the default parameters had masked the true influence of the length factor. On average, trapped sediment increased as road standard decreased. Both WCS and TB modeled sediment rates also followed a similar average class ranking.

The primary advantage of using WEPP was its consistency. WEPP consistently produced values that were closer to measured values in comparison to USLE, which produced estimates that were grossly inaccurate in comparison. Even though both programs produced 5 site estimates that were closer to actual, WEPP’s margin of inaccuracy was far less than that of USLE. The primary disadvantage to WEPP is time and site visits required to collect many parameter needed as input to yield more accurate results. This may not be warranted for managers seeking to merely understand where to best allocate their budget.
Figure 1. Log$_{10}$ tonnes of sediment delivery from two contributing areas (topographic break (TB) and nearest water control structure (WCS)) using WEPP estimates from method 2 and measured estimates from method 1. The table on the right displays measured and modeled sediment averages by road class.

Unlike WEPP predictions, USLE estimates using WCS were generally more accurate than USLE TB estimates (Figure 2). This demonstrates the influence of increased length to generate greater USLE estimates (Figure 2). Eight of 10 USLE estimates using WCS and 7 of 10 using TB accurately predicted erosion above and below 1 tonne. This method appropriately ranked road classes according to average sediment rates with WCS estimates, but not TB estimates. This was likely due to a lack of replication and a much greater approach length in the class 2 road approach (>250 m). Using USLE with such extensive slopes extrapolates outside of its original intended use.

USLE and other empirical models are sometimes overlooked in their usefulness because they do not take into account many parameters that confer to high levels of heterogeneity within the environment. When employed correctly, USLE can be easily applied to most places in the US, quickly computed, and is free to use. A disadvantage is its inability to reliably predict accurate sediment loads. Calculated rates of erosion can change by season making this method difficult to understand true water quality issues. This model is also not intended as measure of sedimentation.
Figure 2. Log$_{10}$ tonnes of sediment delivery from two contributing areas (topographic break (TB) and nearest water control structure (WCS)) using USLE estimates from method 2 and measured estimates from method 1. The table on the right displays measured and modeled sediment averages by road class.

The third method using InFOREST and USLE showed the least accurate estimates. USLE estimates tended to overestimate the measured. All estimates were at least one order of magnitude different from the measured (Figure 3). WCS and TB estimates incorrectly predicted erosion above and below 1 tonne in 70% and 80% of approaches, respectively (Figure 3). Both modeled predictions had inaccurately ranked average sediment with road class. In other words, the higher standard class 2 approach had the greatest predicted sediment, while the lower standard classes 3 and 4 had progressively less sediment estimates. Much of the error in this method could stem from the inability to interpret WCS locations on aerial photographs and difficulty estimating elevation differences using 40 foot contours within InFOREST topographic maps.
Figure 3. $\log_{10}$ tonnes of sediment delivery from two contributing areas (topographic break (TB) and nearest water control structure (WCS)) using USLE estimates from method 3 and measured estimates from method 1. The table on the right displays measured and modeled sediment averages by road class.

Conclusions

Most forestry BMPs recommendations recognize disturbed areas near streams have potential to impair water quality. However, managers with budget constraints need to employ methods that target the most erosion prone areas in order to optimize BMP efforts. Our results indicated that erosion prone stream crossing approaches can be identified by inputting actual road characteristics into either USLE or WEPP models as per method 2. USLE is likely a better fit for managers seeking to apply BMPs on the most erosion prone areas primarily because of its ease of use and lesser time constraint than employing WEPP.

On average, higher standard roads yielded less sediment than lower standard roads. Sheet flow was likely the primary erosion force on these road approaches and possibly caused unanticipated silt fence efficiencies for clay particles. While the models in method 2 did not perfectly rank erosion from each approach, they were able to identify erosion above and below 1 tonne in most instances. Method 3 inadequately ranked average erosion rates by road class and were typically an order of magnitude different from measured. Simply using online information to assess stream crossings can easily be misinterpreted and pales in comparison to using actual site characteristics. Each model has its limitations and scope of usefulness that need to be considered when utilizing these models in estimations. Despite the various methods that exist within each type of soil erosion model, problems with accuracy and applicability are always present due to the uniqueness of each individual environmental setting.

Literature cited


