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Assessing RUSLE and Hill-slope Soil Movement Modeling in the Central Appalachians

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***Abstract*.** The determination of the topographical attributes responsible for the origination and transfer of sediment were investigated in a central Appalachian mixed hardwood forest from 2002 through 2005. Two study watersheds were chosen on the left fork of Clover Run within the Indian Run watershed in Tucker County, West Virginia. Silt fence was installed around all the stream channels within both watersheds to ensure all sediment material delivered from adjacent hill-slopes was captured and collected. Visual, physical, and spatial observations were made before, during, and after road construction within the treatment watershed. Data were analyzed both spatially and statistically to determine the magnitude of effects from the topographical attributes, the road construction, and the harvesting operations on sediment delivery to the stream channel. The Revised Universal Soil Loss Equation (RUSLE) was tested to compare modeled results to field measured results under these mountainous conditions. The soil loss equation displayed poor accuracy, yielding predictions hundreds of times larger than the actual masses of collected data. The modeled estimate for the treatment watershed was 2.68 tons per-acre per-year, while the modeled estimate for the control watershed was 2.86 tons per-acre per-year. However, the treatment watershed actually produced 0.01, 0.02, 0.03 and 0.01 tons per-acre, respectively; while the control watershed produced 0.002, 0.001, 0.005, and 0.003 tons per-acre, respectively, for 2002 through 2005. The poor performance of the RUSLE may be attributed to several factors, particularly the extremely variable conditions that exist within Appalachian forested watersheds which may reach outside the predictive capabilities of the RUSLE.

Keywords. *Appalachian Forests, Soil Erosion, RUSLE, Timber Harvesting, Best Management Practices*

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Introduction

Forest road construction involves purposely displacing soil using mechanized equipment, including excavators, bulldozers, and loaders. The amount of soil displaced during forest management varies based on many variables at the construction site, including natural hillside grades and lengths, road grades, road widths and lengths, geology, size, and landform of the area and the period during which the management is applied (Pope 1991, Croke and Hairsine 2006). Other types of soil disturbance are harder to recognize; such as, leaf litter can be scoured and soil exposed when trees are winched or skidded along the ground, creating potential areas for accelerated erosion to take place (Hatchell et al. 1970, Pope 1991, Eisenbies et al. 2005). Nearly all modern harvesting operations use heavy equipment, which in most cases disturbs the litter layer and the underlying soil (Steinbrenner and Gessell 1955, Lull 1959, Froehlich 1979). Road and landing construction are the major disturbances that can increase soil erosion during forest management (Hatchell et al. 1970, Pope 1991, Croke and Hairsine 2006), however, they are necessary to complete most forest management treatments.

Newly constructed roads and landings are the primary sources of sediment and water-body sedimentation in managed forest watersheds (Case and Donnely 1979, Kochenderfer 1977, Stuart and Edwards 2006). Roads can affect erosion and geomorphic processes by four primary mechanisms: 1) they accelerate erosion from the road surface and prism itself by both mass and surface erosion processes; 2) they affect channel structure and geometry; 3) they alter surface flowpaths, leading to diversion or extension of channels onto previously un-channelized portions of the landscape; and 4) they cause interactions among water, sediment, and woody debris at engineered road-stream crossings (Gucinski et al. 2001). Erosion and sedimentation tend to be greatest while road and embankment soils are still bare and vegetation has yet to become established (Haupt 1959, Parson 1999). Proper road location is critical to reducing erosion and sedimentation especially where it is necessary to cross streams (Yoho 1980, Swift 1988). In addition, it should be noted that most sediment sources in forests are primarily small definable areas (Bonnell and Williams 1986, Rice and Lewis 1986, Croke et al. 1999, Croke and Hairsine 2006); because these contributing sources are small and definable, they can also be treated more easily.

Since the USLE was intended for cropland and the erosion estimates for sheet and rill erosion often were predicted improperly for other land uses, additional modifications were made to the USLE. Some major modifications of the USLE include the revised universal soil loss equation (RUSLE) and the modified universal soil loss equation (MUSLE). The RUSLE fills gaps that were present in the original data and corrects errors by providing improved coefficients. It also incorporates more data from different locations and types of cropping systems than the USLE including forests. One adjustment made for RUSLE is the addition of a factor that accounts for surfaces covered by or embedded with mulch or rock fragments (Weltz et al. 1987). Additionally, the RUSLE is the most widely used method of predicting soil loss in forestry applications (Lane et al. 1992, Hood et al. 2002). It allows foresters to compare potential soil loss resulting from different harvesting scenarios and evaluate which method is likely to result in the least soil erosion (Hood et al. 2002). The MUSLE improves on the USLE by considering surface runoff and road erosion (Barfield et al. 1983). It was developed to model sediment delivery where deposition was expected down slope before reaching a waterbody. Essentially, the model takes into account the sediment deposited before reaching the waterbody downslope, thus, eliminating this sediment from its final soil loss predictions.

The processes of sediment delivery in forested watersheds of the central Appalachians were studied for baseline levels of sediment delivery and levels delivered under managed conditions involving road construction and harvesting to identify the contributors to sediment delivery to streams, both natural and anthropogenic. The main objectives of this study were to 1) identify the attributes that are key to controlling sediment delivery in two forested watersheds under conditions of no anthropogenic disturbance and under conditions of forest management and 2) model sediment delivery using the Revised Universal Soil Loss Equation (RUSLE) and compare those modeled predictions against what was actually obtained from field sampling to make some generalizations about the applicability of RUSLE to forested watersheds within the central Appalachians.Your ordinary text and equations use the Normal Style. You can use italics, bold, underlines, superscripts and subscripts. It's best to choose symbols from the Symbol or Arial Basic, Latin, or Greek sets; avoid unusual symbols. Use plain text or Equation Editor for equations. Put several spaces (not a tab) between the equation and the equation reference number.

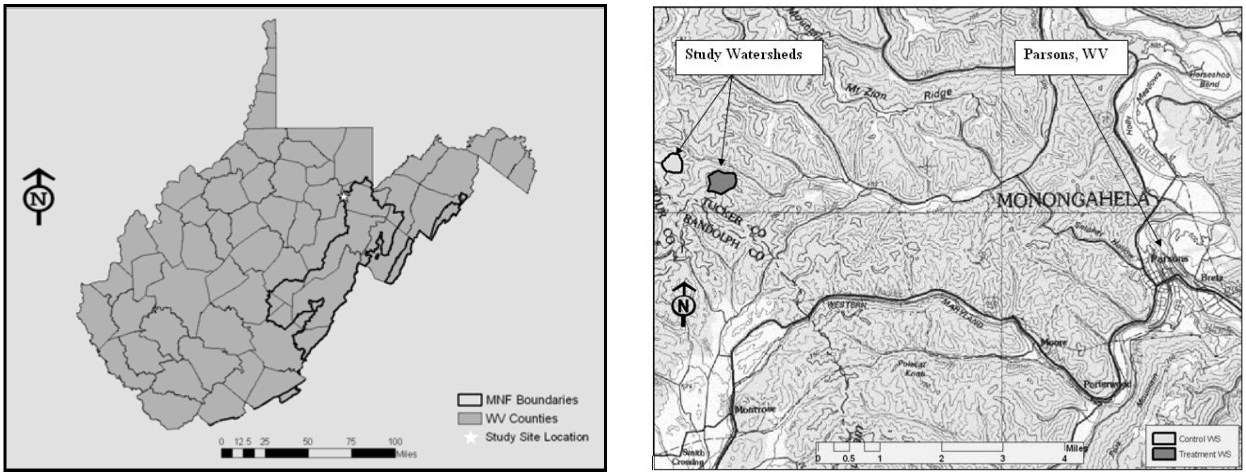
Materials and Methods

Two study watersheds which are located in the Cheat Ranger District of the Monongahela National Forest (MNF) in West Virginia were selected for this project (Fig. 1a and Fig. 1b). One watershed is a treatment watershed, and one is an undisturbed control. The control watershed is 20.2 ha and the treatment watershed is 32.7 ha. Elevation ranges from 713.6 m to 858.7 m in the control watershed, and from 625.7 m to 805.1 m in the treatment watershed. Based on 3 m digital elevation maps (DEMs) for the two watersheds, slopes on the control watershed range from 0.21-44 degrees with a mean hillside slope of 22 degrees. The treatment watershed slopes range from 0.42-47 degrees with a mean slope of 25 degrees. Total stream length of all tributaries in the control watershed is 905 m and 1,265 m in the treatment watershed. Both watersheds were fully forested with mixed Appalachian hardwoods at the initiation of the study. The dominant species present were northern red oak (*Quercus rubra*), yellow-poplar (*Liriodendron tulipifera*), sugar maple (*Acer saccharum*), black cherry (*Prunus serotina*), and yellow birch (*Betula alleghaniensis*) (Bill 2005).

Silt fence was used to collect and quantify the sediment delivered to the stream channels from the adjacent hill-slopes within both watersheds. The silt fence was installed just upslope from the bankfull position along both sides of the stream channel, including all ephemeral, intermittent, and perennial reaches within both watersheds (Fig. 2). Uniquely numbered metal tags were nailed to the tops of selected posts to identify silt fence sections, so when samples were collected their location would be known and could be associated with field attributes.

Sample collection was performed annually within both watersheds. All of the material, both mineral and organic, captured in the silt fence was removed and placed into garbage bags or plastic buckets. Information about the source of mineral sediment, when obvious (e.g., tree falls), was recorded in a field notebook. Each sample was air dried and transferred to a Kraft paper lawn and leaf bag for oven-drying at 100 ºC until a constant weight was obtained. The total mineral weights associated with each section of silt fence each year within each watershed were recorded and entered in a spreadsheet for further analyses.

The treatment watershed 2002 samples represent the period prior to the initiation of road construction. The 2003 samples represent the period from beginning of road construction to when the road was pioneered. The 2004 samples represent the period from when the road was completed by properly grading it, smoothing and graveling the surface, constructing cutbanks to final slope, and seeding the cutbanks and fillslopes. Harvesting a small area (2.83 ha) along the ridge near the last stream crossing also occurred during this period. The 2005 samples represent the period when no activities were performed and the road and other disturbances were stabilized or stabilizing.



a b

Figure 1. a) study site locations within West Virginia b) study sites relative to Parsons, WV.

Figure 2. Amoco™ 1198 silt fence installed along stream channel.

The haul road construction process began in July of 2002 and was not finished until autumn 2003. The road was left in a disturbed condition with few BMPs and water control structures in place over the winter. The road had culverts and broad-based dips installed, and was excavated to the appropriate grade, and graveled with 10 cm limestone during the summer of 2003 (Bill 2005). All of the cutbank and fillslopes were initially seeded and mulched in late November 2002 for overwintering. However, vegetation establishment was unsuccessful due to the onset of winter conditions. In May 2003, the fillslopes over the cross drain culverts and the cutbanks in the near-crossing areas were reseeded at double the initial rate and chopped mulch was also applied. During road construction, sediment was unintentionally mechanically pushed down the fillslope and into the silt fence. This was the case at several areas approaching stream crossings. This sediment in the silt fence was a result of steep slopes below the roads and short distances between the roads and the silt fence. In some areas this resulted in a considerable volume of sediment material reaching the silt fence.

SAS® (2004) was used to analyze whether the topographical variables (independent variables) listed previously explained a significant amount of the variability in the mineral mass collected in the silt fence (dependent variable). The data was evaluated on a per-silt fence-section basis for each watershed as well as evaluated on a per-unit-area basis with respect to the derived contributing areas. The data were analyzed on a per-silt fence-section basis to identify specific attributes associated with small areas that contribute to significant increases in hill-slope soil movement. The contributing area analysis was then performed to draw more specific conclusions on a per-unit-area basis about what topographical attributes may contribute to hill-slope soil movement and to provide per-unit-area estimates for comparison to other studies. The SAS® Generalized Linear Model (GLM) procedure was used to perform analysis of variance tests on the variables for the treatment and control watersheds. The model was modified to exclude the distance to road and distance to fillslope variables for the control watershed analysis.

Results

From 2002 to 2005 6.17 metric tons of sediment material were delivered to the silt fence within the treatment watershed; during that same period, the control watershed produced 0.56 metric tons of mineral material. Within the treatment watershed the total amount of captured sediment increased approximately 81% from 2002 to 2003, and another 21% from 2003 to 2004, it then decreased 182% from 2004 to 2005. By comparison, the sediment delivery in the control watershed decreased approximately 62% from 2002 to 2003, then increased 381% from 2003 to 2004, and then decreased 50% from 2004 to 2005 (Fig. 3). Average annual sediment production for the four years was significantly greater in the treatment watershed than in the control watershed (1.54 metric tons vs. 0.14 metric tons; $P = 0.019$).

The difference in sediment delivery between the two watersheds can partly be attributed to the size differential and the difference in stream length between each watershed. The treatment watershed is 11.21 ha larger in area and the stream length is 423 m longer than in the control watershed. However, when analyzed on an area basis, the treatment watershed still produced significantly more ($P = 0.016$) sediment on average than the control watershed (0.0198 metric tons ha^{-1} vs.0.0028 metric tons ha^{-1}, respectively) (Fig. 4). Similarly, on a stream-length basis the treatment watershed produced approximately 7.5 times more sediment (0.0012 metric tons m^{-1} vs. 0.0002 metric tons m^{-1}) on average than did the control watershed.

Sediment collected in silt fence sections that were within 30.48 horizontal meters (100 feet) of the road surface in 2003 accounted for 73 percent of the mineral material that year (Fig. 5). Fifty-five sections, or about one-third of the total number of sections in the treatment watershed, were completely or partially within 30.48 m of the road surface. These high loads of delivered sediment were most likely attributable to side cast material that was mechanically pushed downslope into the silt fence during road construction to create the fillslope, and then subsequently eroded from the fillslope. Smaller, but still substantial amounts of sediment were transported to the silt fence from two cross drainage features on the road that were also located within 30.48 m of the stream. The percentage of mineral material captured in these sections declined each year as the road surface and cut banks and fillslopes stabilized (Fig. 5). In 2004, sediment collected from these same sections accounted for only 43% of the total sediment material and only 26% of the total in 2005. The disturbed areas stabilized enough by 2005 that the amount of sediment material collected from these silt fence sections (0.22 metric tons) fell below those that were present prior to road construction in 2002 (0.35 metric tons).

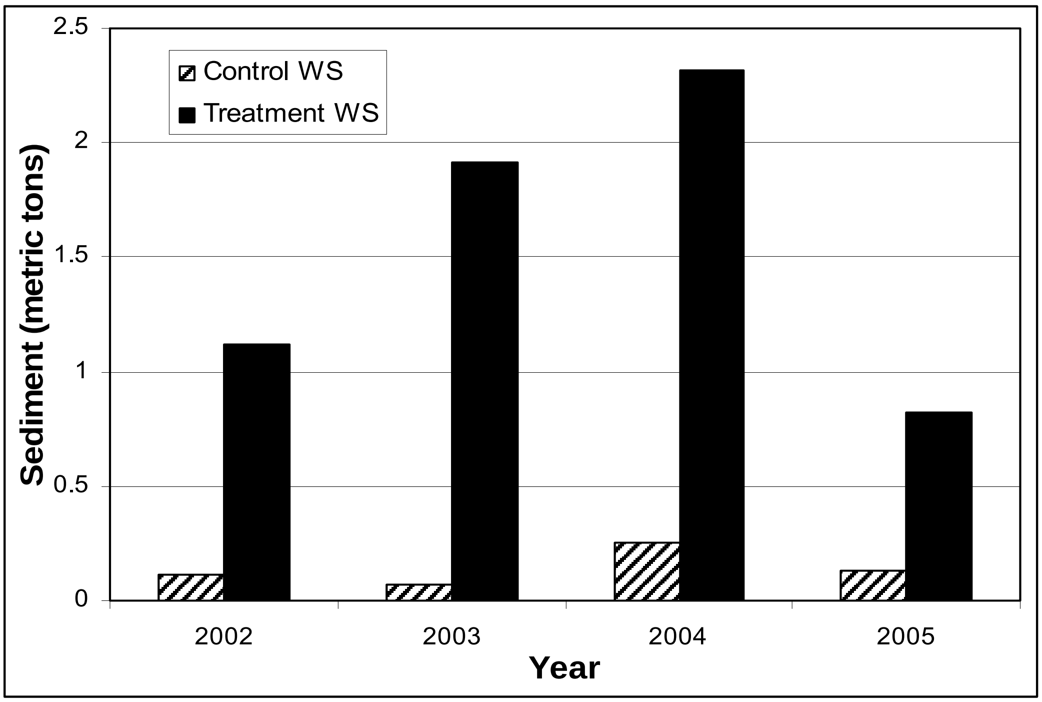


Figure 3. Total metric tons of sediment delivered to the silt fences each year.

Variables that were found to be important to explaining sediment delivery are presented in Table 1. For both watersheds within and across years, there were far fewer significant variables (α=0.10) than nonsignificant ones. Furthermore, not all variables were consistently significant or nonsignificant across years, though there were two that were consistently nonsignificant for both watersheds: tree fall soil area and distance to slope breaks. In the control watershed, across all years, bare soil area and distance to bare soil were clearly the variables that most consistently explained sediment delivery. Bare soil area was significant all four years, and distance to bare soil was significant three years (2002, 2003, and 2005) and borderline significant the remaining year (2004). During pretreatment, only one variable was significant in the treatment watershed – distance to animal trails – though distance to bare soil was again borderline significant. After road construction began, distance to WDEFs, distance to bare soil, and distance to tree falls became more important, and distance to animal trails was no longer significant.

The distance to bare soil obviously was an important variable in explaining sediment delivery in both watersheds. As expected, generally the smaller the distance between bare soil and the silt fence, the greater the delivery. Sediment levels associated with bare soil areas that were within 2 m of the silt fence accounted for 84 and 83 percent of the sediment delivered in the treatment and control watersheds, respectively, for those sections that had bare soil attributes associated with them.

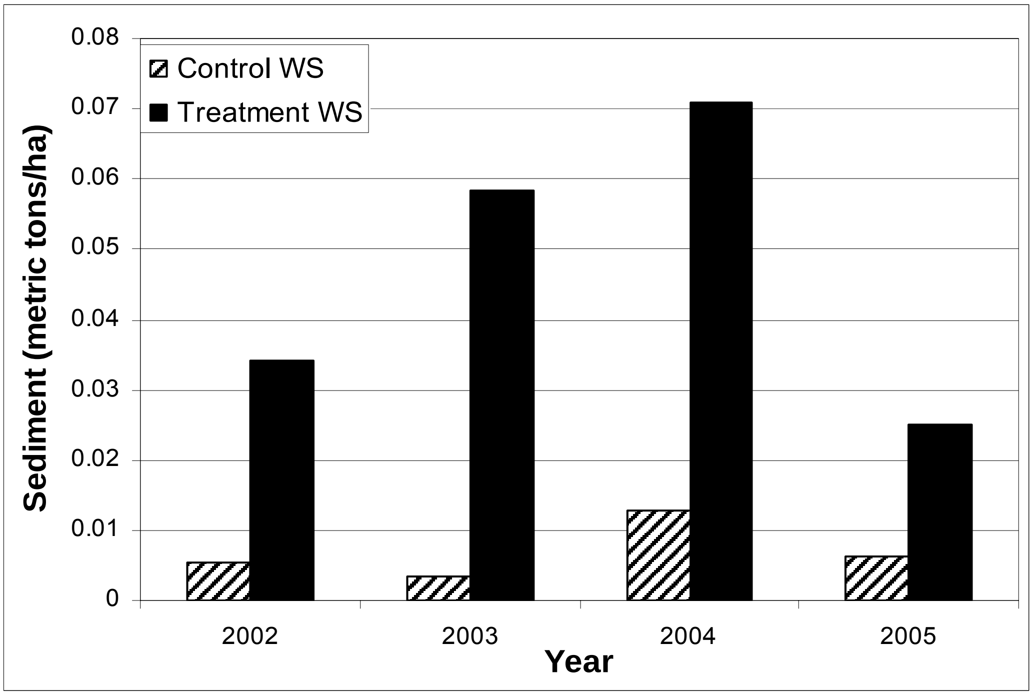


Figure 4. Sediment delivery expressed on an area basis for each watershed each year.

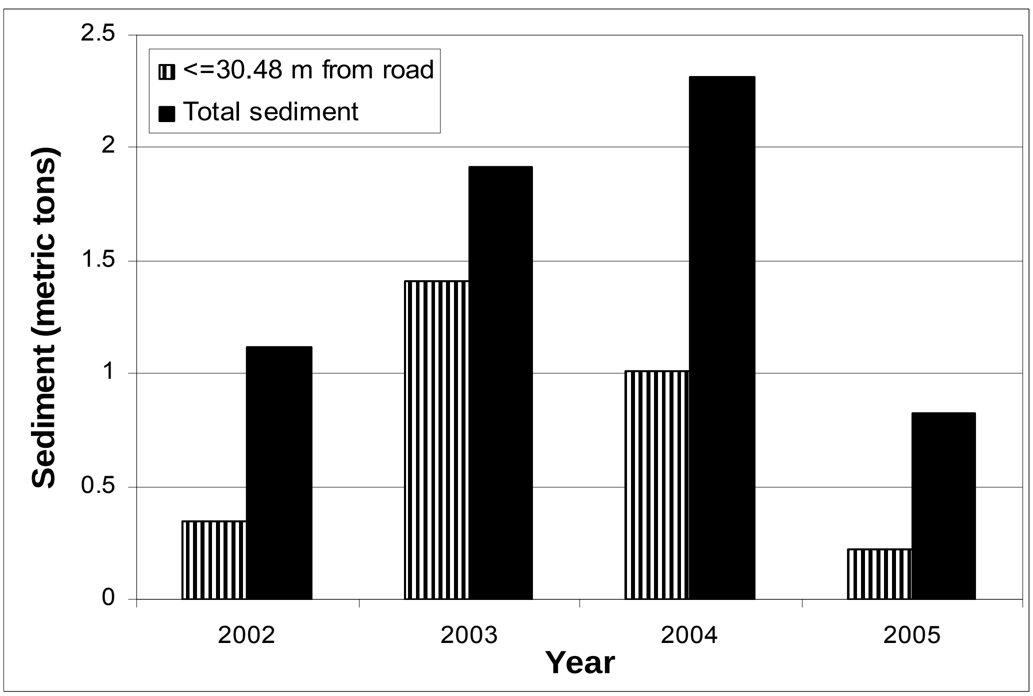


Figure 5. Sediment collected from silt fence sections located within 30.48 horizontal meters (100 feet) of the road surface in the treatment watershed.

The amount of area of exposed soil associated with tree falls was not a significant explanatory variable in either watershed. Presumably it is the presence and distance of the tree fall that is important, and not the size of the associated root wad. Trees which are large enough to uproot, whether from heavy snow loads, high winds, etc., instead of break, likely have large root wads that have the potential to contribute high sediment masses to a stream if they are sufficiently close to it.

Slope was a significant explanatory variable for only one year (2005) in the control watershed and never for the treatment watershed (Table 1); which may be because most of the slopes were fairly steep exceeding an average of 22 degrees in both watersheds.

The horizontal distance of water driven erosion features from the fence (WDEFs) was important in explaining sediment delivery in the treatment watershed only after the road was constructed (Table 1). The WDEFs that were closest to the fence were associated with the greatest masses of delivered sediment. Cross drains, particularly the culverts, are the likely source of much of the sediment delivered to the silt fence. It is unlikely that the broad-based dips played a large part in contributing sediment after BMPs were implemented because of the way the dip outlets are constructed and water is controlled.

Analyses involving the distance between the fillslope and silt fence also showed this distance variable to be nonsignificant (Table 1). However, the large increase in the P-value in 2004 compared to 2003, suggests that the effect of the fillslope became much less important after it became at least partially revegetated. Delivery associated with fillslope distances is greatest within the first 25 m, after that delivery decreases sharply. The same reasons given for the distance from the road not being significant apply to the fillslope.

The contributing areas that were included in the high and low sediment delivery groups for the treatment and control watersheds are shown in Fig. 6a and Fig. 6b. The distributions of the high and low contributing areas within the treatment watershed are related to the sediment sources within those contributing areas. For example, all the high group contributing areas within the treatment watershed contain silt fence sections which are downslope of the road fillslope. Areas 1, 2, 3, and 4 also contain silt fence sections that are below stream crossings, alluding to the influence from the stream crossings and their associated fills (Figure 6a).

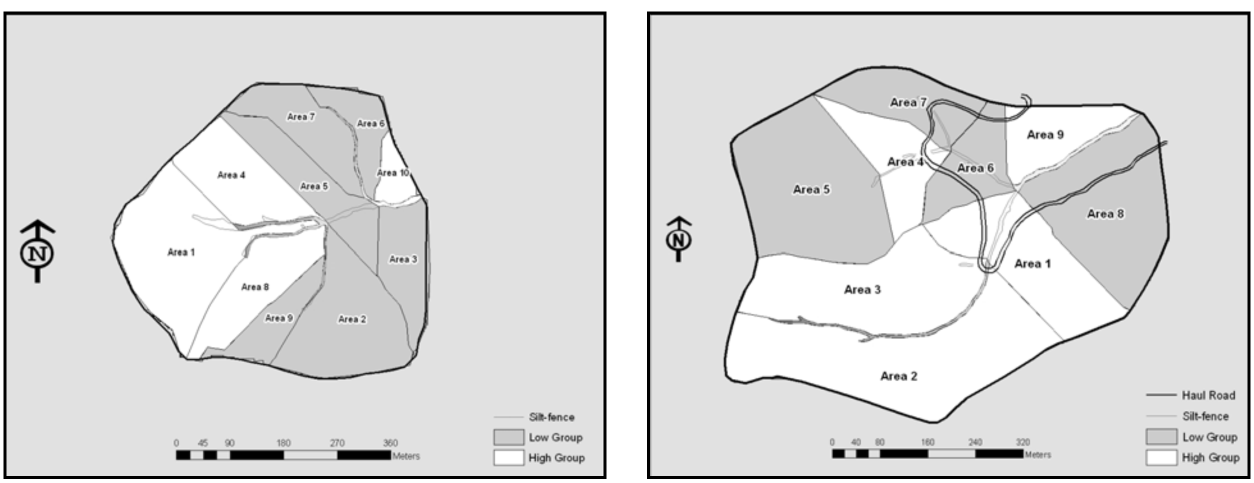


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Figure 6. Distribution of high and low contributing area subgroups within the control (a) and treatment (b) watersheds.

Table 1. Significance levels (P-values) of independent variables tested for explaining sediment delivery to the silt fence in the section-based analysis.

Year	Slope	Dist. Tree falls	Bare Soil Area	Dist. To Slopebreaks	Dist. To Animal Trails	Dist. To WDEFs	Dist. To Bare Soil	Tree Fall Soil Area	Dist. To Roads	Dist. To Fillslopes
Treatment Watershed										
2002	0.4792	0.1545	0.4043	0.2269	0.0868	0.8276	0.1064	0.6312	.	.
2003	0.3651	0.7022	0.105	0.3223	0.909	0.0365	0.0418	0.7993	0.1709	0.8898
2004	0.2124	0.0545	0.1126	0.5128	0.176	0.0002	0.0195	0.3917	0.6122	0.7385
2005	0.6354	0.0036	0.159	0.8866	0.2779	0.0027	0.3422	0.2306	0.9843	0.9801
Control Watershed										
2002	0.415	0.8825	<.0001	0.1325	0.5235	0.9272	0.0012	0.7921	.	.
2003	0.2143	0.5104	0.0016	0.2473	0.0045	0.9767	0.0025	0.9969	.	.
2004	0.2428	0.5204	0.0171	0.7167	0.6749	0.901	0.1136	0.7061	.	.
2005	0.0068	0.2911	<.0001	0.6751	0.081	0.4621	0.0001	0.9952	.	.

The distributions of the high and low contributing areas within the control watershed are also related to sediment sources that exist within the boundaries of each particular contributing area. Contributing areas 1, 4, and 8 are grouped around steep tributaries which have various major sediment sources including tree falls and bare soil areas. Contributing area 10 does not include a major tributary; however, it is steep, exceeding 30 degrees in some places, and contains numerous sediment sources including tree falls and areas of bare soil (Figure 6b).

The results for the contributing area analyses show how each variable was important to explaining sediment delivery for the low sediment group in the control watershed (Table 2). For the treatment watershed many, but not all, of the variables were also significant for the low sediment group. By contrast, many fewer variables were significant for the high group in both watersheds. In the control watershed, the significant variables were confined only to the distance and area variables for bare soil and tree falls. In the treatment watershed, only the distance to bare soil and distance to fillslopes were significant.

The RUSLE delivery prediction was calculated by multiplying the modeled GIS RUSLE estimate by 0.52 as recommended by Gianessi et al. (1986), where they stated that this was the estimated ratio for gross erosion to sediment delivery for West Virginia forestlands. Even with this correction, the soil loss predictions resulting from RUSLE were much higher than the actual sediment collected from the silt fences within both study watersheds. The RUSLE estimate for the treatment watershed was 2.68 tons per-acre per-year, while the RUSLE estimate for the control watershed was 2.86 tons per-acre per-year. These values are somewhat comparable to the estimate by Gianessi et al. (1986) for West Virginia forestlands of 2.07 tons per-acre per-year as interpreted by Hood et al. (2002). However, the treatment watershed actually produced 0.01, 0.02, 0.03 and 0.01 metric tons of sediment per-acre, respectively; while the control watershed produced 0.002, 0.001, 0.005, and 0.003 tons per-acre, respectively, for 2002 through 2005. The soil loss prediction was 134 times higher than the average mass collected for the treatment watershed and 953 times greater than the average mass collected from the control watershed. The prediction from the treatment watershed would also likely have been comparably high if it were not for the vast quantities of sediment contributed by the mechanical additions to the silt fence during road construction.

Discussion and Conclusions

The results from the ANOVA tests illustrates that many factors have an affect on the soil movement process to some degree and display patterns of increasing or decreasing affect with changes in their size and/or their distance to the stream for each topographical feature of interest. However, these variables were not always found to be significant even though they clearly display an indicative pattern of affect on hill-slope soil movement at various locations.

Overall, the average sediment yields from the two study watersheds, 0.007 tons/ha/yr for the control watershed and 0.049 tons/ha/yr for the treatment watershed, were considerably less than the 0.12 to 0.25 tons/ha/yr considered normal for undisturbed and carefully managed lands (Patric 1976; 1975). Additionally, the average sediment yielded from the treatment watershed in this study was less than the 0.15 tons/ha/yr recorded for a “no treatment” control watershed in a study by Kochenderfer and Helvey (1984) but more than the 0.016 tons/ha/yr yielded from a long undisturbed forested watershed as reported by Kochenderfer et al. (1987). Kochenderfer and Helvey (1984) also reported a rapid decrease in sediment yields following the end of logging treatments in the same study, similar to the findings of this study. Supporting the observations made during this study they attributed this decrease to the establishment of vegetation which stabilized the eroding soil. The majority of the difference in sediment yields between the control and treatment watersheds is likely attributable to the road construction

Table 2. Significance levels (P-values) for independent variables tested for explaining sediment delivery to the silt fence in the contributing area analysis.

Watershed Grouping	Slope	Dist. Tree falls	Bare Soil Area	Dist. To Slopebreaks	Dist. To Animal Trails	Dist. To WDEFs	Dist. To Bare Soil	Tree Fall Soil Area	Dist. To Roads	Dist. To Fillslopes
Treatment Watershed										
High	0.3321	0.4912	0.4345	0.7239	0.3916	0.2165	0.057	0.5494	0.3286	0.0754
Low	0.0532	0.3493	0.0022	0.0096	0.0095	0.8152	0.0139	0.007	0.5855	0.6297
Control Watershed										
High	0.1365	0.0361	0.0298	0.3411	0.1126	0.1967	0.0361	0.0361	.	.
Low	0.0002	0.0009	0.0594	0.026	0.0594	0.0155	0.0179	0.0119	.	.

treatments but some differences may simply indicate the differences between the two watersheds; as Kochenderfer et al. (1987) reported that the stability of stream channels and banks vary widely even among undisturbed watersheds due to differences in channel slopes, rock abundance, and stream sinuosity.

The poor performance of the RUSLE may be attributed to several factors, particularly the extensive spatial variability among sediment generations exhibited within these forested watersheds. Also, the RUSLE predicts only sheet and rill erosion (Hood et al. 2002) but excludes other types of erosion that may occur, such as gully erosion. The RUSLE overemphasizes sediment delivery, even though the sediment movement this study measured included mechanical fillslope additions that are typically not even measured (normally sediment measurements are made after road construction is completed, so that part of the sediment inputs would be missed), thus, for a "typical" erosion study, the overestimation by RUSLE would have been even greater.

Another shortcoming of the RUSLE is that it was initially designed for relatively flat, homogenous agricultural lands. Even with modifications for forested areas, applying the RUSLE to steep forested landscapes, similar to those used in this study and throughout the Appalachian region, probably reaches outside the realm of the predictive capabilities of these equations. Additionally, these forested watersheds consist of long (greater than 60.96 m), steep slopes covered with organic materials, which the RUSLE also is not well suited to consider in its parameter coefficients. The RUSLE relies on linearity of slopes and homogeneity of conditions, which are not present on these specific watersheds and generally do not occur in forested watersheds. Furthermore, the coefficients and mathematical form of the RUSLE have room for alteration to bring the predictions close to measurements; however, the sediment delivery ratio described by Gianessi et al. (1986) would require considerable modification to fit the existing conditions for these watersheds with the present form of the equation.

The results of this study illustrate that models to predict sediment delivery to streams must be able to include considerations of the non-uniform location of sediment sources, including giving more importance to those in close proximity to the stream or otherwise connected via water to the stream (e.g., cross drainage), as well the heterogeneity of the amount of sediment contributed by different sources. The predictions resulting from the RUSLE were highly overestimated and provide little insight into soil loss or the processes involved. Modifying the input variables of the RUSLE may reduce the predictions somewhat, but the equation still lacks the ability to be widely applicable and in all probability would need calibrated for every forested watershed to which it would be applied. The lack of accuracy without significant intervention from the user makes the effectiveness of the RUSLE questionable when applying it to entire forested watersheds within the Appalachian region.

Peak sediment delivery occurred during and directly after the haul road construction process. The majority of sediment came from the road fillslopes located just downslope of the stream crossings. Sedimentation in the two study watersheds was dominated by a few definable primary sources within each study watershed. That is, within the treatment watershed, the primary sediment sources were identified as the fillslopes associated with the roads, primarily the fillslopes which were close to stream crossings (<25 m), and the bare soil areas ≤2 m of the stream channel. The primary sediment sources within the control watershed are, similarly, the largest areas of exposed soil within that watershed, the soil associated with tree falls (typically <4 m), and the bare soil areas (< 2 m).

Regarding the RUSLE, modeling soil erosion in forested watersheds remains a difficult task. The RUSLE estimated sediment delivery poorly in both the control and treatment watershed. Sediment delivery was overestimated by 134 times and 956 times in the treatment and control watersheds, respectively. If it were not for the mechanical sediment addition within the treatment watershed the overestimation would have been likely as high as or higher than the control. The RUSLE is an overly simplistic model for complex forested terrains where there are highly heterogeneous surface and slope conditions and complex erosion processes that are dominated by discrete sediment sources. Consequently, prediction models that are overly simplistic and assume homogenous environments within forested watersheds will likely predict sediment delivery poorly.

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