The Society for engineering in agricultural, food, and biological systems

An ASAE Meeting Presentation

Paper Number: 052016

Application of WEPP to a Southern Appalachian Forest Road

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Written for presentation at the
2005 ASAE Annual International Meeting
Sponsored by ASAE
Tampa Convention Center
Tampa, Florida
17 - 20 July 2005

Abstract. *Forest roads can be major sources of sediment and soil erosion from southern Appalachian Mountain watersheds. Sediments from forest roads are a concern due to their potential delivery to stream systems resulting in degradation of water quality. Prediction of sediment yields from forest road components can provide valuable information in planning, locating, and maintaining road systems to reduce erosion potential. This paper reports an application of the WEPP (Water Erosion Prediction Project) model to cut- and fillslopes during the post-construction and establishment period for an access road constructed in 1995. The WEPP predictions of sediment yield from cut- and fillslopes with two vegetation treatments and an untreated (bare soil) condition were compared to yields observed from replicated erosion control plots over an 8-year period. The rate of soil loss was greatest during the first year and decreased thereafter for treated cut- and fillslopes. Average annual sediment yield was overpredicted for the untreated cutslope which resulted in a somewhat lower model efficiency (ME=0.51) than for the treated cutslope (ME=0.92). The overprediction of the untreated cutslope sediment yields is attributed to accelerated losses observed in the field experiment during the first three years which removed most of the soil available for transport. In contrast, predicted average annual sediment yield was in close agreement with the observed values for the vegetation treatments for both slope types. Model efficiencies ranged from 0.51 to 0.92 for the cutslope and 0.53 to 0.99 for the fillslope. These relatively high model efficiencies indicate that the model adequately describe sediment yields observed in the field experiment.*

Keywords. WEPP, Modeling, Sediment Yield, Erosion, Appalachians

Introduction

Soil erosion and sediments from forested watersheds are a concern due to their potential delivery to stream systems resulting in degradation of water quality. The road corridor (Figure 1) is frequently cited as a major source of sediment and soil erosion on the forest landscape (Brinkley and Brown, 1993; Grace, 2005). All components of the road corridor have increased potential for accelerated soil losses due to cover conditions, concentration of flow, increased slopes, etc. (Grace, 2005). In southern Appalachian Mountain watersheds, graveled and unsurfaced roads have been identified as accounting for 80 percent of sediment sources (Van Lear et al., 1997). Controlling soil erosion and sedimentation from forest roads in this region will likely require a reliable tool to identify problem areas and provide better understanding of processes that accelerate erosion.

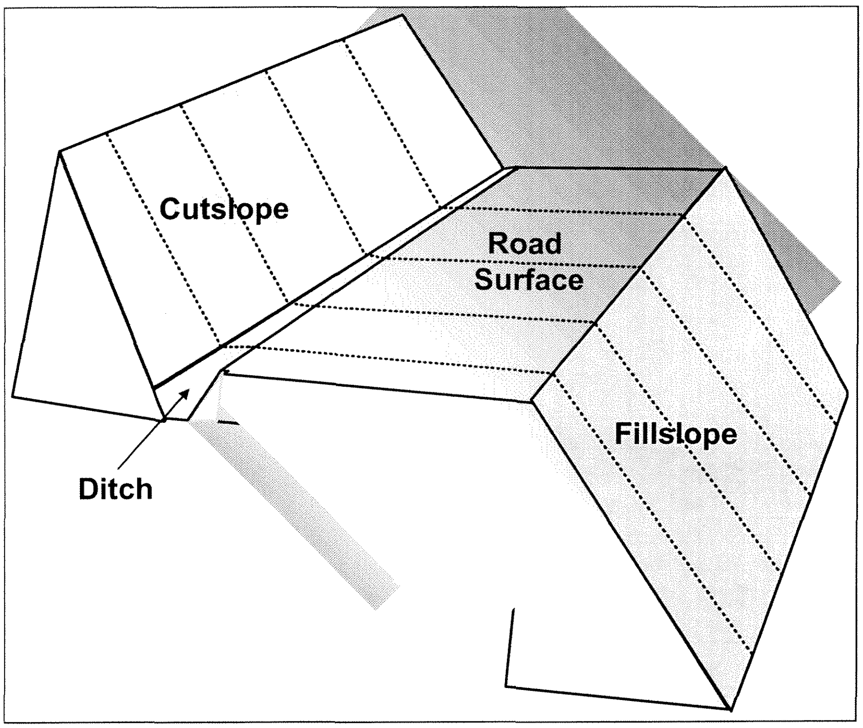

Figure 1. Illustration of a typical road corridor for a mid-slope half-bench crowned road including the cutslope, fillslope, ditch, and road surface.

The need to develop a tool that can be used to aid forest managers in planning or evaluating forest road operations has been cited since the early road erosion work in the 1950's (Haupt, 1959; Megahan and Ketcheson, 1996; Packer, 1967; Swift, 1986; Trimble and Sartz, 1957). In recent years, several models have been presented which could have application with further development; USLE, RUSLE, WEPP, and SEDMODL. The Water Erosion Prediction Project (WEPP), perhaps the most robust model for road erosion prediction at this time, consists of a physically based soil erosion model (Laflen et al., 1997; Flanagan and Nearing, 1995) with a climate generator and a user-friendly shell with file builders. The WEPP model uses physically based input to estimate infiltration, interrill erosion, rill erosion, runoff, and sediment yield (Flanagan and Livingston, 1995). The model has several output options and a number of typical forest application input files, including road templates (Elliot and Hall, 1997; Elliot et al., 1994). The model has been validated for insloped roads in the Rocky Mountain Region (Tysdal et al., 1997; Elliot and Tysdal, 1999). WEPP predictions for insloped road erosion were within the range of observed data from road erosion plots. WEPP predictions of cross drain spacings have also been validated with predictions slightly less than observed data (Morfin et al., 1996; Elliot et al., 1998).

Objectives

Field data were collected from forest road sideslopes under varying levels of treatment and cover conditions over an 8-year study period. The objective of this paper was to apply WEPP to a southern Appalachian road sideslopes and validate predictions with data from the field experiment. The benefit of this exercise is to assess the applicability of WEPP in predicting soil erosion from southern Appalachian road sideslopes. This application would be useful in evaluating WEPP as a tool for estimating soil erosion from similar forest roads in the region.

Methods

Field data were collected from a road sideslope study in the southern Appalachian Region conducted from September 1995 – December 2003. The study site is located at approximately 33° latitude and 85° longitude on the Talladega National Forest in Cleburne County near Heflin, Alabama. The study road was constructed as a mid-slope half-bench crowned road during the summer of 1995. Soils were of the Tatum series, a fine-loamy mixed-thermic Typic Hapudult. The soil profile features 0.10 m thick silt loam surface soil overlaying clay loam subsoil.

Sediment yield was collected from 24 plots, each 1.5 x 3.1 m, from September 1995 to January 2003. Three replications of four treatment levels were evaluated on each of a 2.2:1 cutslope and a 1.5:1 fillslope over the study period. The four levels of treatment in the randomized complete block design, ranging from passive to aggressive erosion control techniques, were a bare (untreated), exotic vegetation mixture (vegetation 1), native vegetation mixture (vegetation 2), and exotic vegetation (vegetation 1) in combination with an erosion control mat. Vegetation 1 consisted of Kentucky 31 fescue (*Festuca arundinacea*), Pensacola bahiagrass (*Paspalum notatum*), annual lespedza (*Lespedza cuneata*), and white clover (*Trifolium repens*). Vegetation 2 consisted of big bluestem (*Andropogon gerardii*), little bluestem (*Andropogdon scoparius*), and Alamo switchgrass (*Panicum virgatum*). Detailed descriptions of vegetation species, seed mixtures, and application rates have been reported by Grace (2002). The three levels of treatment, a total of 9 study plots on each slope type, modeled in this application were the untreated condition, vegetation 1, and vegetation 2 treatment conditions.

Study plots were bound on three sides by 20-cm high borders to isolate treatment areas from the surrounding slope. At the outlet of the treatment areas, a collection gutter routed plot runoff to a 130-L sediment tank. Prior to August 1999, the frequency of data collection events ranged from 1 to 12 weeks depending on the time required to fill sediment tanks. Data collection procedures during the initial 4-year period have been detailed by Grace (2002). In August 1999, study plots were set-up for long-term monitoring by replacing sediment tanks with 1-micron sediment bags. Sediment bags were collected bi-annually for each plot and were a composite of several storm events. Collected sediment bags were transported to the laboratory and oven-dried at 105°C to a moisture content of 1 percent or less (dry basis).

Precipitation was primarily recorded by an on-site gauge during the 8-year study period. Precipitation data included total accumulated precipitation amounts, storm intensity, and storm duration. During periods of missing precipitation due to rain gauge malfunction, daily precipitation amounts were obtained from the Anniston weather station located 15 km west of the study site.

Modeling Procedures

The WEPP model requires input including climate, soil, slope, and management files. The WEPP climate generator (CLIGEN, Version 5.2) was used to create a 50-year climate input file for Heflin, AL. The clay loam cutslope and silt loam fillslope soils were used to characterize the soils on the cutslope and fillslope. The slope file was developed as a uniform 45 percent and 67 percent slope for the 3.05 meter cutslope and fillslope, respectively. Management files were created for the untreated slopes (bare soil) and each vegetation treatment based on initial conditions and percent cover measurements for each of the eight study years (Table 1).

Table 1. Percent cover observations of road sideslope treatments during the 8-year period following construction and application.

	Cutslope			Fillslope		
Year	Untreated	Vegetation 1	Vegetation 2	Untreated	Vegetation 1	Vegetation 2
1	0	57	80	0	47	61
2	0	93	97	23	97	88
3	6	78	69	11	77	81
4	8	82	100	52	93	100
5	16	73	92	87	100	100
6	55	80	98	98	100	100
7	55	83	98	100	100	100
8	55	83	98	98	100	100

The management condition for the untreated slopes was initialized as immediately following tillage with no canopy cover during the first year. Subsequent years were initialized with observed data from the field study to characterize management conditions. Both vegetation treatments initial conditions were set as immediately following tillage; however, initial cover was provided by mulch applied to facilitate vegetation establishment and reduce soil loss.

Evaluation of goodness-of-fit

Model "goodness-of-fit" evaluates a model's ability to provide an accurate representation of a real world situation. That is, "goodness-of-fit" provides information on how successful a model is in meeting the objective of accurately describing observed phenomenon. Model "goodness-of-fit" was evaluated in this application by comparing observed average annual sediment yield values with predicted average annual sediment yield over the study period with a "goodness-of-fit" statistic, model efficiency (ME), presented by Nash and Sutcliffe (1970).

Model efficiency was calculated to evaluate accuracy of model predictions of annual sediment yield for the untreated condition and vegetation treatments for each of the 8 study years. Model efficiency was determined as:

$$ME = 1 - \frac{\sum_{i=1}^{n}(Q_o i - Q_p i)^2}{\sum_{i=1}^{n}(Q_o i - \overline{Q}_o)^2}$$

Where $Q_o i$ = observed annual sediment yield, $Q_p i$ = predicted annual sediment yield, $\overline{Q}_o$ = mean of observed annual sediment yield, and n = number of observed values (n = 24). The ME coefficient approaches unity as the difference in predicted and observed values approach zero. That is, perfect agreement between predicted and observed values would result in a ME = 1.

Results and Discussion

WEPP simulations were made for the untreated condition, vegetation 1, and vegetation 2 treatments on the cut- and fillslope for the eight years included in this study. Average annual mean sediment yield for each treatment was determined for the cutslope and fillslope (Figure 2). Predicted average annual sediment yield based on 50-year simulations for each of the eight study years were compared to observed sediment yield from the field experiment. Predicted average annual sediment yield for the untreated cutslope was 10 t ha^{-1} yr^{-1} greater than the observed values (P=0.01) based on paired t-test on the observed and predicted means. No difference (P=0.09) was found between predicted and observed fillslope average annual sediment yields with means of 8.6 and 9.8 t ha^{-1} yr^{-1}, respectively (Figure 2). Similarly, predicted average annual sediment yields for vegetation 1 and vegetation 2 treatments were similar to observed values on both the cut- and fillslope over the 8-year period (Figure 2).

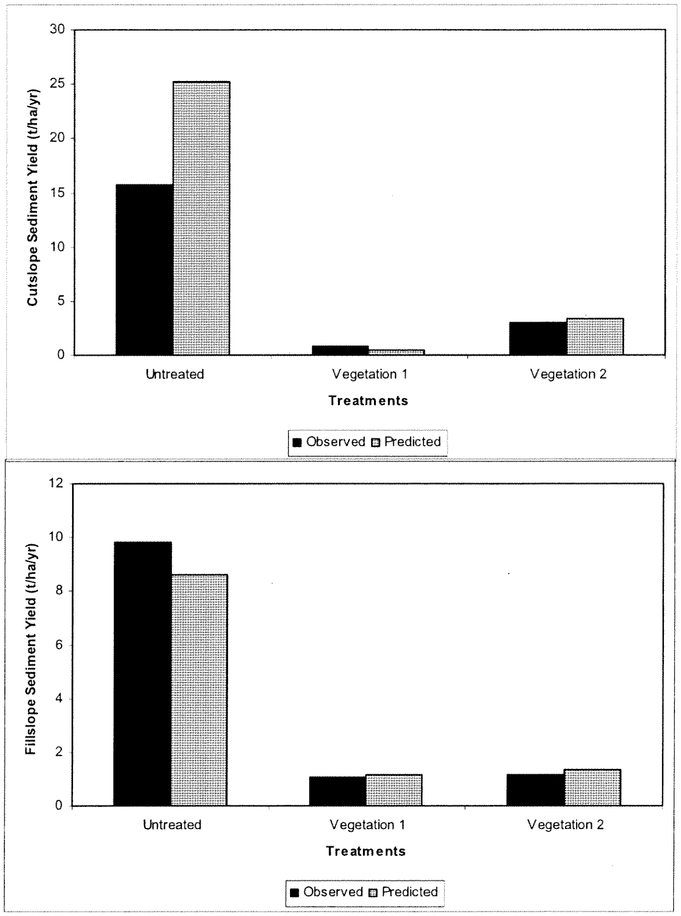

Figure 2. Average annual sediment yield observed and predicted by WEPP for untreated and vegetated road cutslope (top) and fillslope (bottom).

Cumulative sediment yield plots for the cutslope and fillslope illustrate the sediment yield differences in simulated and observed yields for the untreated condition (Figure 3). Cumulative sediment yield predictions were similar to observed sediment yields during the first two study years. However, during the third year predicted sediment yield for both the cut- and fillslope began to diverge from observed yield for the untreated condition. The divergence in sediment yield was small on the fillslope and, as stated above, did not result in a significant difference in average sediment yield over the period. The divergence on the cutslope; however, did result in a difference between predicted and observed annual sediment yields for the untreated condition. During the fourth year observed cutslope sediment loss for the untreated condition decreased to 9.5 t/ha/yr and had decreased to 1.2 t ha^{-1} yr^{-1} by the end of the study (year 8) (Figure 3). Whereas, WEPP predictions of the untreated cutslope sediment yield continued at 20 t ha^{-1} yr^{-1} during this five year period (years 4-8).

The difference in observed and predicted cutslope sediment yield during these years is likely a result of differences in the amount of sediment available for erosion due to the removal of easily transported sediment from the cutslope surface. That is, during the first three years of the field experiment the majority of the cutslope surface soil was eroded away leaving only larger particles and rocks. However, WEPP predictions did not account for this depletion of source sediment from the cutslope surface. This hypothesis seems to be supported by the fact that the sparse cover, less than 20 percent during the first 5 years, on the untreated cutslope (Table 1) gave minimal protection and sediment yield reductions. Therefore, the reductions in sediment yields observed during years 3-6 were likely due to a depleting source of sediment that could be easily detached and transported.

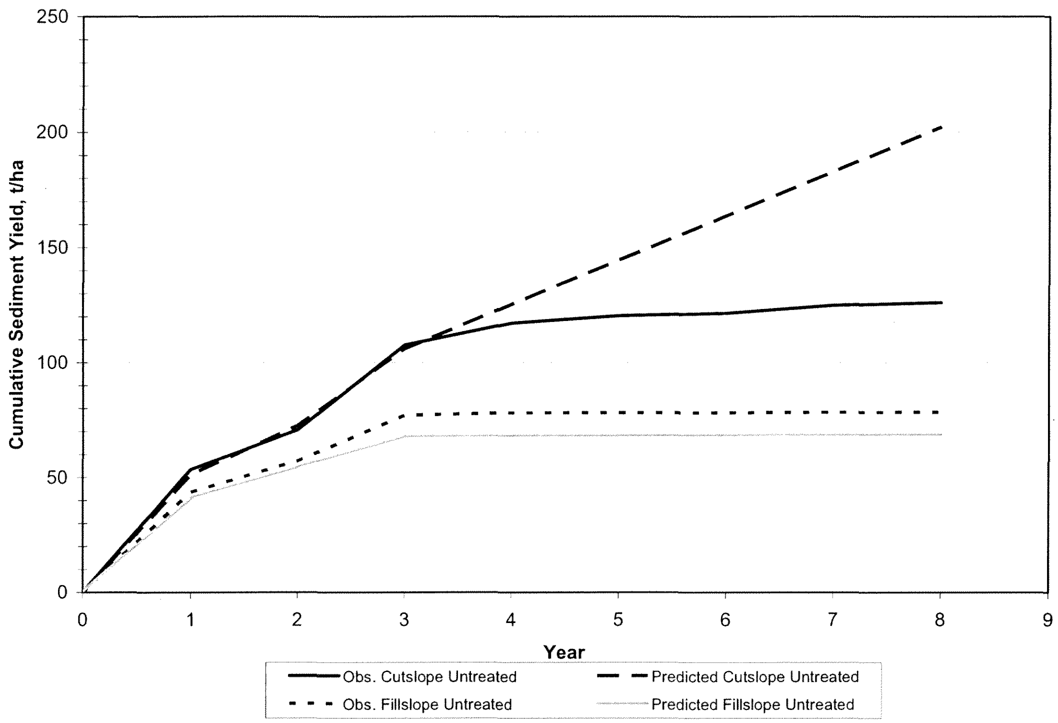

Figure 3. Cumulative sediment yield for observed and predicted by WEPP for untreated cutslopes and fillslopes.

Observed cumulative sediment yield for the vegetation treatments exhibited diminishing yields for each year following the initial establishment (year 1). WEPP predicted the diminishing pattern in sediment yields for both vegetation treatments used in the simulation (Figures 4 and 5). Predictions were also in close agreement during the first year for vegetation 2 with agreement within 3 t ha^{-1} yr^{-1} for both slopes. The accuracy of predictions during the first year was likely influenced by the characterization of the management in the model during this establishment year. That is, the characterization of the ryegrass and mulch cover in this forest road sideslope application. The cover during the first year was primarily a function of the *ryegrass cover crop and straw mulch which may not have been optimally described in the* WEPP management file. Despite possible insufficiencies in describing the cover on the cutslope and fillslope, predictions were in agreement with observed sediment yields over the entire period.

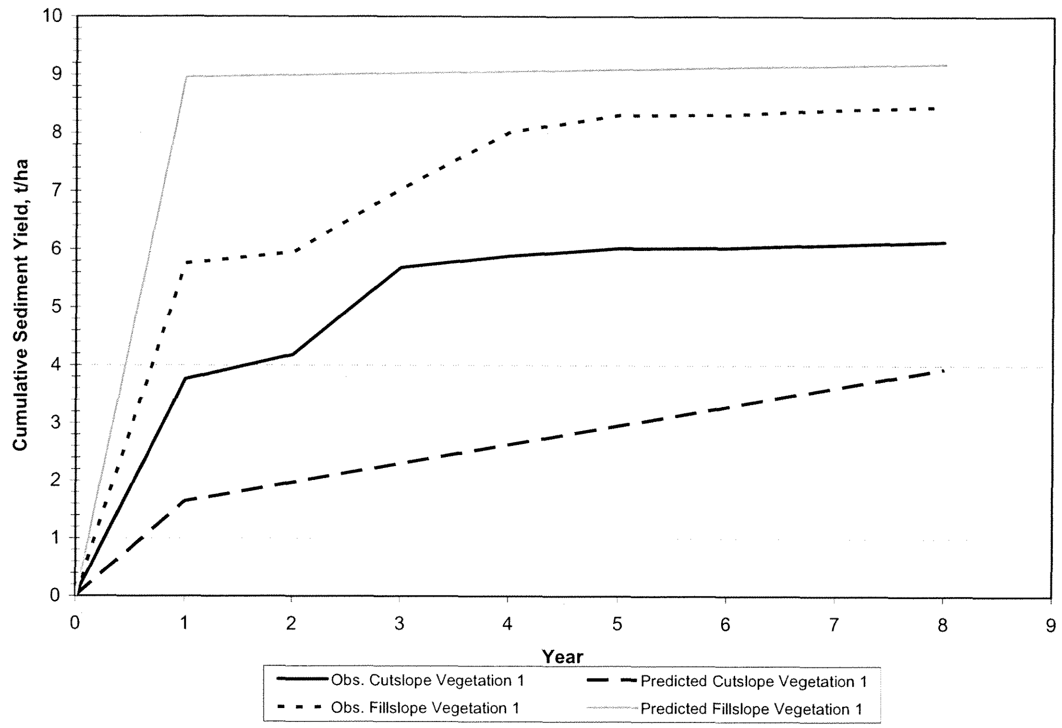

Figure 4. Cumulative sediment yield for observed and predicted by WEPP for Vegetation 1 cutslopes and fillslopes.

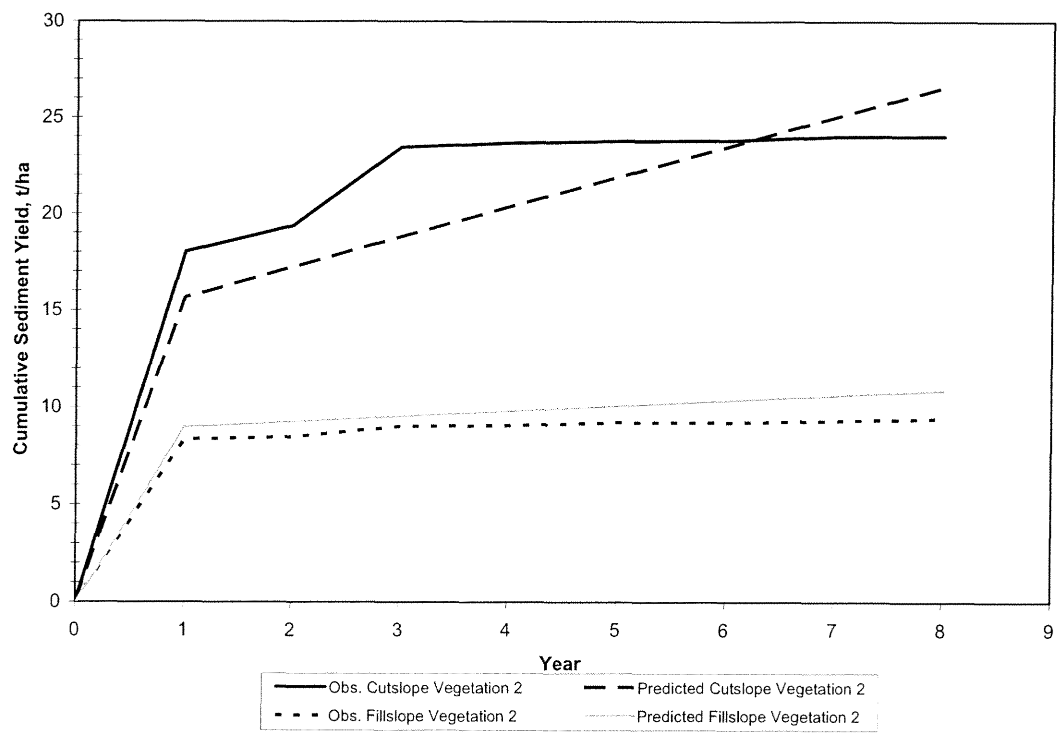

Figure 5. Cumulative sediment yield for observed and predicted by WEPP for Vegetation 2 cutslopes and fillslopes.

Average model efficiencies in sediment yield prediction ranged from 0.51 to 0.92 for the cutslope and 0.53 to 0.99 for the fillslope. The model was most efficient in predicting sediment yield from vegetation 2 which exhibited the upper limit of ranges for the cutslope and fillslope (ME =0.92 for the cutslope; ME=0.99 for the fillslope). In contrast, the efficiencies for vegetation 1 predictions were the lower limit for model efficiency ranges (ME =0.51 for the cutslope; ME=0.53 for the fillslope). The untreated condition predictions showed close agreement with observed sediment yields with a ME=0.97 for the fillslope predictions. In general, model predictions were in agreement with observed annual average sediment yields with the exception of the untreated cutslope condition.

Conclusions

WEPP was applied to cutslope and fillslope erosion control plots representing an untreated condition and two vegetation treatments from a field experiment in the southern Appalachians. Model efficiencies ranged from 0.51 to 0.92 for the cutslope and 0.53 to 0.99 for the fillslope. The relatively high model efficiencies indicate that the model adequately describe average annual sediment yields observed in the 8-year field experiment.

Predicted average annual sediment yield was similar to observed values for all fillslope treatment scenarios. Predicted sediment yields for vegetation treatments were also in agreement with observed sediment yields over the 8-year study period. However, analysis revealed that average annual sediment yield predictions for the untreated cutslope was 10 t ha^{-1} yr^{-1} greater than the observed sediment yield. This difference was primarily due to greater predicted sediment yields during the last 5 years for the cutslope untreated condition. In general, predicted cumulative sediment yield followed the same trends as observed cumulative sediment yield over the period for all except the cutslope untreated condition.

Acknowledgements

The author wishes to acknowledge the efforts and assistance of Preston Steele in collecting the eight years of field experiment data used in this application. The author acknowledges the National Forests of Alabama for their administrative support and cooperation in this research.

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