Applying the WEPP Erosion Model to Timber Harvest Areas

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Abstract

Disturbed forest lands are prone to increased erosion. Predicting the effects of timber harvest on surface hydrology and erosion is difficult. Hydrologic models have been developed for agricultural conditions, but they may not be valid in forests. The WEPP model, a process-based erosion model under development, may have limi-tations in modeling erosion in timber harvest areas. Field research has shown that timber harvest area soil properties may vary widely. However, the range of variation observed in the Southeastern United States is similar to the range observed in the Northern Rocky Mountains. The WEPP model accounted for differences in erosion due to management and climate. Initial simulations with the model may be overpredic-ting runoff due to summer storms in the Northern Rockies. A model that better des-cribes the unique attributes of this region's upland hydrology may be needed. Addi-tional research is also needed for modeling the large spatial variability observed in timber harvest areas.

Introduction

The USDA Forest Service's mission "is to achieve quality land management under the sustainable multiple-use management concept to meet the diverse needs of people." One aspect of this mission is minimizing the offsite impacts of any activity or operation.

Sediment can harm critical fish spawning areas, and can generally degrade upland stream habitats. Determining the sources of upland sediment, and methods to reduce erosion, have been a major management concern and research activity.

The Water Erosion Prediction Project (WEPP) soil erosion model is being developed by an interagency group of scientists including the U. S. Department of Agriculture's Forest Service, Agriculture Research Service, and Natural Resource Conservation Service, and the Department of Interior's Bureau of Land Management and U. S. Geological Survey. Over 100 scientists from these agencies, and from universities

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throughout the United States and abroad have been working since 1985 to develop WEPP. It may replace the Universal Soil Loss Equation (USLE) now commonly used to predict soil erosion.

The WEPP model is physically based, so it is more easily transferred to a wider range of conditions than are empirical models like the USLE. One of the research problems we study is determining the suitability of the WEPP model to predict erosion on timber harvest areas. Field experiments are being carried out to provide calibration and validation data for the WEPP model. This paper presents some results of the field work and validation studies, and indicates the direction of future research in modeling soil erosion and hydrology in timber harvest areas.

Harvest Area Practices

Forest managers are using an ecosystem approach to manage their resources. Ecosystem management:

> "... ensures that stewardship of lands and resources is accomplished in an environmentally sensitive, socially responsive, and scientifically sound manner. It enables resource managers to view natural resources from a landscape or whole system perspective. It integrates the human, biological and physical dimensions of natural resource management to promote healthy, productive, and sustainable forest and rangeland ecosystems." (USDA Forest Service, 1994)

Ecosystem management may mean converting intensively managed stands to more natural conditions. Practices to accomplish ecosystem management may include increased use of partial cuttings, where only a portion of the trees are removed. Some past management activities, such as fire suppression, increased the risk of catastrophic fires. Prescribed fires now play a significant a role in maintaining a healthy forest, while meeting management objectives (Reinhardt et al., 1994). Burning post-harvest residue is another common method of fire hazard reduction and site preparation. Burning is conducted alone, and in combination with other treatments, to dispose of slash, reduce the risk of insects and fire hazards, prepare seedbeds, and suppress plant competition for both natural and artificial regeneration.

Harvest Area Hydrology

Forest practices can have significant effects on local hydrology. Understanding of the relationship between rainfall, runoff, and erosion is essential in developing models for any natural system. Dunne (1978) describes two processes creating overland flow: Horton overland flow and saturation overland flow. Either process may potentially occur in forest harvest areas.

Horton overland flow occurs when the rainfall intensity is greater than the infiltration capacity of the soil. Horton overland flow seldom occurs in undisturbed for-ests. Soil disturbance by forest practices may reduce infiltration capacities, allowing Horton overland flow to occur under high intensity precipitation. These practices include removing the organic forest floor layer by fire and compacting the soil surface by harvesting equipment.

Disturbances within forest harvest areas are generally patchy, making it difficult to model Horton overland flow processes. Springer and Cundy (1988) describe how high spatial variability of infiltration capacity can affect runoff and erosion. Compac-ted areas or severely burned areas may produce runoff through the Horton overland flow mechanism, but often they drain to less disturbed areas having high infiltration capacities where the surface flow ceases. Input files to the WEPP model do not read-ily describe the variation in forest hillslope hydrologic properties. Consequently, the effective or aggregate behavior of a hillslope as an homogenous unit must be deter-mined before the WEPP model can be used.

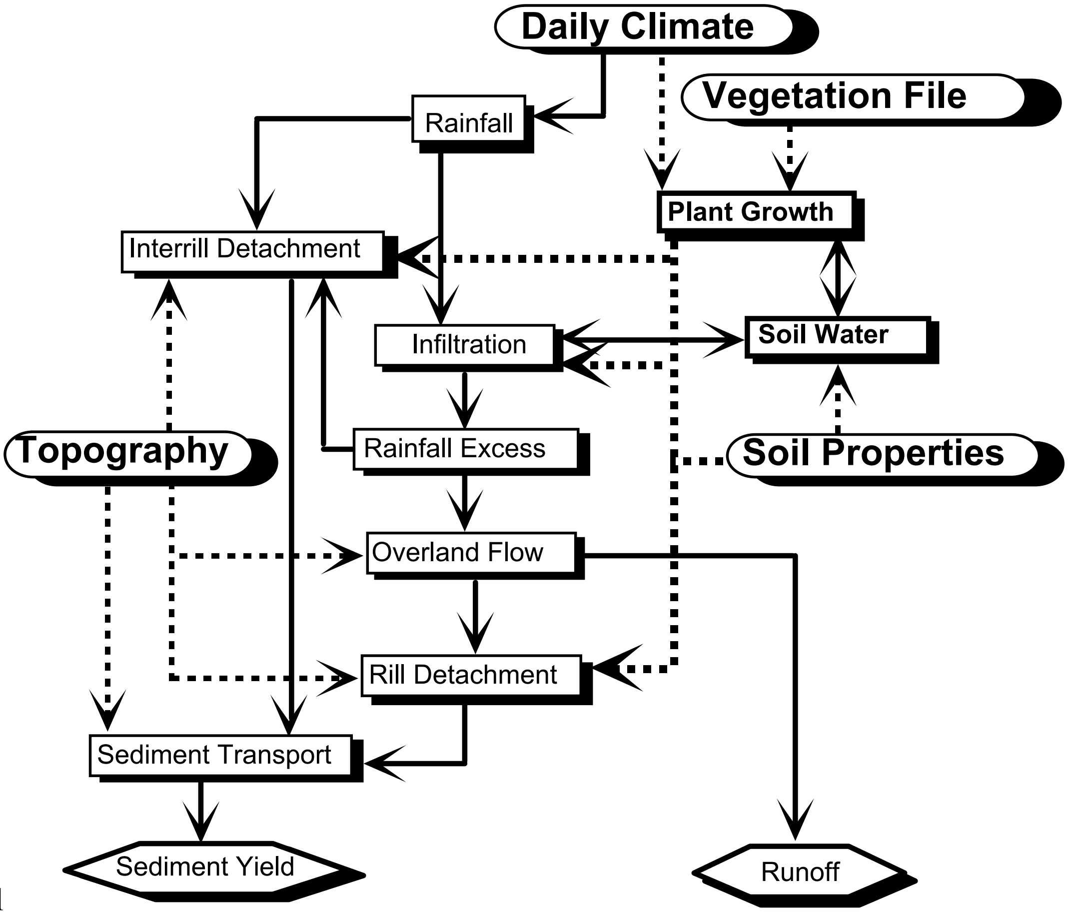
Saturation overland flow occurs when precipitation falls on soils saturated by lateral subsurface flow. Water seeping back to the surface and direct precipitation onto the saturated soils become overland flow. Saturation overland flow is most often a result of local topography and long-duration, low-intensity precipitation or sustained snowmelt. Saturation overland flow can occur on soils with high infiltration capa-cities due to hillslope geometries that concentrate water, such as hillslope draws.

Saturation overland flow is the most common process producing overland flow in undisturbed forest areas. Reducing the soil's ability to carry subsurface water downslope by removing the forest floor and compacting the soil can increase satur-ation overland flow. When considering the overall behavior of a hillslope in a forest harvest area, saturation overland flow should be considered.

The WEPP model does not model saturation overland flow processes. It will predict increased runoff due to increased soil water content using the Green-Ampt infiltration model, but will not reduce infiltration to zero under saturated conditions. The planar hillslope geometry used by the WEPP model will not allow the conditions leading to saturation overland flow to be described accurately. Identifying circum-stances where the WEPP model may or may not work for estimating sediment produc-tion from harvest areas is important. This requires determining whether Horton or saturation overland flow dominates the erosion process for an area.

Differences in the climates of the Southeastern United States and the Northern Rockies provides an example of how climate can determine dominant runoff behavior. Storms in the Southeast include strong wet flows from the Gulf of Mexico, delivering frequent, high-intensity precipitation. Storms in the Northern Rockies are typically of low-intensity but long-duration. Snow melt events also tend to be of long duration and low intensity, with intensities seldom greater than a few mm/h. One would expect Horton overland flow to play a more important role in runoff in the Southeast than in the Northern Rockies.

The WEPP



Model

Figure 1. Outline of WEPP Model

The WEPP model is a complex computer program that describes the processes that influence erosion (Fig. 1). These processes include infiltration and runoff; soil detachment, transport, and deposition; and plant growth, senescence, and residue decomposition. The model has a daily time step to calculate soil water content in multiple soil layers and plant growth and decomposition. The effects of management activities and soil consolidation are also modeled (Laflen et al., 1991). One of the major benefits of a process-based model is that sediment yield can more readily be predicted. This is important for predicting the effects of erosion on water quality. In addition, the model can more easily be used in different areas where soils, climate, and vege-tation may vary widely. The WEPP model was released in 1989 for scienists to begin validation studies. In 1991, a version was released, incorporating numerous improvements, correcting errors in earlier code, and including a file builder. The entire code was rewritten. In 1994, the recoded version was released for a year of validation and field testing by scientists before the model's release to the public. All of these releases were a "Hillslope" version, which restricted the user to modeling topographies that could be described by a hillslope profile. A "Watershed" version which links hillslope elements, channel elements, and impondment elements is being released in 1995.

Field Studies

Several studies have been completed and others are ongoing to develop the para-meters needed to model runoff and sediment production from timber harvest units. These studies address different harvesting methods, fire severity, and spatial vari-ability associated with these treatments. Simulated rainfall events were used to deter-mine infiltration and erodibility parameters. Natural rainfall on both large hillslope plots and small watersheds is being used to validate the erosion parameters and the model's overall performance for forest conditions.

Previous studies by Robichaud and Waldrop (1994) and Robichaud and Shahlaee (1991) indicate a large variation in runoff and sediment production between and within timber harvest units. This variation is attributed to differences in surface conditions throughout the timber harvest unit (due to management activities) and to natural variation in soil characteristics. Management activities include designated and single-use skid trails, low- and high-severity burned areas, and unburned areas, as well as mitigation measures such as grass seeding. Robichaud et al. (1993) suggest that the variety of surface conditions found in harvest units could be reduced to two or three categories for modeling purposes, based on the severity of disturbance. Add-itional field observations suggest that only three or four categories may be needed.

In the small plot studies, simulated rainfall events were applied to hydrologic-ally undisturbed timber harvest sites to 0.5 to 1 m^2 plots with a USDA Forest Service oscillating nozzle rainfall simulator. Each plot received three 30-min rainfall events. Event 1 was conducted at the existing soil water condition. The plot was then covered with a plastic tarp. Event 2 was conducted the following day. Event 3 was conducted about 30 minutes after Event 2. Timed runoff samples were collected, weighed, and oven-dried to develop hydrographs, sedigraphs, total runoff volumes, and sediment yields. Hydrographs were analyzed using the methods of Luce and Cundy (1994) to obtain infiltration parameter values.

Interrill erodibility parameters were calculated from a modified version of Laflen et al.'s (1991) sediment delivery equation, which is a function of applied rainfall, rain-fall excess, canopy, ground cover, and slope adjustment factors. Robichaud et al. (1993) suggest that in a forest environment, interrill erodibility and the cover factor should be analyzed as one factor, because management conditions affect both the percent ground cover and physical disturbances of the soil.

Results of studies in the Southern Appalachian Mountains are summarized in Table 1, where tractor logging with skid trails is a common method of timber harves-ting. Skid trails have the highest erodibility and lowest hydraulic conductivities. The calculated parameters indicate the extremes for a given soil type. The inherent vari-ability in the soil properties and forest floor characteristics add to the variation from management activities.

Rainfall simulation experiments in the northern Rocky Mountain states include skidder-logged and sky line-logged timber harvest systems. Studies have been con-ducted on soils ranging from fine-grained volcanic ash-capped (Robichaud et al. 1994) to coarse-grained metamorphic derived soils. A summary of soils and calculated parameters from the Northern Rocky Mountains is shown in Table 2.

Table 2. Summary of soil physical properties and calculated parameters from the rainfall simulator experiments in the Northern Rocky Mountains.

Soil class	Soil type	Parent material	Sand (%)	Silt (%)	Clay (%)	Saturated hydraulic conductivity (mm/hr) Skid Trail	Saturated hydraulic conductivity (mm/hr) Undisturbed	Interrill erodibility * Ground cover factor (kg s/m^4) * 1000 Skid Trail	Interrill erodibility * Ground cover factor (kg s/m^4) * 1000 Undisturbed
Typic Vitrandepts	fine loamy	gneiss w\ ash cap	24	68	8	13	38	305	109
Typic Vitrandepts	fine loamy	gneiss w\ ash cap	28	61	11	22	65	860	144
Un-classified	coarse loamy	transition gneiss/ granite	66	28	6	28	87	1912	131
Typic Crychrept	fine loamy	basalt	35	40	25	4	87	2792	10

In addition to small-plot field studies, larger plots have been established to study erosion from natural rainfall. Because of the unpredictability of the natural climate, several years of data are necessary to evaluate a model. Robichaud and Waldrop's (1994) small-plot data suggest that the optimized saturated hydraulic conductivity cal-culated from small plots needs to be reduced by a factor of 10 to determine an effective hydraulic conductivity when the WEPP model is applied to large plots (22.5 m^2). This reduction is necessary because of greater spatial variability of soil properties, depressional storage, and ground cover on larger plots.

Measurements taken from a small watershed (about 3 ha) near McCall, Idaho, are presented in Figure 2. The daily precipitation depth is plotted only for days with one-min rainfall intensities greater than 25 mm/h, which was the median observed sat-urated hydraulic conductivity of bladed skid roads, the disturbance yielding the lowest infiltration capacity. The most noticeable aspect of these data is that all of the runoff is during the spring snowmelt period. No runoff is recorded from the high-intensity summer thunderstorms. Snowmelt intensity rarely exceeds 10 mm/hr, and should be less on this north-facing watershed. The surface hydrology and erosion of this sys-tem appears to be driven by saturation overland flow. About 120 kg of sediment were trapped from the one runoff period before the sediment trap was filled, which was about three days into the two-week runoff period. Data collection from this water-shed, and six others, will continue for several more seasons to obtain a range of validation conditions

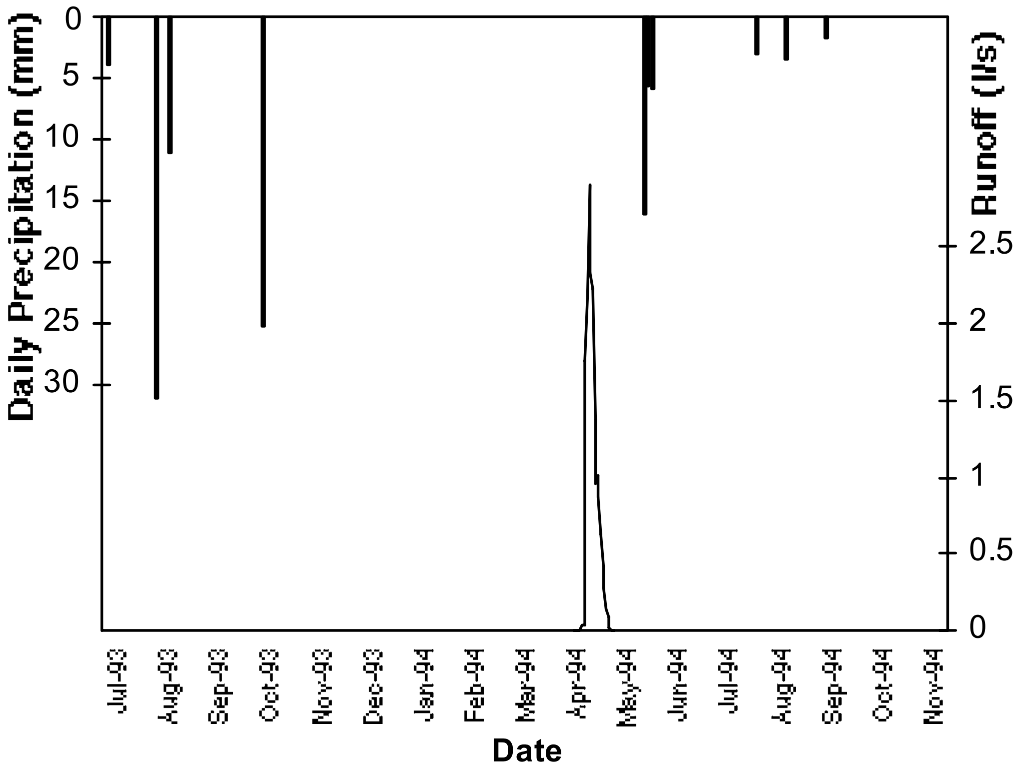


Figure 2. Distribution of storms with 1 minute intensities greater than 25 mm/hr and Runoff on Idaho watershed.

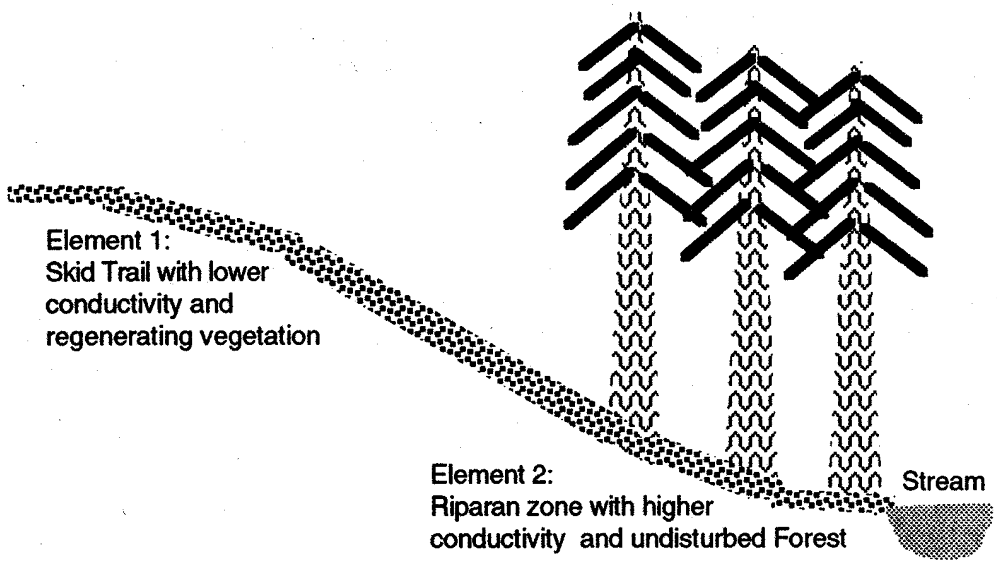


Figure 3. The two overland flow element model of a skid trail with riparian zone.

WEPP Predictions

The WEPP model was set to describe three watershed conditions common after har-vest, a severe burn scenario that assumed the site was burned to the bottom of the slope, a skid trail to the bottom of the slope, and a skid trail with a 30-m wide riparian zone at the base of the hill, using two overland flow elements (Figure 3). In all scen-arios, it was assumed that during Year 1, the site was undisturbed forest, during Year 2 a fire occurred in July in one scenario, and a skid trail was formed in July in the others. During Years 3, 4, 5, and 6, vegetation was regenerating, increasing the amount of canopy and surface litter. Two climates for both scenarios were generated with the CLIGEN climate generator provided with the model (Nicks and Lane, 1989). The Northern Rockies climate was based on Deadwood Dam in Idaho, a climate typical of the environmentally sensitive South Fork of the Salmon River watershed. The Southeast climate was based on Cullowhee, North Carolina, typical of the South-ern Appalachians. The slope length was 200 m with a steepness varying from flat at either end to 45 to 50 percent in the middle (Figure 4). The results of these sim-ulations are presented in Tables 3 and 4.

The average precipitation in the Southeast was 56 percent greater than in the Northern Rockies, but the sediment delivered from a given hillslope was at least 12 times as great, reflecting the major role that climate plays in soil erosion. Generally, the autumn precipitation in Year 2, or the spring precipitation occurring in Year 3 should give the greatest amount of erosion because the vegetation has not had suf-ficient time to become reestablished following disturbance, but Year 3 was not the most erosive for any of the scenarios. Apparently the distribution of erosive events is overshadowing the differences due to the modeled vegetative regeneration. In the Northern Rockies, there were so few erosive events, that the occurrence of an event in a given year tended to dictate the occurrence or absence of erosion following a disturbance.

Table 3. Year, cover, precipitation (mm), and sediment yield (kg per m width of disturbed area) for simulated forest conditions disturbed by fire, a skid trail, and a skid trail with a riparian zone.

Yr	Cover	Southeast Precip mm	Southeast Fire kg/m	Southeast Skid kg/m	Southeast Skid+Rip kg/m	Northwest Precip mm	Northwest Fire kg/m	Northwest Skid kg/m	Northwest Skid+Rip kg/m
1	Forest	1222	62.5	62.5	18.4	929	0.0	0.0	0.0
2	Fire/Skid	1302	143.8	62.1	17.3	853	0.0	0.0	0.0
3	Regen. 1	1573	78.0	135.9	6.6	793	13.8	37.2	0.0
4	Regen. 2	1167	57.7	150.6	1.9	930	0.0	0.0	0.0
5	Regen. 3	1293	177.3	299.4	77.9	815	51.3	54.8	4.5
6	Regen. 4	1121	57.4	137.5	35.7	818	2.2	5.7	0.0
Ave		1280	96.1	141.3	26.3	856	11.2	16.3	0.75

Table 4 shows the effects of management and climate on the number of runoff and erosion events, predicted runoff, upland erosion, and sediment yield. The South-east has many more runoff and erosion events during the 6 years of simulation, with most of those events due to rainfall. The Northern Rockies has most of the runoff occurring as a result of snowmelt, but the predicted erosion was from either rainfall or snowmelt, depending on the weather sequence. During the six years of simulated weather, only one rainfall

Table 4. Site condition, average simulated precipitation; predicted number of runoff and erosion events, average runoff from snow and rain, average erosion, and sediment yield, for hillslopes in the southeast and northwest experiencing disturbance by either fire, skidding, or skidding with a riparian zone in Year 2 of a six-year simulation.

Condition	Average precip. (mm)	Total events runoff	Total events erosion	Average runoff (mm) Snow	Average runoff (mm) Rain	Average erosion Mg/ha	Sediment yield kg/m
Southeast	1313						
Fire		29	22	2.2	31.1	5.3	96.1
Skid		33	27	2.5	39.4	7.1	141.3
Skid+Rip		33	14	1.5	15.8	6.9	26.3
Northwest	856						
Fire		10	3	9.36	.67	0.7	11.2
Skid		9	4	53.65	4.93	0.9	16.3
Skid+Rip		9	1	4.77	0.00	0.4	0.75

event resulted in erosion for all three conditions. The other runoff and erosion events were due to snow melt in the early winter or spring. This is similar to the observations that are presented in Figure 2. Further study is needed to determine if the WEPP-simulated events that caused runoff were typical of the climate, if the modeled post-disturbance regeneration is typical of what occurs, and how the WEPP model performs when using observed storms rather than a simulated climate.

Table 4 shows that the predicted upland erosion and sediment yield are greater on the skid trail than on the burned site, which was observed in the field studies. The predicted sediment yield is least from the skid with the riparian zone. This shows the importance of riparian zones in protecting streams from sediment, and also shows the utility of the WEPP model in comparing the effectiveness of riparian zones for dif-ferent climatic, topographic, and management conditions. If a riparian zone were incorporated into the fire scenario, a similar reduction in sediment yield would occur.
Figure 4 shows the distribution of erosion and deposition all along the hillslope for the Southeast climate. The jagged levels of deposition in the riparian zone are due to the different lengths of the predicted deposition. Generally, there is a deposition peak at the end of each plume, and so multiple storms will result in multiple deposition peaks.

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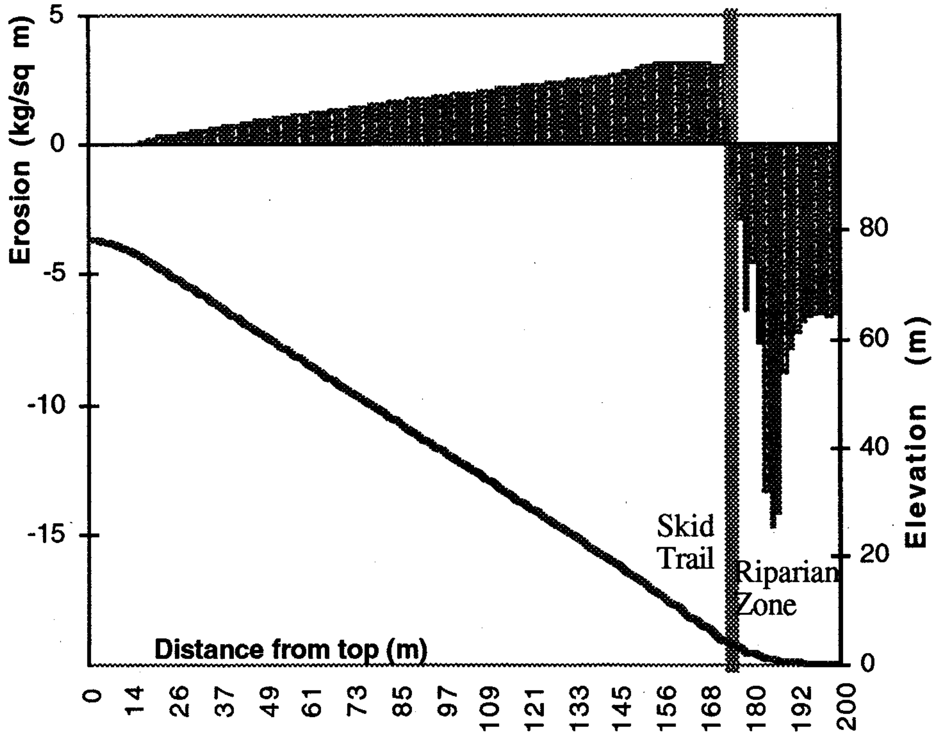

Figure 4. Predicted soil erosion (positive values) or deposition (negative erosion values) and elevation vs. distance from the top of hill for scenario modeling the Southeast climate and a two-element skid trail.

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Conclusions

The WEPP model shows considerable promise as a tool to help forest managers predict the onsite erosion and offsite sedimentation due to timber harvest. Additional validation with large plot, natural rainfall field data is necessary to determine the accuracy of the predicted erosion. Further research is needed on the effects of spatial distribution of harvest area hydrologic and erosion properties, on the unique attributes of forest hydrology on erosion prediction, and on the accuracy of modeling vegetation regeneration following a forest disturbance.

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