

SPATIALLY-VARIED EROSION MODELING USING WEPP FOR TIMBER HARVESTED  
AND BURNED HILLSLOPES

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**Summary:** Spatially-varied hydrologic surface conditions exist on steep hillslopes after timber harvest operation and site preparation burning treatments. Site preparation burning creates low- and high-severity burn surface conditions or disturbances. In this study, a hillslope was divided into multiple combinations of surface conditions to determine how their spatial arrangement would effect erosion. More erosion occurred when high-severity burn conditions occurred above low severity burn conditions. Various hillslope configurations conclude that the spatial distribution of fire severity conditions on a hillslope affects predicted soil erosion rates.

**Keywords:**

erodibility, prescribed fire, spatial variability

## Introduction

Prescribed fires play a significant role in maintaining a healthy forest, while meeting management objectives (Reinhardt et al. 1991). Burning post-harvest residue is a common method of fire hazard reduction and site preparation. Burning is conducted alone or in combination with other treatments, to dispose of slash, reduce the risk of insects and fire hazard, prepare seedbeds, and suppress plant competition for both natural and artificial regeneration. Conditions at the time of ignition impact the severity of the burn. It is essential that managers have a means to predict the consequences of various fire severity effects on stream water quality with acceptable accuracy. These predictions can be used to evaluate and develop better management strategies and burn prescriptions. The use of prescribed fire will increase during the next decade. It is important to know how prescribed fire will affect the environment in relation to soil erosion.

In 1986, the USDA-Agricultural Research Service, initiated the Water Erosion Prediction Project (WEPP) for use on croplands, rangelands and forests to replace the Universal Soil Loss Equation (USLE). The WEPP model is a complex computer program that describes the processes that influence erosion (Laflen et al. 1991 and Nearing et al. 1989). These processes included infiltration and runoff; soil detachment, transport and deposition, plant growth, senescence and residue decomposition. The WEPP model is physically-based, therefore it is more easily transferred to a wider range of conditions than are empirically-based models like the USLE.

Field experiments have been carried out in forest environments to provide calibration and validation of data for the model (Elliot et al. 1995, Robichaud 1996, Robichaud and Waldrop 1994). One of the characteristics of forest hillslopes is spatial variability. This is a result of natural variations in soil, vegetation cover, ground cover (duff), topographic differences and management practices. The spatial variability increases the difficulty of modeling the erosion process. Previous work by Robichaud et al. (1993) and Robichaud (1996) indicated that there are four surface conditions that need to be identified from timber harvest and burned hillslopes. These are natural areas (unburned), low-severity burn areas, high-severity burn areas, and skid trails or other highly disturbed areas. Since most fires do not burn uniformly on a hillslope it is necessary to investigate how various burning patterns can effect runoff and erosion. This paper describes the results of a computer exercise that examines the arrangement of different surface conditions and their erosion potential.

## Methods

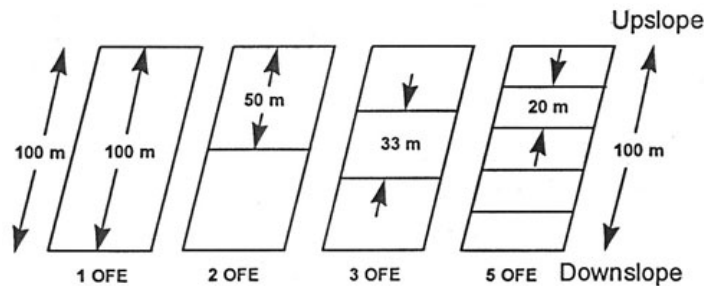
WEPP computer runs were conducted using various scenarios that are commonly encountered in the forest environment. Specifically, analysis were conducted on low- and high-severity burn conditions and their distributions on a hillslope. Four input files are needed to run WEPP, these are: slope, climate, soil and management files. The parameters for the soil and slope files were from field measurements from one of our field sites located on the Bitterroot National Forest in Western Montana (Robichaud 1996) and were held constant for this study. Changes were made in hydraulic conductivity, interrill erodibility and interrill cover (Table 1). All other variables in the soil, management and climate files were held constant throughout the runs so

that effects of surface conditions (burn severity) could be analyzed. WEPP allows the user to divide a hillslope into numerous overland-flow-elements (OFEs) where each element is a unique combination of soil and ground cover characteristics.

**Table 1. Selected input parameters used for the WEPP runs for low- and high- severity burn conditions. Bold parameters values were different between conditions.**

Input Parameter	Burn Conditions	
	Low Severity	High Severity
<b>Interrill Erodibility (<math>\text{kg s m}^{-4}</math>)</b>	1 E6	1 E7
<b>Rill Erodibility (<math>\text{s m}^{-1}</math>)</b>	0.005	0.005
<b>Saturated Hydraulic Conductivity (<math>\text{mm hr}^{-1}</math>)</b>	30	24
Critical Shear ( $\text{N m}^{-2}$ )	2.0	2.0
Initial Saturation (%)	13	13
Ridge Roughness (m)	0.01	0.01
<b>Groundcover (%)</b>	85	35
Slope ( $\text{m m}^{-1}$ )	0.36	0.36
Soil Type	loamy skeletal	loamy skeletal

A hillslope template was used to compare multiple OFEs with various low- and high-severity burn scenario arrangements (Figure 1). The hillslope was 100 m long and 50 m wide with a uniform slope of 36 percent. A single-storm climate file was developed with 160 mm of precipitation over 6 hrs, with rainfall intensity of  $27 \text{ mm hr}^{-1}$ . A second climatic file had 60 mm of precipitation over 3 hrs with rainfall intensity of  $20 \text{ mm hr}^{-1}$ . These high rainfall intensities were used to provide ample energy for comparing surface conditions. For the single-storm event, conditions used are those occurring immediately after the burn prior to vegetation regrowth.



**Figure 1. Hillslope profile layout for single and multiple overland flow elements.**

The first scenario was a single overland-flow-element (OFE) for low- and high-severity burn surface conditions. Runoff depth and sediment leaving the profile were obtained for low- and high-severity burn surface conditions. To compare the effects of dividing the hillslope into multiple OFE's, results from five consecutive low-severity burns OFE's were compared with a single OFE of low-severity burn. A similar comparison was done for the high-severity burn treatment.

The hillslope was then divided into two OFEs, each 50 meters long. WEPP runs were completed for a high-severity burn condition uphill from a low-severity burn condition, and a low-severity burn condition uphill of a high-severity burn condition. The third scenario was a hillslope with three OFE's (each OFE 33 m long). Low- and high-severity burn conditions were arranged to compare relative position of burn severity ranging from all low, low-high-low, high-low-high, and all high. The fourth scenario examined thirty two arrangements of five OFEs. The length of each OFE was 20 m. The sixth scenario was to test the effect of different ratios of the hillslope area in low- and high-severity burn conditions. Multiple WEPP runs were conducted varying the areas for two OFE's from 99 to 1 percent through 10 to 90 percent for both low-severity burn above high-severity burn, and high-severity burn above low-severity burn conditions.

## Results and Discussion

Sediment leaving the hillslope profile were predicted by the WEPP model and compared for the various scenario. Figure 2 shows the sediment yield in kilograms per meter width for two surface conditions, low- and high-severity burn areas from a 100 m length hillslope. The low-severity burn conditions produced little sediment whereas the high-severity burn produced 25 kilogram per meter width ( $\text{kg m}^{-1}$ ) or about four times the amount of the low-severity burn.

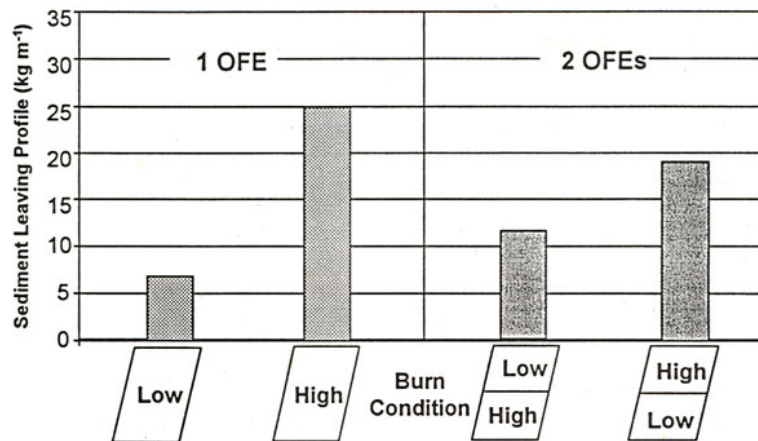


Figure 2. Sediment yields for low- and high-severity burn conditions for one and two overland flow elements.

The remainder of the analysis examined the arrangement of the low- and high-severity burn conditions. Hillslopes consisting of all low-severity or high-severity burn conditions but with multiple OFEs had the same amount of sediment leaving the profile as a hillslope with a single OFE element describing the same hillslope. A comparison of two OFEs with low- above high-severity burn and high- above low-severity burn conditions shows that the high-severity burn condition above the low-severity burn condition produced more sediment (Figure 2). Comparing sediment leaving the profile for three and five OFEs indicate similar trends (Figures 3 and 4). When two thirds of the upper portion of the hillslope is in high-severity burn conditions, it produced  $22 \text{ kg m}^{-1}$  whereas when the upper two-thirds were in low-severity burn conditions it produced  $9 \text{ kg m}^{-1}$  (Figure 3). The runoff generated when the top portions of the hillslope were burned under high-severity conditions continued eroding through the areas of low-severity burn.

Whereas the opposite arrangement, little runoff was generated from the upper portions of the hillslope and only the lower high-severity burn conditions contributed to the runoff and erosion.

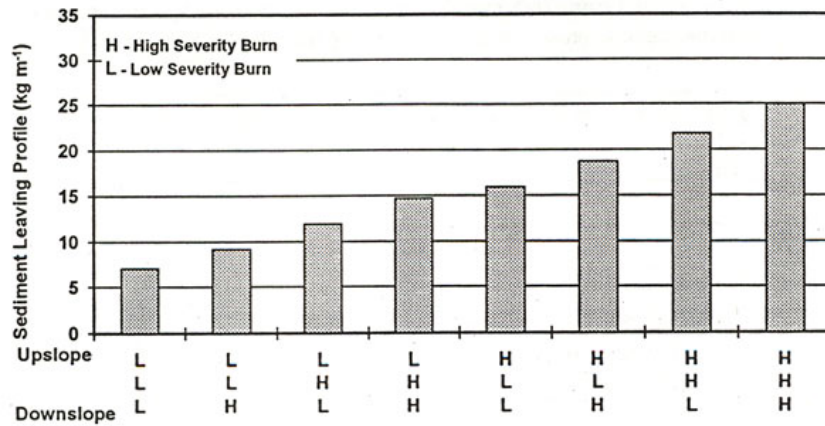


Figure 3. Sediment yields for three OFEs with various arrangements of low- and high-severity burn conditions.

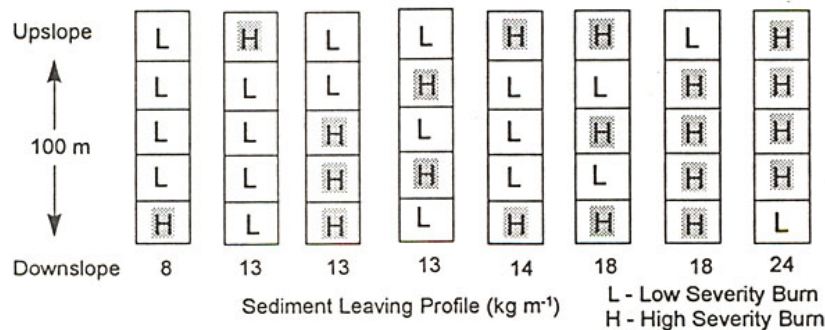


Figure 4. Sediment yields for selective five OFEs with various arrangements of low- and high-severity burn conditions.

Sediment produced from various arrangements of low- and high-severity burn conditions with five OFEs, each OFE was 20 m long were compared (Figure 4). The smallest sediment producing arrangement was with all five OFEs as low-severity burn condition and the largest was with all OFEs as high-severity burn conditions. As each low-severity burn condition OFE is replaced with a high-severity burn condition OFE, more sediment was produced leaving the profile. As the single high-severity burn condition was arranged higher upslope, sediment leaving the profile increased. This uphill arrangement indicated that a single high-severity burn condition as the top OFE, produced the same amount of sediment as an arrangement with three times the area of high-severity burn condition as the lower three OFEs and the upper two OFEs as low-severity burn condition (Figure 4). A second storm (60 mm of rain in 3 hrs) was also compared and similar trends were obtained but the total erosion was proportionally less (Figure 5).

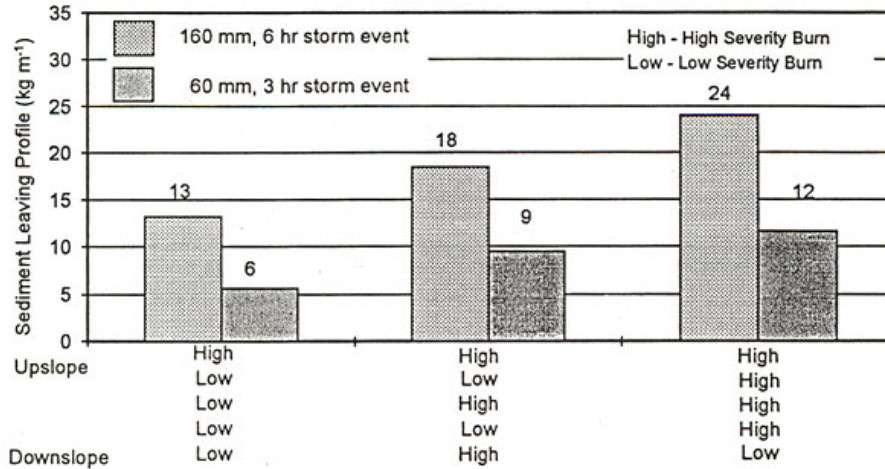


Figure 5. Sediment yields for five OFEs with various arrangements for a 160 mm, 3 hr and a 60 mm, 3 hr rainfall events.

To further investigate the effect of positioning and percentage of area in low- and high-severity burn conditions, two OFEs were compared with varying percents of burn area severity (Figure 6). Sediment produced from ten percent of the area at the top of the hillslope as high-severity burn condition was equal to forty percent of the area as high-severity burn condition at the lower portion of the hillslope.

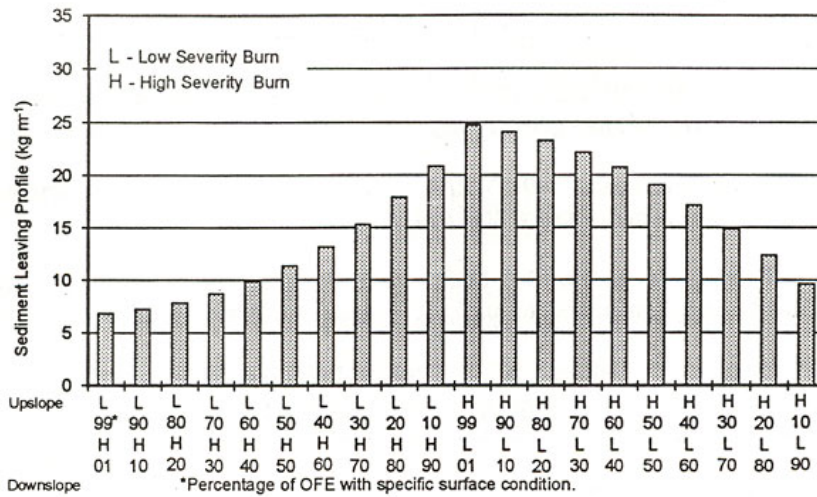


Figure 6. Sediment yields comparison for five OFEs with various lengths.

### Conclusions

Spatially-varied surface conditions occurred after prescribed fires and wildfires. To examine the effect of position and extent of burn severity several scenarios were created and sediment yield compared. On a uniform hillslope, the results indicate that high-severity burn conditions produced about four times as much sediment as low-severity burn conditions for a 160 mm 6-hr storm. Various combinations of

low- and high-severity burn conditions with equal size OFEs indicate that a high-severity burn above a low-severity burn condition produces about one and half times more sediment than a low-severity burn above a high-severity burn for severe storms. For a 60 mm 3-hr storm, similar results were obtained but proportionally smaller.

Ten percent of the area in a high-severity burn condition at the top of the hillslope produced the same amount of sediment as a hillslope with the lower forty percent of the area in high-severity burn condition. Apparently, with high-intensity storms, runoff generated on upland areas is sufficiently great to traverse the entire hillslope, eroding both upslope and downslope areas. If areas of high severity are nearer the bottom of the hill, then only the lower portions of the slope contribute to runoff. The arrangement of high-severity burn conditions above the low-severity burn condition on a hillslope is common. As a fire burns, the heat generated can dry-out the upper portions of a hillslope and cause it to burn more severely. This has been observed from studies by Robichaud (1996).

These results indicate that forest managers may need to adjust burning practices to reduce the upland area in high-severity burn condition to reduce erosion from timber harvested hillslopes. Burning so that little heat is carried upslope by changing ignition patterns and timing of ignition may reduce the occurrence of high-severity burn conditions above low-severity burn conditions.

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