Predicting Sedimentation from Timber Harvest Areas with the WEPP Model

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W. J. Elliot[1], C. H. Luce, and P. R. Robichaud

ABSTRACT

Disturbed forest lands are prone to increased erosion. Predicting the effects of forest operations 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 limitations in modeling erosion in forest areas. Field research has shown that timber harvest area soil properties may vary widely. Validation studies with the Watershed Version of the WEPP model show that as observed, snow melt dominates the runoff processes in the Northern Rockies, and that disturbed areas generally have a greater influence on runoff and erosion that do undisturbed areas. The model overpredicted snow melt rate, and did not allow snow to accumulate, but rather melted any accumulation on the first day above freezing following a snow event. It may be necessary to reduce hydraulic conductivities from those observed on small field plots to obtain runoff. A model that better describes the attributes of this region's snowmelt processes and upland hydrology is needed. Additional research is also needed for modeling the large spatial variability observed in timber harvest areas. Research is ongoing with this research unit to address all of these forest-specific problems.

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 forest 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 throughout the United States and abroad have been

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[1] Project Leader, Research Hydrologist, and Research Engineer, respectively, Intermountain Research Station, USDA Forest Service, 1221 South Main, Moscow, ID 83843.

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 USLE. One of the research problems we study is determining the suitability of the WEPP model to predict erosion on disturbed forest 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 disturbed forest environments.

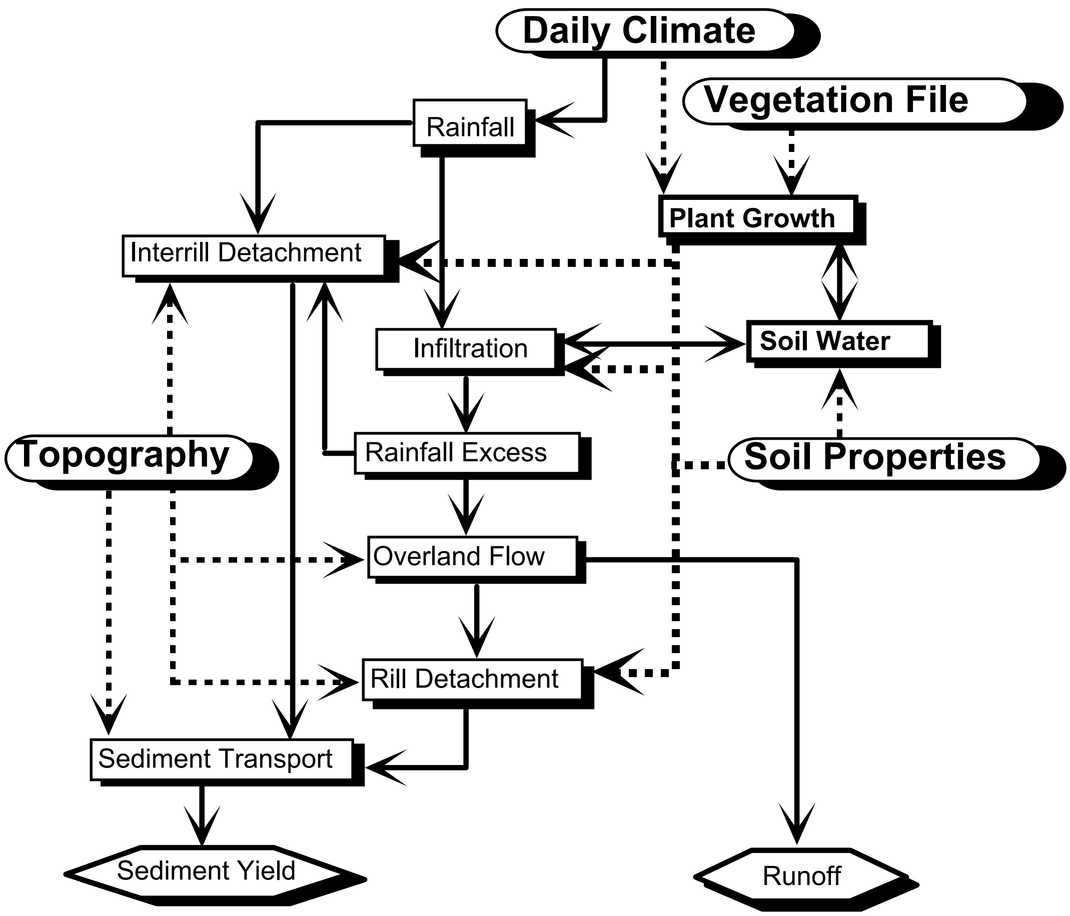

Figure 1. Outline of WEPP Model

The WEPP Model

The WEPP model is a complex computer program that describes the processes that influence erosion (Figure 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 daily plant growth and decomposition (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 applied to areas where soils, climate, and vegetation may vary widely from traditional research plots. The WEPP model was released in 1989 for scientists to begin validation studies. In 1991 a version was released incorporating numerous improvements, correcting errors in earlier code, and including a file builder. In 1994, a recoded version was released for a year of validation and field testing by scientists before the model's release to the public in August, 1995. All of these releases were a "Hillslope" version, which restricted the user to modeling topographies that could be described by a hillslope profile. The Hillslope Version also allows the user to describe different vegetation and soil conditions along a hillslope as different "overland flow elements" or OFEs. A "Watershed" version which links hillslope elements, channel elements, and impoundment elements was also released in August, 1995, which allows the user to combine hillslope elements with channel and structural elements (such as culverts and silt fences) (Ascough II et al., 1994).

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 role in maintaining a healthy forest, while meeting management objectives (Reinhardt et al., 1994). Burning post-harvest residue is a 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 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 forests. 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. Compacted 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 readily describe the variation in forest hillslope hydrologic properties. Consequently, the effective or aggregate behavior of a hillslope as an homogenous unit or a series of homogenous overland flow elements must be determined 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 steep local topography and long-duration, low-intensity precipitation or sustained snowmelt. Saturation overland flow can occur on soils with high infiltration capacities 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 saturation 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, increasing infiltration to the maximum saturated hydraulic conductivity in the profile 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 circumstances where the WEPP model may or may not work for estimating sediment production from harvest areas is important. This requires determining whether Horton or saturation overland flow dominates the erosion process for an area.

Table 1. Summary of soil physical properties and calculated parameters from the rainfall simulator experiments near McCall, Idaho.

Operation	Conductivity mm/hr	Interrill Erodibility kg s/m^4 x 10^6
Undisturbed	75 - 85	0.1 - 0.2
Burned	11 - 75	0.1 - 3.6
Unbladed Skid Trail	22 - 85	0.2 - 1.2
Bladed Skid Trail	12 - 65	0.4 - 1.8
Access Road	4 - 11	1.1 - 1.8

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. In a study comparing WEPP predictions for two typical climates, Elliot et al. (1995) found that the WEPP model apparently predicted the general trends observed in the Southeast and the Northern Rockies. This paper summarizes further validation work to compare predictions from the WEPP Watershed Version to data collected from a small harvested watershed in Central Idaho.

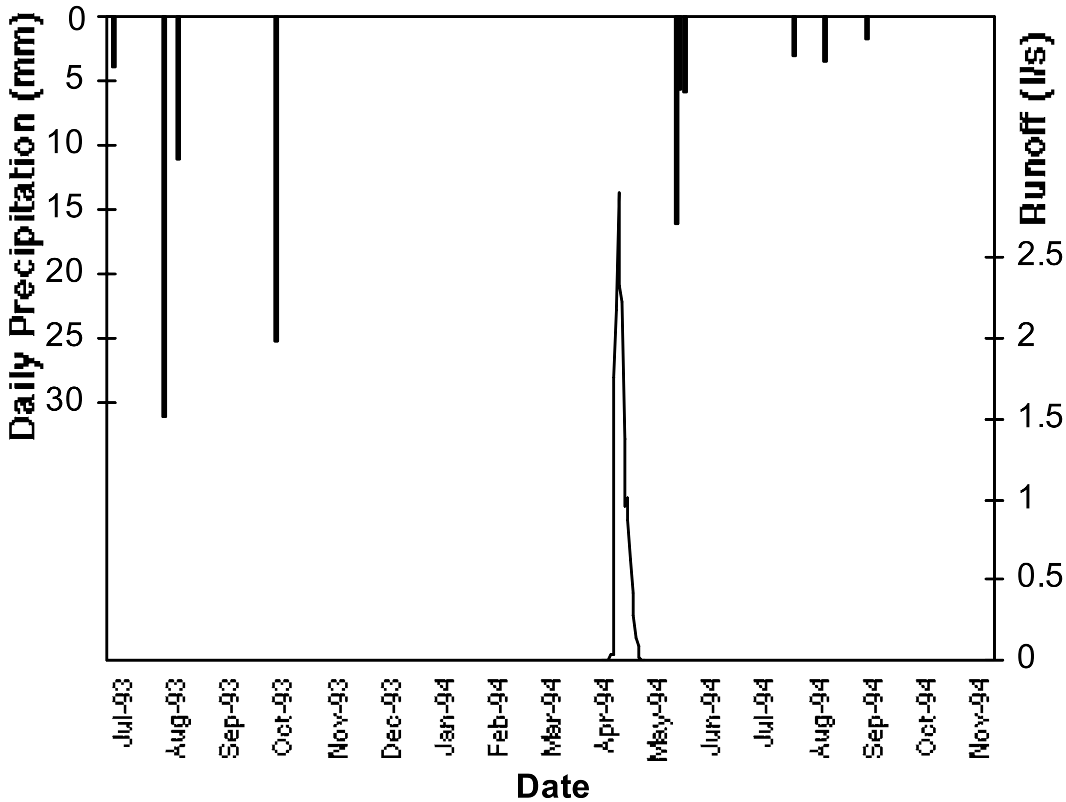

Figure 2. Distribution of storms with 1 minute intensities greater than 25 mm/hr and Runoff on Idaho watershed.

FIELD STUDIES

Several studies have been completed and others are ongoing to determine the parameters values needed to model runoff and sediment production from forest operations. These studies address different harvesting methods, fire severity, and spatial variability associated with these treatments. Simulated rainfall events were used to determine 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.

For this study, a 2-ha watershed was located in the Payette National Forest, between Riggins and McCall, in Central Idaho. The site was harvested several years prior to the study, and was covered in regrowth up to 1 m high prior to burning. Interrill erodibility and infiltration rates were measured on small undisturbed plots prior to a prescribed burn, and on plots with low and high severity burns after the prescribed burn as well as access roads, and skid trails. The site naturally converged to a channel at the bottom. The runoff was diverted through a sediment trap and a calibrated weir to measure runoff rates. The soil was a fine loamy Typic Crychrept derived from basalt, with a surface horizon sand content of 35 percent, silt of 40 percent, and clay of 25 percent. Table 1 shows the range of observed hydraulic conductivities and interrill erodibility values. 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.

In the small plot studies, simulated rainfall events were applied to hydrologically undisturbed timber harvest sites on 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. The maximum intensity of the rainfall simulator was 85 - 95 mm/hr, so it is possible that some plots may have had hydraulic conductivities in excess of the 85 mm/hr maximum that was measured. 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, as a function of applied rainfall, rainfall excess, canopy cover, ground cover, and slope adjustment factors. There are limitations to small plots in that any hydrologic observations on the plots will have a much greater variation in properties than will larger plots where such variation tends to be averaged. Generally, our observations show that the conductivities observed on small plots are greater in both magnitude and variation than on larger plots.

Rainfall and runoff observations for 16 months from the small watershed 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 saturated 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 system 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. The total sediment yield is estimated to be between 500 and 1000 kg, and the total runoff was nearly 1500 m^3 or a depth of 76 mm on the 2 ha watershed.

On such large plot studies, several years of data are necessary to evaluate a model, because of the variability of the natural climate. Data collection from this watershed, and six others, will be ongoing to obtain a range of validation conditions.

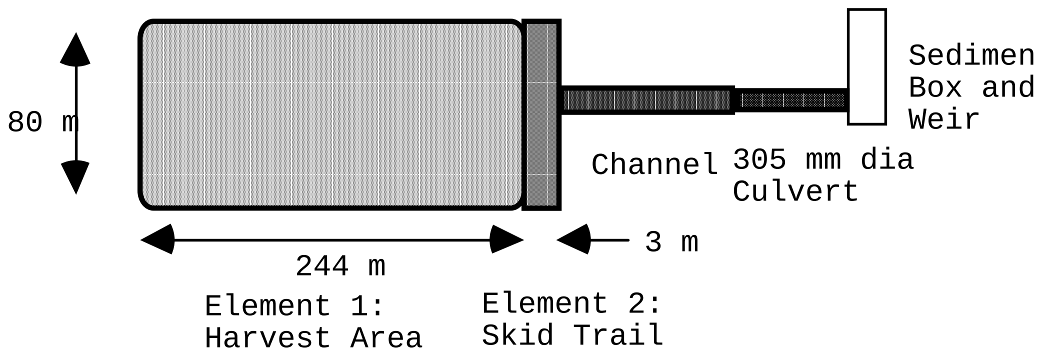

Figure 3. Schematic of McCall Watershed.

WEPP PREDICTIONS

The WEPP Watershed model was set to describe the McCall watershed conditions as shown in Figure 3. The harvest area and skid trail were defined as a single hillslope element with two OFEs. The harvest area had a slope of 44.7 percent, and the skid trail, which was approximately on the contour, had a downslope steepness of about 9 percent. The hillslope drained into a channel with a 44.7 percent gradient, which led to a culvert with a slope of 70%. The observed climate was available for one winter season, and was formatted for the WEPP model. Vegetation was described as a regenerating forest (Elliot et al., 1995).

Previous validation studies have shown the importance of ensuring that the conductivity is correct, so a number of WEPP scenarios were developed. The soil profile was based on a typical forest soil found nearby and site observations. To determine the relative importance of the range of observed hydraulic conductivities and soil variation, a range of values were run with the WEPP model. In the lower soil layers, hydraulic conductivity is determined by the clay content, and calculated internally (Flanagan et al., 1995). A summary of the runoff and erosion rates for different conductivities is presented in Table 2.

From the simulation results in Table 2, it appears that their is a threshold conductivity for the harvest area between 40 and 80 mm/h. For harvest area conductivities greater than 40 mm/h, there is no runoff from the harvest area and for conductivities below 40 mm/h, there is combined runoff from the skid trail and the harvest area.

All of the observed runoff and erosion in Table 2 occurred from snow melt during several days in early April as shown in Figure 2. The predicted runoff, however, occurred in a single day of snow melt in mid-December. It appears that the WEPP model is overpredicting the rate of snow melt so that the large observed snowfalls in early December (over 120 mm) are predicted to melt as soon as the temperature rises above freezing, and there is insufficient snow remaining to melt and cause runoff for the warm weather observed in early April.

The importance of the clay content in the subsoil is also apparent in Table 2. Frequently, the depth and texture of a forest subsoil is not well known because of the limited detail available from forest soil surveys. Such a lack of information may restrict the application of WEPP to areas lacking detailed forest soil surveys. As discussed previously, in forest conditions, the subsurface soil water may play a major role in determining surface runoff and it appears that WEPP is able to account for part of this process. In the very steep hillslopes in forest conditions, however, additional consideration may be necessary to determine whether the subsurface flow from the top of the hillslope is accumulating at the base of the hillslope to cause less infiltration and greater runoff from this part of the slope. The current input and output options from the WEPP model make it difficult to determine subsurface flow influences, and further work is required to fully evaluate WEPP's performance under such high infiltration, steep slope conditions.

Table 2. Summary of total runoff and erosion predicted by the WEPP model for the McCall watershed for the range of observed soil hydraulic conductivity properties.

Hydraulic Conductivity mm/h		Runoff	Sediment Yield
Harvest Area	Skid Trail	cubic meters	Mg
Observed			
15 - 80	15 - 65	1486	0.5 - 1.0 *
Predicted			
Subsoil Clay = 20 %		Sand = 30 %	
80	60	0	0
	30	4	0
	15	4	0
40	30	150	1.3
	15	150	1.3
20	15	150	1.3
Subsoil Clay = 40 %		Sand = 10 %	
80	60	0	0
	30	10	0
	15	10	0
40 **	**30 ****	**617**	**11.1**
	15	617	11.1
20	15	617	11.1
Subsoil Clay = 60 %		Sand = 5 %	
80	60	0	0
	30	12	0
	15	12	0
40	30	764	14.6
	15	767	14.7
20	15	767	14.8

* Estimated
** Median of values observed on the site

The sediment yield is over-estimated, so some additional consideration needs to be given to paramaterizing forest soil rill and channel erodibility and ground cover factors. The high sediment yield is also due to the very high runoff rates predicted on December 10, causing considerable upland erosion, with some channel deposition. Table 3 shows that there was predicted rill erosion, with channel deposition. Site observations indicated little rilling, but apparent channel downcutting. In almost every scenario, the runoff occurred during a single day, and not two weeks as was observed. This is likely due to the lack of any subsurface flow consideration in the hydrology routines to give an extended runoff period. If the modeling of the snow melt and near-surface runoff can be improved, then the predicted sediment yields may decline significantly, because of the reduced surface and subsurface runoff rates.

Table 3. Summary of the distribution of total runoff and erosion predicted by the WEPP model for the McCall watershed

Location	Runoff (m^3)	Sediment Yield (Mg)
Hillslope bottom	622	34
Channel Outlet	623	18
Culvert outlet	628	10

CONCLUSIONS

The WEPP model shows promise as a tool to help forest managers predict the onsite erosion and offsite sedimentation due to timber harvest. Additional validation with small watershed, natural rainfall and snowmelt field data is necessary to determine the accuracy of the predicted erosion. Further research is needed in modeling snow melt effects on runoff, in modeling saturated overland flow, and in determining the equivalent hydraulic conductivities of hydrologically complex watersheds. This work unit is currently researching all of these areas to improve future model performance.

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Authors can be contacted at The Forestry Sciences Laboratory, Intermountain Research Station, 1221 South Main Street, Moscow, ID 83843. Tel 208 882 3557, Fax 208 883 2318.

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Moscow Forestry Sciences Laboratory
Rocky Mountain Research Station
USDA Forest Service
1221 South Main Street
Moscow, ID 83843

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