Validation of Water Erosion Prediction Project (WEPP) Model for Low-Volume Forest Roads

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Erosion rates of recently graded nongravel forest roads were measured under rainfall simulation on five different soils. The erosion rates observed on 24 forest road erosion plots were compared with values predicted by the Water Erosion Prediction Project (WEPP) Model, Version 93.1. Hydraulic conductivity and soil erodibility values were predicted from methods developed for rangeland and cropland soils. It was found that on four of the five soils, runoff values were closely predicted and that the predicted erosion was not significantly different from the observed erosion when using rangeland methods for predicting soil erodibility. It was also found that interrill erosion rates were underpredicted using rangeland methods for predicting soil erodibility, but slightly overpredicted when using cropland interrill erodibility prediction methods. Rill erosion rates for road wheel ruts were closely predicted from rangeland rill erodibility algorithms.

There is an increased awareness of the importance of maintaining the global ecosystem with all its biologic diversity. The USDA Forest Service manages large areas of the nation's forestlands and has an ongoing commitment to apply the best technology available in its management processes. One of the areas of concern in the forest ecosystem is the amount of sediment eroded from forest roads into waterways that serve as spawning and rearing habitats for fish and as habitats for aquatic macroinvertebrates.

The authors have been participating in the development of the Water Erosion Prediction Project (WEPP), a major interagency research and model development project. The major thrust of the WEPP project has been to predict soil erosion for agricultural and rangeland conditions. Further research is being conducted to apply the WEPP model to forest roads and harvest areas.

OBJECTIVES

The purpose of this study was to determine the suitability of the WEPP model for forest road conditions and to contribute to the validation of the WEPP hillslope model by comparing runoff and erosion estimates produced by the model with observed data from rainfall simulation studies carried out on forest roads.

The objectives of this paper are to (a) give an overview of the WEPP erosion prediction technology and its application to predicting forest road erosion and (b) determine the suitability of estimating the erodibility of nongravel road surfaces from cropland and rangeland research results.

SEDIMENT FROM FOREST ROADS

Dirt roads constructed to access forestlands are major and persistent sources of sediment to headwater streams. Reid (*1*) found that for a coastal Washington stream basin with a road density of 2.5 km/km^2, appropriate for skyline cable logging systems, sediment derived from road surface erosion accounted for between 13 and 18 percent of the total sediment in the stream. Sediment from roads contributed between 34 and 40 percent of the sediment less than 2 mm in diameter. Her results demonstrate that road sediment production can be a significant contribution to a basin's sediment budget and is a significant source of fine sediment in particular.

Given the potential for sediment production, forest roads have been the focus of a great deal of research to estimate rates of soil loss from road surfaces and to determine the best control methods. In some of the earliest quantitative research Hoover (*2*) and Weitzman and Trimble (*3*) measured erosion from cross-sectional lowering. Cross-sectional lowering data can be questionable because both compaction due to traffic and erosion contribute to the lowering. More recent quantitative work has concentrated on measuring sediment in traps (*4*) or suspended sediment concentrations from cross drains and culverts (*5*) under natural rainfall conditions. Other recent work has used rainfall simulation to estimate runoff and erosion from forest roads (*6–8*).

Some of the recent quantitative work using natural rainfall has been linked to empirical model building. Megahan (*9*) constructed an exponential decal model of sediment production over time following construction. Reid and Dunne (*5*) built an empirical model relating traffic, road segment length, and road gradient to sediment production.

The quantitative work using rainfall simulation has been used for both empirical and process-based models of road erosion. Burroughs and King (*10*) used rainfall simulation on varying degrees of mitigation, such as straw and mulch, to develop empirical relationships between application rate and effectiveness. Ward (*6*) used rainfall simulation to identify parameter values for the ROSED road erosion model (*11*).

In summary, the literature shows that roads are a significant source of sediment in forests. To date, there has been little attempt to predict the amount of sediment from a given section of road to aid in evaluating the impacts of roads on upland streams.

MODELING

Computer simulation modeling makes a valuable contribution to hydrologic research and practice (*12*). Research involving data collection from long-term field studies is a time-consuming and expensive process. An alternative approach is to conduct computer simulations to analyze the hydrologic effects of management under certain climate conditions.

Scientists are developing physically based erosion prediction models for computers that allow the user to model the individual processes that lead to soil erosion, including rainfall intensity and distribution, infiltration and runoff, and soil detachment, transport, and deposition. Early modeling in the 1970s with physically based models required mainframe computer capabilities and large input data sets. The widespread availability of desktop and portable computing systems now makes such technology available to most natural resource managers. Physically based models can be successfully applied to many more conditions than statistical models as long as the factors affecting the processes can be identified and characterized (*13*).

In 1984, the USDA Agricultural Research Service (ARS) and the Soil Conservation Service (SCS) in cooperation with the Bureau of Land Management and the Forest Service launched a cooperative research effort known as the Water Erosion Prediction Project. Their goal was to develop a user-friendly physically based erosion prediction model that would operate on a portable computer and could be used by SCS and other field technicians as an aid in erosion prediction and conservation planning for cropland, rangeland, and forests. After five years of field, laboratory, and computer research, the first completed research version of the WEPP program was released in August 1989 and the first field version in 1991. It is expected that the model will begin receiving widespread use by SCS in the late 1990s and will be the erosion prediction model of choice well into the next century (*14*).

The WEPP model is based on fundamentals of infiltration, surface runoff, plant growth, residue decomposition, hydraulics, tillage management, soil consolidation, and erosion mechanics (*15*). Table 1 summarizes the important input parameters for the model. This model combines physically based erosion and hydrology models with a stochastic climate generator to estimate soil loss and deposition and thus facilitate the selection of management practices to minimize soil erosion.

The WEPP technology includes a hillslope profile version, a watershed version, and a grid version (*16*). The hillslope profile version predicts when and where soil loss and deposition will occur on a hillslope, taking into account management practices and climate. It is continuous, simulating the processes that affect erosion prediction as a function of time with a daily time step. The model may also be used in the single-storm mode (*16*). The watershed version combines a number of hillslopes and channel elements to describe a small watershed. The grid version, now under development, will combine a grid of hillslopes into a catchment that can exceed several square miles.

TABLE 1 Input Requirements for WEPP Model

Input File	Contents
Slope	Pairs of points indicating distance from top of slope and respective slope
Soil	For top layer: Albedo, Initial Saturation, Interrill and Rill Erodibility and Critical Shear For up to ten layers: Thickness, initial bulk density, initial hydraulic conductivity, field capacity, wilting point, contents of: sand, clay, organic matter, and rock fragments, cation exchange capacity
Climate	For each day of simulation: precipitation amount, duration, time to peak rainfall, peak rainfall, maximum, minimum and dew point temperatures, solar radiation, average wind speed and direction
Management	Type of vegetation (crop, or range), plant growth parameters, tillage sequences and effects on soil surface and residue, dates of harvesting or grazing, if necessary description of irrigation, weed control, burning, and contouring.

The WEPP model divides erosion into two types, rill and interrill. Interrill erosion is driven by detachment and transport of sediment due to raindrop impact and shallow overland flow. Interrill erosion is estimated from the equation (*17*)

$$D_i = K_i I^2 S_f\, f(c) \tag{1}$$

where

D_i = detachment rate (kg/m^2/sec);
K_i = interrill erodibility (kg-sec/m^4);
I = rainfall intensity (m/sec);
S_f = slope factor (*17*); and
$f(c)$ = function of canopy and residue.

Rill erosion is the detachment and transport of sediment by concentrated channel flow. The erosion rate is a function of the hydraulic shear and amount of sediment already in the flow. Rill erosion is calculated in the WEPP model from

$$D_r = K_r(t - t_c)(1 - G/T_c) \tag{2}$$

where

D_r = rill erosion rate (kg/m^2/sec);
K_r = rill erodibility (sec/m);
t = hydraulic shear of the water flowing in the rill (Pa);
t_c = critical shear below which no erosion occurs (Pa);
G = sediment transport rate (kg/m/sec); and
T_c = rill sediment transport capacity (kg/m/sec).

The individual processes that lead to soil erosion are generally the same for agricultural and forested lands and also occur on forest roads. One of the erosion-related processes that is different on roads from cropland and rangeland is the absence of plant growth, although there may be some effects from overhanging tree limbs and leaf or needle drop. The hydrologic response of the road may be different from agriculture or range soils due to compaction and higher gravel contents.

VALIDATION

With reference to the operational requirements for the WEPP model, Foster and Lane (*14*) stated that one of the major factors important to the users is the validity of the model. They stipulated:

> The procedure must be sufficiently accurate to lead to the planning and assessment decision that would be made in the large majority of cases when full information is available. However, more than accuracy is to be considered in establishing the validity of the procedure. The procedure is to be validated, and the validation process and its results are to be documented. The prediction procedure is expected to be composed of a number of modules. Each major module is to be individually validated and the procedure is to be validated as a package (*14*, pp. 10–11).

One of the criteria for validity (*14*) was the requirement that the model should provide a reasonable representation of data covering a broad range of conditions, including situations not appropriate for the Universal Soil Loss Equation (USLE), such as deposition in furrows and complex slope shapes and/or management practices. Judgments on the goodness of fit of the estimates from the procedure to observed data were to be based on the data sets as a whole and not on a few specific and isolated data sets. Quantitative measures of the goodness of fit were to be calculated and presented, but a quantitative level of accuracy figure was not specified because of the great variation in the experimental data that would be used in validation. However, the results were to be at least as good with respect to observed data and known relationships as those predicted by the USLE.

METHODS

Road Erosion Data Collection

National forests in Idaho, Montana, and Colorado were surveyed about which soils were particularly troublesome from an erosion viewpoint. Using this survey, five sites were chosen that contained dirt roads with no added gravel (Figure 1). The d_{50} of the sites ranged from 0.05 to 0.80 mm. Two sites were located on the Clearwater National Forest southwest of Boville, Idaho. One of the sites, Potlatch River, was a sandy loam with a parent material of loess and volcanic ash. The other site, Tee Meadow, was a loam with a loess and volcanic ash parent material. The Tin Cup Creek site was located on the Caribou National Forest southeast of Idaho Falls, Idaho. At this site, the textural description was loam with a parent material of highly weathered shale. The Hahn's Peak site was located on the Routt National Forest north of Steamboat Springs, Colorado. The textural description was a loamy sand with a parent material of fluvial siltstone, claystone, and conglomerate mixed with a loosely consolidated aeolian sandstone and volcanic ash. The fifth site, Paddy Flat, was located on the Payette National Forest southeast of McCall, Idaho. The material was a gravely loamy sand derived from decomposed granite, characteristic of the Idaho batholith. Table 2 gives the site characteristics and Table 3 the soil characteristics of each site.

Two paired 1.52-m-wide by 30.5-m-long bordered plots were used to determine the sediment yield from an overland flow surface and from a wheel rut. The 1.52-m distance corresponded to a typical wheel-to-wheel distance for pickup-sized vehicles. The 30.5-m-long distance was a compromise between a desire to have long plots and the capability of the rainfall simulator.

Either a sheet metal gutter or a wheel rut was aligned with the long dimension of the plot (see Figure 2). By laying out the plots in this manner, overland flow entered the gutter or the rut, flowed parallel to the contributing area, and was measured and sampled at the bottom of the plot. Concentrated flow occurred on both the rut and the gutter, but erosion from the concentrated flow could take place only in the rut. These conditions provided lateral inflow into the gutter or the wheel rut, creating the same conditions as would occur on a rutted forest road.

Since the roads were insloped, the ends of the plots were aligned with the combination of the road and inslope grade. On a road graded with an inslope equal to the road grade, the plot borders would make an angle of 45 degrees to the road centerline.

The inslope also had an effect on the overland flow paths. While the plots appeared to be 1.52 m wide by 30.5 m long, the interrill flow paths were actually 2.2 m long (1.52 × $\sqrt{2}$) and 30.5 m wide. However, the length of the flow path in the rut, 30.5 m, was not changed.

The wheel rut was made by digging a shallow trench (80 to 100 mm deep by 200 mm wide, the approximate dimensions of a pickup truck tire), placing burlap to protect the bed of the rut, soaking the trench with water, and then driving the front and back tire of a pickup in the trench. This shaped the rut and compacted the rut bottom.

The total sediment load as a function of time was measured from grab samples from a free overfall at the outlet from the plot. The samples were taken at regular intervals and the beginning and ending times of runoff recorded. Measurements of the volume or the weight of the samples and the time required to obtain the samples

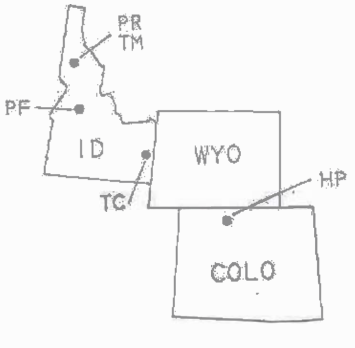

FIGURE 1 Location map of simulator sites.

TABLE 2 Site Characteristics

Site	Porosity	Slope	Water Content $\left(\frac{kg}{kg} \times 100\right)$		
	(%)	(%)	Dry	Wet	Very Wet
Paddy Flat 2	28	7.3	11.0	10.9	14.7
Paddy Flat 3	28	7.0	12.4	13.5	15.0
Hahn's Peak	33	6.8	9.5	11.1	11.4
Tin Cup Creek	38	9.0	9.8	15.9	18.7
Potlatch River	33	5.3	20.6	19.3	19.6
Tee Meadow 1	36	6.5	23.0	23.4	26.8
Tee Meadow 2	35	6.0	22.0	26.8	26.8
Tee Meadow 3	37	7.1	19.4	19.5	22.0

TABLE 3 Bed Material Composition

Site	Percent > 2 mm	d_{84} (mm)	d_{50} (mm)	d_{16} (mm)	G^a	$\frac{d_{84}}{d_{16}}$
Paddy Flat 2 & 3	24	2.70	0.76	0.080	6.53	33.8
Hahn's Peak	8	0.82	0.30	0.085	3.13	9.7
Tin Cup Creek	6	0.72	0.11	0.017	6.51	42.3
Tee Meadow 1,2,3	2	0.66	0.04	0.005	11.8	132.0
Potlatch River	2	0.90	0.05	0.014	10.8	64.3

$^a G = \frac{1}{2}\left(\frac{d_{50}}{d_{16}} + \frac{d_{84}}{d_{50}}\right)$

were used to determine the flow rates. The weight of the oven-dried samples was used to determine the sediment concentration. A 25-kg sample of the top 25 mm of the road surface was taken at each site. This sample was used to determine the size gradation of the road surface.

Rainfall was provided by a Colorado State University (CSU) type simulator (*18*) consisting of Rainjet 78C sprinklers mounted on top of 3-m-tall risers. The risers were placed in two parallel rows 5.28 m apart and arranged in equilateral triangles of 6.1 m on a side. This arrangement resulted in a nominal 50 mm/hour rainfall intensity.

Three 30-minute applications of the 50 mm/hour intensity were applied to the plots. A typical WEPP sequence of three rainfall applications (*18*) was used: a dry run on existing soil water conditions, followed 24 hours later by a wet run, then immediately by a very wet run.

The CSU-type simulator provides 40 percent of the raindrop energy of natural rainfall (*6*). This has often been cited as a drawback to this simulator for investigating erosion due to raindrop impact. In this study, where the depth of flow in the ruts is greater than a few raindrop diameters, the argument is less valid. Additionally, it may be argued that since the energy provided by natural rainfall generates many times more sediment than can be transported (*19*), the entire question of rainfall energy may not be an appropriate concern.

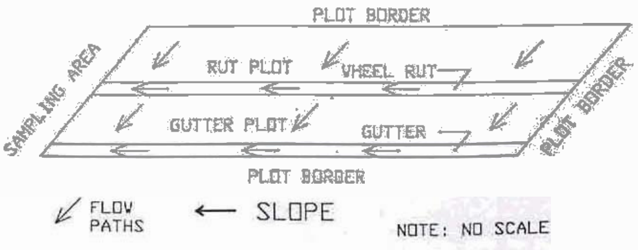

FIGURE 2 Typical plot layout.

WEPP Simulations

WEPP Version 93.1 was used for all simulations. A single storm climate file was specified for each rainfall event to have an average intensity and duration equal to that of the rainfall simulator. Soil files were developed using the details presented by Foltz (*8*). A fallow condition was assumed for the management file with no initial canopy or residue cover. The observed slopes and lengths of each of the plots (*8*) were described in the slope file.

To run the WEPP model, it is necessary to estimate several soil properties not readily available for forest roads: saturated hydraulic conductivity, interrill erodibility, rill erodibility, and critical shear (Table 1). The WEPP model documentation had regression equations to estimate conductivity and erodibility based on rangeland studies (*16*). Elliot et al. (*20*) had nomographs to estimate erodibilities based on cropland soil research. Both crop and range methods were used to estimate erodibilities. The estimated values are presented in Table 4.

After the initial computer runs were complete, the results were studied. It was noted that the cropland erodibility values resulted in an overprediction of erosion rates by a factor of 10. The soils that made up the forest roads had very little silt, and most had less than any of the cropland soils. The nomographs had not been extrapolated beyond the textural levels observed on those soils. In this case, extrapolation may have given a more nearly correct value than the minimum value stated in the nomograph. It was also noted that the predicted runoff from the Paddy Flat sites was much greater than the observed runs. The hydraulic conductivity was increased to 2.87 mm/hour to ensure that the runoff was similar to the observed value so that the accuracy of the erosion estimates could be evaluated and the computer runs carried out again for those sites.

For this study, only the total runoff amount in millimeters and the total erosion in kilograms of sediment per square meter of plot were studied. The output from

TABLE 4 Estimated Soil Erodibility Properties Using Rangeland and Cropland Methods

Site	Texture for fraction < 2 mm			Ksat	Ki, kg s/m^4		Kr, s/m		τ_c, Pa	
	Sand %	Silt %	Clay %	mm/hr	Range	Crop	Range	Crop	Range	Crop
Paddy Flat 2 & 3	81.5	15.9	2.6	2.87*	170,000	2,300,000	0.000417	0.0024	0.1	2.3
Hahn's Peak	89	2.2	8.8	0.0038	82,035	800,000	0.000256	0.0030	0	2.6
Tin Cup Creek	51.0	46.0	3.0	0.1487	512,150	3,300,000	0.000461	0.0080	1.7	2.5
Potlatch River	45.0	50.9	4.1	0.0018	564,588	3,500,000	0.000262	0.0065	2.2	1.9
Tee Meadow 1	46.2	51.6	2.2	0.2399	561,310	3,000,000	0.000591	0.0070	1.8	1.8
Tee Meadow 2	46.2	51.6	2.2	0.0858	561,310	3,000,000	0.000340	0.0070	2.1	1.8
Tee Meadow 3	46.2	51.6	2.2	0.1358	561,310	3,000,000	0.000443	0.0070	2.0	1.8

* Increased after initial computer runs from predicted value of 0.0287 mm/hr to achieve a runoff similar to observed to allow reasonable comparison of erosion results.

the WEPP program provides considerable detail about the distribution of erosion or deposition along a hillslope, a runoff hydrograph, average erosion, sediment yields, and sediment size distribution. The WEPP output file also contains the amount of interrill erosion in kilograms per square meter. This predicted rate should be comparable to the erosion observed from the plots with the metal gutter lining the wheel rut because there was no deposition observed in the channel. Future studies considering the sediment size distributions and runoff hydrographs may provide additional insight into the appropriateness of WEPP for modeling forest road erosion processes.

RESULTS AND DISCUSSION

Runoff

The observed and predicted runoff rates are presented in Table 5. A statistical analysis of these data showed that there were differences in runoff between sites ($P < .001$), which would be expected with different soil conditions. There were differences in runoff between runs ($P < .001$), with the wet and very wet runs generally having greater runoff amounts. Generally, the WEPP model predicted these differences. There were still statistically significant differences between observed and predicted runoff rates ($P < .001$) in spite of the manual adjustment made to the saturated hydraulic conductivity for the Paddy Flat sites. The differences were seldom greater than 10 percent and, generally, the predicted runoff was greater than the observed runoff, so the hydraulic conductivity may have been underestimated. Because of the low hydraulic conductivities of most roads compared to the rainfall and the uniformity of simulated rainfall, large differences would not be expected. Under conditions of lower rainfall amounts, or higher conductivities, greater discrepancies in runoff prediction may be expected. The hydraulic conductivity of the Paddy Flat site was much greater than the other sites, and greater than the prediction equations estimated. The material at Paddy Flat is decomposed granite, with a much higher sand content.

There was a significant interaction between the determination method (observed or predicted) and sites ($P < .001$), meaning that on some sites, runoff was overpredicted, whereas on other sites it was underpredicted. There was also a significant interaction between sites and runs ($P < .001$), meaning that not all sites had greater runoffs from the wet or very wet runs. These interactions can be noted in the runoff values presented in Table 5, for example, the Tee Meadow 3 site, where the site was wet for the initial event (Table 2).

Erosion

The results of the predicted and observed erosion rates are presented in Table 5 for the plots with ruts. When using the rill and interrill erodibilities as predicted by cropland methods, the predicted erosion rate was approximately 10 times the observed sediment yield. This would suggest that managers hoping to estimate road erosion rates using any type of agricultural method should be extremely cautious to ensure that all of the differences between the forest conditions and the agricultural conditions are carefully considered.

TABLE 5 Runoff and Sediment Yield Results Observed in Field from Rut Plots and Predicted by WEPP Model

Site and Texture	RUN	Runoff		Erosion		
					Predicted	
		Observed mm	Predicted mm	Observed kg/m^2	Range kg/m^2	Crop kg/m^2
Hahn's Peak	DRY	22.08	23.39	2.87	0.74	6.58
(Loamy Sand)	WET	21.14	21.87	1.29	0.35	6.30
	VWT	21.14	21.92	0.87	0.35	6.22
Potlatch River	DRY	27.66	28.04	0.62	0.68	9.21
(Sandy Loam)	WET	27.18	29.01	0.57	0.69	8.84
	VWT	27.15	29.89	0.68	0.72	9.07
Tee Meadow 1	DRY	23.24	23.27	1.39	1.77	14.33
(Loam)	WET	25.16	26.79	1.05	2.01	16.28
	VWT	25.06	25.12	0.77	1.89	15.35
Tee Meadow 2	DRY	19.20	23.36	1.28	1.28	16.97
(Loam)	WET	22.42	26.34	1.01	1.43	18.90
	VWT	23.87	27.84	0.83	1.51	24.82
Tee Meadow 3	DRY	24.54	26.51	1.16	1.20	12.86
(Loam)	WET	23.36	26.11	0.82	1.18	12.67
	VWT	22.15	22.15	0.73	1.15	12.44
Tin Cup Creek	DRY	20.10	18.62	1.96	1.01	10.31
(Loam)	WET	22.01	20.87	1.52	1.12	11.52
	VWT	26.36	24.65	1.12	1.32	13.54
Paddy Flat 21	DRY	16.67	16.73	0.90	1.00	4.42
(Gravelly	WET	16.96	16.85	0.57	1.01	4.43
Loamy Sand)	VWT	17.44	17.18	0.58	1.03	4.51
Paddy Flat 22	DRY	19.26	18.64	1.19	0.98	5.82
(Gravelly	WET	19.43	20.68	0.84	0.89	5.51
Loamy Sand)	VWT	19.46	20.69	0.64	0.89	5.53
Means of Runs	DRY	21.59	22.32	1.42	1.06	10.06
	WET	22.21	23.56	0.96	1.06	10.56
	VWT	22.83	23.68	0.78	1.08	11.43
Overall	Mean	22.21	23.19	1.05	1.07	10.68
	Std Dev	3.19	3.84	0.51	0.42	5.21

An analysis of variance was carried out on the sediment yields based on rangeland rill and interrill erodibilities. There were no significant differences between the observed and predicted sediment yields ($P = .211$). There were site differences ($P < .001$), indicating the assumptions about determining different erodibilities for each soil were valid. There were also differences in sediment yields between runs ($P < .001$). On all sites except Potlatch River, sediment yields were lower for succeeding runs, with Run 3 dropping to as little as one-third of Run 1. The WEPP model did not predict this phenomenon, and the reasons for it are the subject of ongoing research (*8*).

To gain additional insight into the modeling of road erosion, it was assumed that on the plots with the gutters, all of the erosion was due to the interrill erosion processes. Table 6 shows the same observed and predicted erosion amounts from the rut plots presented in Table 5 with the observed erosion amounts from the gutter plots and the predicted erosion from the gutter plots based on the interrill erosion rate given in the WEPP model using crop and rangeland interrill erodibility values. Generally the interrill erosion on the gutter plot is underpredicted with the rangeland erodibility and is slightly overpredicted with the cropland values. This suggests that the interrill erodibility of recently graded road is substantially greater than on a similar rangeland soil but is somewhat less than on a similar cropland soil. Because the road was recently graded, it is expected that the soil would behave more like the freshly tilled agricultural soils than the undisturbed rangeland soils. The Paddy Flat experiments had only rut plots at Site 2, and only gutter plots at Site 3.

The rangeland interrill erodibility values were underpredicting on every site, so the rill erosion must have been slightly overpredicting to achieve a similar total erosion rate. This suggests that the rill erodibility of a road rut is somewhat less than the rill erodibility observed on undisturbed rangeland soils of similar texture.

TABLE 6 Estimation of Total and Interrill Erosion Rates

SITE and RUN	Rut Plot Erosion = Rill + Interrill		Gutter Plot Erosion = Interrill Only		
	Observed kg/m^2	Predicted kg/m^2	Observed kg/m^2	Predicted, kg/m^2 Range	Crop
HP DRY	2.870	0.739	0.386	0.015	0.137
HP WET	1.290	0.346	0.327	0.013	0.119
HP VWT	0.870	0.347	0.380	0.013	0.117
PR DRY	0.622	0.677	0.250	0.170	0.836
PR WET	0.568	0.690	0.218	0.168	0.822
PR VWT	0.676	0.717	0.284	0.180	0.885
TM 1 DRY	1.394	1.767	0.553	0.135	0.749
TM 1 WET	1.048	2.006	0.747	0.165	0.916
TM 1 VWT	0.771	1.890	0.614	0.144	0.803
TM 2 DRY	1.283	1.282	0.476	0.120	0.581
TM 2 WET	1.012	1.428	0.668	0.140	0.677
TM 3 DRY	1.159	1.202	0.520	0.160	0.774
TM 3 WET	0.817	1.178	0.476	0.147	0.712
TM 3 VWT	0.730	1.152	0.469	0.136	0.659
TC DRY	1.960	1.007	0.83	0.089	0.486
TC WET	1.520	1.123	1.180	0.097	0.531
TC VWT	1.120	1.321	1.100	0.124	0.68
PF21 DRY	1.187	0.999	*	*	*
PF21 WET	0.839	1.007	*	*	*
PF21 VWT	0.637	1.025	*	*	*
PF22 DRY	0.899	0.976	*	*	*
PF22 WET	0.572	0.885	*	*	*
PF22 VWT	0.585	0.885	*	*	*
PF31 DRY	*	*	0.354	0.036	0.401
PF31 WET	*	*	0.256	0.039	0.436
PF31 VWT	*	*	0.231	0.039	0.436
PF32 DRY	*	*	0.367	0.035	0.401
PF32 WET	*	*	0.282	0.038	0.436
PF32 VWT	*	*	0.257	0.038	0.436
MEANS	1.062	1.093	0.488	0.097	0.567
St Dev	0.516	0.417	0.260	0.059	0.235

* Paddy Flat experiments had only rut plots at site 2 and only gutter plots at site 3.
Rut erosion rates are for rangeland erodibility values only.

CONCLUSION

From an initial study to compare the predicted and measured runoff and erosion from forest roads using the WEPP hillslope model, the following conclusions were reached.

1. WEPP input files can be developed for forest roads.
2. With the rainfall intensities much greater than hydraulic conductivities, the use of the prediction equations in the WEPP manual and the WEPP model predicted runoff within 10 percent of the observed total volume on four out of five soils. On the poorly predicted soil, the observed hydraulic conductivity was greater than predicted by the equations and was also significantly greater than generally observed on native-surface roads.
3. The interrill erosion of a recently graded, non-gravel forest roads is significantly greater than would be expected from undisturbed rangeland soils, but generally not as great from a cropland soil of similar texture.
4. The rill erosion from a wheel rut is somewhat less than the rill erosion of an undisturbed rangeland soil of similar texture, and considerably less (10 percent) than would be predicted with cropland erodibility values. This substantial difference shows the potential hazard of using agriculture erosion technology on forest roads.
5. Following a grading disturbance, soil erosion from forest roads reduces with successive storms, but the WEPP program does not model for this process.

From this initial study, it appears that the WEPP model may provide reasonable estimates of runoff and erosion from forest roads, but further study is necessary to determine road erodibility parameters, and reasons for declines in erosion rates with successive storms. Additional work with more detailed field data and the watershed version of WEPP is necessary to fully evaluate runoff and sediment load rates from complex road prisms.

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REFERENCES

1. Reid, L. M. *Sediment Production from Gravel-Surfaced Forest Roads, Clearwater Basin, Washington.* FRI-UW-8108. Fisheries Research Institute, University of Washington, Seattle, 1981.
2. Hoover, M. D. Water and Timber Management. *Journal of Soil Water Conservation,* Vol. 7, 1952, pp. 75–78.
3. Weitzman, S., and G. R. Trimble. Skid-Road Erosion Can Be Reduced. *Journal of Soil Water Conservation,* Vol. 17, No. 3, 1952, pp. 122–124.
4. Megahan, W. F. and W. J. Kidd. *Effects of Logging Roads on Sediment Production Rates in the Idaho Batholith.* Research Paper INT-123. USDA Forest Service, Intermountain Research Station, Ogden, Utah, 1972.
5. Reid, L. M. and T. Dunne. Sediment Production from Forest Road Surfaces. *Water Resources Research,* Vol. 20, No. 11, 1984, pp. 1753–1761.
6. Ward, T. J. *A Study of Runoff and Erosion Processes Using Large and Small Rainfall Simulators.* WRRI Report No. 215. New Mexico Water Resources Research Institute, Las Cruces, 1986.
7. Elliot, W. J., R. B. Foltz, C. H. Luce, and P. R. Robichaud. A Tool for Estimating Disturbed Forest Site Sediment Production. *Proc., Interior Cedar-Hemlock-White Pine Forests: Ecology and Management Symposium,* Department of Natural Resource Sciences, Washington State University, Pullman, 1993.
8. Foltz, R. B. *Sediment Processes in Wheel Ruts on Unsurfaced Forest Roads.* Ph.D. dissertation. University of Idaho, Moscow, 1993.
9. Megahan, W. F. *Erosion Over Time on Severely Disturbed Granitic Soils: A Model.* Research Paper INT-156. USDA Forest Service, Intermountain Research Station, Ogden, Utah, 1974.
10. Burroughs, E. R., Jr., and J. G. King. *Reduction of Soil Erosion on Forest Roads.* Gen. Tech. Rep. INT-264. USDA Forest Service, Intermountain Research Station, Ogden, Utah, 1989.
11. Simons, D. B., R. M. Li, and T. J. Ward. *Simple Procedural Method for Estimating On-Site Soil Erosion.* Report CER76-77DEB-RML-TJW38. Colorado State University, Fort Collins, 1977.
12. Ferreira, V. A., and R. E. Smith. The Limited Physical Basis of Physically Based Hydrologic Models. In *Modeling Agricultural, Forest, and Rangeland Hydrology, Proc., 1988 International Symposium,* Chicago, Ill. ASAE, St. Joseph, Mich., 1988, pp. 10–18.
13. Foster, G. R., and L. D. Meyer. Mathematical Simulation of Upland Erosion by Fundamental Erosion Mechanics. *Proc., Sediment-Yield Workshop.* USDA Sediment Lab, Oxford, Miss., 1972.
14. Foster, G. R., and L. J. Lane, compilers. *User Requirements: USDA Water Erosion Prediction Project (WEPP).* NSERL Report No. 1. USDA-ARS, National Soil Erosion Research Laboratory, Purdue University, West Lafayette, Ind., 1987.
15. Nearing, M. A., G. R. Foster, L. J. Lane, and S. C. Finkner. A Process-Based Soil Erosion Model for USDA-Water Erosion Prediction Project Technology. *Transactions of the ASAE,* Vol. 32, No. 5, 1989, pp. 1587–1593.
16. Lane, L. J., and M. A. Nearing, eds. *USDA-Water Erosion Prediction Project: Hillslope Profile Model Documentation.* NSERL Report No. 2. USDA-ARS, National Soil Erosion Research Laboratory, Purdue University, West Lafayette, Ind., 1989.
17. Liebenow, A. M., W. J. Elliot, J. M. Laflen, and K. D. Kohl. Interrill Erodibility: Collection and Analysis of Data From Cropland Soils. *Transactions of the ASAE,* Vol. 36, No. 6, 1990, pp. 1882–1888.
18. M. E. Holland. *Design and Testing of a Rainfall System.* CER 69-70 MEH 21. Colorado State University Experiment Station, Fort Collins, 1969.
19. Schwab, G. O., D. D. Fangmeier, W. J. Elliot, and R. K. Barnes. *Soil and Water Conservation Engineering,* 4th ed. John Wiley and Sons, New York, 1993.
20. Elliot, W. J., J. M. Laflen, and G. R. Foster. *Soil Erodibility Nomographs for the WEPP Model.* Paper No. 932046, ASAE, St. Joseph, Mich., 1993.

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