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## Rangeland Evaluation of WEPP Hydrology

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### Abstract

The hydrology component of the Water Erosion Prediction Project (WEPP) utilizes the Green and Ampt infiltration equation to simulate the rate and volume of excess rainfall. Excess rainfall is routed along the hillslope using the kinematic wave model to determine the duration of runoff and peak runoff rate for erosion calculation. The model was evaluated on 25 rangeland sites in the western United States. The result indicates that, in general, the model is doing an acceptable job of predicting infiltration rate, volume, and peak runoff rate.

### Introduction

Since the 1960's, the Universal Soil Loss Equation (USLE), an empirical equation (Wischmeier and Smith, 1978), has been used widely to estimate water induced soil loss. In the 1980's, there was a pressing need for a physically-based, process oriented model to overcome many of the deficiencies associated with USLE in predicting soil loss. In the light of this, the USDA-Water Erosion Prediction Project (WEPP) model was initiated. The model represents a new erosion prediction technology based on fundamentals of infiltration theory, hydrology, soil physics, plant science, hydraulics, and erosion mechanics (Lane and Nearing, 1989). The model provides several major advantages over existing erosion models, namely, it reflects the effects of land-use changes due to agricultural, range and forestry practices and it models spatial and temporal variability of the

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factors affecting the hillslope hydrologic and erosion regime.

Accurate estimates of the total storm infiltration and infiltration rate are essential in the WEPP model. Total infiltration provides total excess rainfall and runoff while infiltration rate permits estimation of excess rainfall rates and runoff rates. The model calculated storm total runoff and peak runoff are used in calculating rill erosion and flow sediment transport capacity. The objective of this study was to evaluate the infiltration and runoff routing component of the WEPP model on various rangeland sites with different soil, climate, and vegetal cover in the western United States.

### Model Description

Only a brief description of the WEPP hydrology (infiltration and runoff routing) is provided and readers may refer to Lane and Nearing (1989) for more details.

### Infiltration

The infiltration equation used in the WEPP model is a solution of the single layer Green and Ampt equation (1911) for unsteady rainfall as presented by Chu (1978),

$$f_t = \left[ K_e \left( 1 + \frac{N_s}{F} \right) \right] \quad (1)$$

where  $f_t$  = infiltration rate, L/T  
 $K_e$  = effective hydraulic conductivity, L/T  
 $t$  = time, T  
 $N_s$  = effective matric potential L, and  
 $F$  = cumulative infiltration depth, L.

The effective matric potential,  $N_s$  is given by,

$$N_s = (\eta_e - \theta) \psi \quad (2)$$

where  $\eta_e$  = effective porosity of 0-20 cm of soil, L/L  
 $\theta$  = volumetric soil water content of 0-20 cm of soil, L/L, and  
 $\psi$  = the average wetting front capillary potential, L.

Soil water content is provided by the water balance routine which estimates evapotranspiration and soil water routing (Savabi et al., 1989).

### Surface Runoff

Rainfall excess is produced when the rainfall intensity exceeds the infiltration rate. Calculated rainfall excess is then routed downslope to estimate the overland flow hydrograph using the kinematic wave method.

The kinematic wave equations for one-dimensional overland flow are derived by assuming that the land slope is equal to the friction slope. The kinematic wave equations for runoff on a plane are the continuity equation,

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = r - f = v \quad (3)$$

and the momentum equation,

$$q = \alpha h^{3/2} \quad (4)$$

where  $h$  = local depth of flow, L  
 $q$  = discharge per unit width, L<sup>2</sup>/T  
 $x$  = distance down the plane, L  
 $r$  = rainfall intensity, L/T  
 $v$  = rainfall excess rate, L/T  
 $f$  = infiltration rate, L/T, and  
 $\alpha$  = depth-discharge coefficient, L<sup>1/2</sup>/T = C  $\sqrt{S}$   
 $C$  = Chezy coefficient L<sup>1/2</sup>/T, and  
 $S$  = slope, L/L

If the rainfall excess rate,  $v$ , is constant, then Eqs. 3 and 4 can be solved analytically by the method of characteristics (Eagleson, 1970). Analytical solutions to these equations have been derived for the case where  $v$  is made up of a series of step functions (Eggert, 1987). The Chezy equation is used in the WEPP model to describe flow characteristics. The Chezy friction coefficient,  $C$ , is calculated for rill and interrill areas based on soil surface roughness and surface cover (Gilley et al., 1989).

### Infiltration Parameter Estimation

The Green-Ampt parameters needed for application of WEPP are porosity ( $\eta$ ), wetting front capillary potential ( $\psi$ ), and hydraulic conductivity ( $K_s$ ). In the WEPP model the average soil properties for the primary tillage zone for agricultural applications and the top 20 cm of the soil for rangeland applications are used to predict infiltration parameters (Rawls et al., 1989).

Saturated hydraulic conductivity can be either chosen by users or calculated by the model using the following equation (Rawls and Baumer, 1989):

$$K_s = \left( \frac{(\phi_c - \theta_r)^3}{(1 - \phi_c)^2} \right) \left( \frac{BD^2}{\theta_r} \right) \left( .00035 (C^2) \right) \quad (5)$$

where  $\phi_c$  = corrected porosity (total porosity corrected for rocks and air), L/L  
 $\theta_r$  = residual soil water, L/L  
 BD = soil bulk density, M/L<sup>3</sup>  
 C = coefficient calculated from soil characteristics given by:

$$C = -0.17 + .181(C1) - 0.00000069(Sa^2)(C1^2) - 0.00000041(Sa^2)(Si^2) + 0.000118(Sa^2)(BD^2) + 0.00069(C1^2)(BD^2) + .000049(Sa^2)(C1) - 0.000085(Si)(C1^2)$$

Si = silt, %  
 C1 = clay, %  
 Sa = sand, %

Management has major effects on ground and canopy cover and thus hydraulic conductivity. These effects are incorporated using the proportions of the unit surface area composed of canopy and open space and further proportioning the canopy space and open space into the soil surface with or without ground cover.

$$K_e = (CF) [(A)(CAN-BC) + CRC(BC)] (K_s) + [(A)(OP-BO) + CRC(BO)] (K_s) \quad (6)$$

where CF = canopy factor = 1 + % canopy cover/100 (dimensionless)

A = macro-porosity factor (dimensionless)  
 CAN = canopy area, L<sup>2</sup>/L<sup>2</sup>  
 BC = bare area under canopy, L<sup>2</sup>/L<sup>2</sup>  
 CRC = crust factor (dimensionless)  
 $K_s$  = hydraulic conductivity of soil, L/T (Eq. 5)  
 OP = open area outside canopy, L<sup>2</sup>/L<sup>2</sup>  
 BO = bare area in open space, L<sup>2</sup>/L<sup>2</sup>

For more detail see Rawls et al. (1989).

Daily canopy cover and ground cover are simulated by WEPP crop growth and residue decomposition components.

### Model Evaluation

The hydrology component of WEPP was evaluated using data from WEPP rangeland field experiments conducted during the summers of 1987 and 1988 on 25 soil/vegetation sites throughout the western half of the U. S. (Simanton et al., 1987).

A rotating-boom rainfall simulator (Swanson, 1965) was employed to simulate rainfall of 65 mm/hr on plots (3.1 x 10.1 m) at each site. Rainfall simulation lasted until the rate of runoff was not changing significantly, about 60 min on most sites. A precalibrated runoff measuring flume was set at the trough exit and flow depths were made using pressure-transducer bubble gages.

A 49 pin-point meter to measure vegetation composition, foliar canopy cover, and ground surface characteristics of each plot was used (Table 1) and a complete soil pedon description and analysis was made by the Soil Conservation Service (SCS) at each site. Pedon analysis includes particle size distribution, soil moisture release curves, organic carbon, cation exchange capacity, and several other soil physical and chemical properties (Table 1).

Table 1. Description of natural runoff plots. Bulk density and soil water content were measured prior to rainfall simulation.

Site	Soil				water		% Veg. Cover	
	% clay	% sand	% rocks	BD (g/cm <sup>3</sup> )	(% by vol.)		canopy ground	
<u>1987 Simulation</u>								
A1 Walnut Gulch, AZ	16	66	52	1.40	15		32	82
A2 Walnut Gulch, AZ	17	60	5	1.50	15		31	45
B1 NTS, NV	7	65	25	1.33	2		17	69
B2 NTS, NV	5	60	19	1.60	15		26	60
D1 Chickasha, OK	16	54	0	1.42	27		64	91
D2 Chickasha, OK	14	53	0	1.46	24		34	56
E2 Woodward, OK	15	43	0	1.38	19		42	47
F1 Sidney, MT	17	47	9	1.28	12		23	81
G1 Meeker, CO	40	8	1	1.29	19		11	42
H1 Cottonwood, SD	49	12	1	1.22	18		31	63
H2 Cottonwood, SD	43	23	2	1.20	21		36	77
I1 Los Alamos, NM	8	44	2	1.37	15		27	71
J1 Cuba, NM	10	64	0	1.33	6		28	61
K1 Susanville, CA	17	44	35	1.00	7		27	64
<u>1988 Simulation</u>								
D1 Chickasha, OK	18	54	0	1.50	7		39	99
D2 Chickasha, OK	14	53	0	1.52	16		7	84
E1 Ft. Supply, OK	3	91	0	1.54	7		43	47
E2 Woodward, OK	15	43	0	1.45	12		52	73
E3 Ft. Supply, OK	3	91	0	1.54	6		39	49
E4 Freedom, OK	14	44	0	1.57	12		88	97
E5 Freedom, OK	14	44	0	1.47	8		39	71
H1 Cottonwood, SD	49	12	1	1.52	15		46	68
H2 Cottonwood, SD	43	23	2	1.47	15		49	81
K1 Susanville, CA	17	44	35	1.11	17		30	83
L1 Los Banos, CA	43	17	0	1.74	15		3	97

The WEPP single storm option requires the following data: soil--texture, bulk density, organic matter, cation exchange capacity, random roughness and saturated hydraulic conductivity ( $K_s$ ); cover--canopy, ground and rock; rainfall--amount, duration, ratio of time to rainfall peak/rainfall duration, and ratio on maximum rainfall intensity/average rainfall intensity. With the exception of saturated hydraulic conductivity, these data were collected and/or calculated for each rainfall simulator plot. Saturated hydraulic conductivity ( $K_s$ ) for each plot was calculated using Eq. 5 and adjusted for vegetation cover and rocks. A value for random roughness was not available on all the plots, therefore, a value of 8 mm was selected. This value will correspond to depressional storage of 1 mm (Onstad, 1984).

### Results and Discussions

The WEPP single storm model was tested on each rainfall simulator plot. The parameter values used in the simulation test were taken from Table 1. The model-simulated total storm infiltration, final infiltration rate and peak runoff rate were compared with field measured values. Generally, the model-simulated total infiltrations compare very well with the measured data (Fig. 1). However, the differences between some simulated and measured total infiltration are more than desirable (Fig. 1). Reasons for such a simulation error include Green and Ampt parameter estimation and/or depressional storage estimation. Data points 1, 2, 3, and 4, which show considerable discrepancy (Fig. 1), correspond to rainfall simulation sites A1, B1, K1-1987 and K1-1988, respectively (Table 1). The soils in these sites contain high rock fragments (>25 % by weight) with site A1 having the highest rock fragments (52%) and showing the highest discrepancy (simulated total infiltration 34 mm and measured 54 mm). The model assumes that saturated hydraulic conductivity ( $K_s$ ) decreases as rock fragment increases using the following equation (Brakensiek et al., 1986):

$$K_{sr} = K_s * (100 - \% \text{ rocks})/100 \quad (7)$$

where  $K_{sr}$  = saturated hydraulic conductivity adjusted for rock fragments, L/T

and  $K_s$  = saturated hydraulic conductivity, L/T.

Therefore, for a given soil and antecedent soil water content the model simulates a lower total infiltration value on soil with rocks than without rocks.

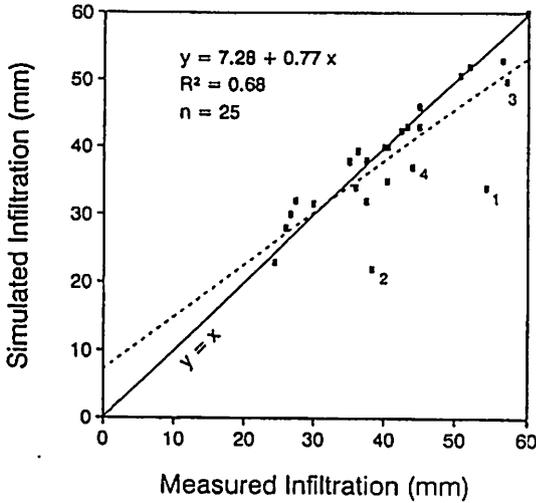


Fig. 1. Comparison of field measured and WEPP simulated total infiltration of natural rainfall simulated plots in 1987 and 1988.

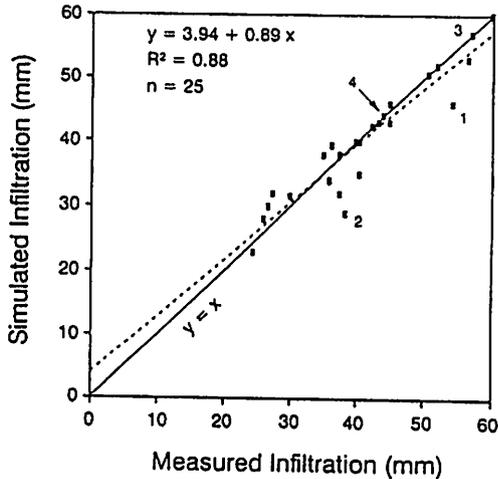


Fig. 2. Comparison of WEPP simulated and measured infiltration depth for natural rainfall simulated plots in 1987 and 1988. ( $K_s$  was not adjusted for coarse fragments).

Qualitative estimates of the effects of rock fragments on soil saturated hydraulic conductivity are limited and are not conclusive. Mehuys et al. (1975) reported that the presence of rock fragments decreased the unsaturated conductivity. The same relationship was reported by Dunn and Mehuys (1984). However, Magier and Ravina (1984) reported that for compacted soils, increasing rock fragment content increased soil hydraulic conductivity.

Therefore, the model was retested neglecting  $K_s$  adjustments for coarse fragments and the new model simulated infiltrations were compared with measured data (Fig. 2). The predictability of the model was improved. The calculated intercept of regression between simulated and measured infiltration was reduced from 7.28 mm to 3.94 mm. Furthermore, the calculated slope of the regressions increases from .77 to .89 (Figs. 1 and 2).

Model simulated final infiltration rates (at the end of a one hour rain) are compared with the field measured final infiltration rate (Fig. 3). The simulation error should be the result of calculation and/or adjustment of  $K_s$  because the influence of depression storage and/or effective matric potential on infiltration rate diminishes at the time when infiltration rates reach a steady state.

Excess rainfall rate (rainfall rate-infiltration rate) is routed along the hillslope to simulate the runoff hydrograph. Comparison of the simulated and measured peak runoff rate is given in Fig. 4. The difference between simulated and measured peak runoff is a result of the error in calculating final infiltration, hence the time of final infiltration coincides with the peak runoff rate for the rainfall simulation tests. Further evaluation of the runoff routing component, particularly the Chezy friction coefficient (C) estimation, is not possible since measuring random roughness on a vegetated site is difficult and was not available.

### Summary and Conclusions

The hydrology component of WEPP utilizes the Green-Ampt infiltration equation to calculate the infiltration rate and volume and excess rainfall. Saturated hydraulic conductivity is determined based on soil physical properties and adjusted for the effect of vegetal cover, crust formation, and macroporosity. Excess rainfall is routed along the hillslope using the kinematic wave approach to provide peak and total runoff for erosion calculation.

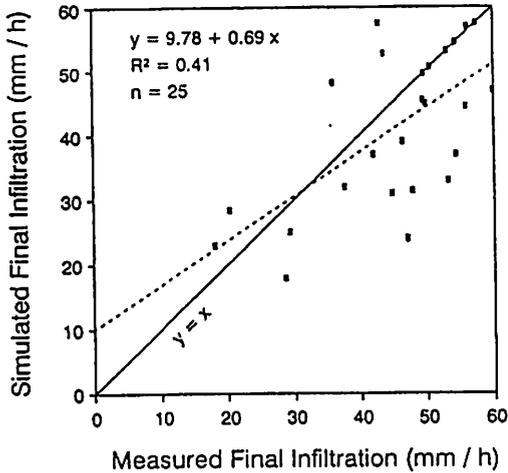


Fig. 3. Comparison of field measured and WEPP simulated final infiltration rate for natural rainfall simulated plots in 1987 and 1988. ( $K_S$  was not adjusted for coarse fragments).

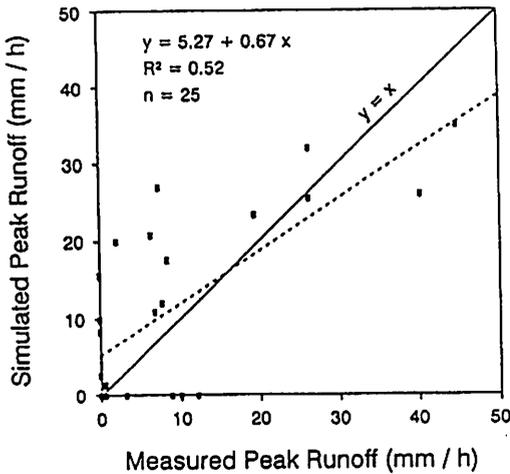


Fig. 4. Comparison of WEPP simulated and measured peak rate of runoff for natural rainfall simulated plots in 1987 and 1988. ( $K_S$  was not adjusted for coarse fragments).

Data obtained from the WEPP rangeland experiments conducted during 1987 and 1988 were used to evaluate the WEPP hydrology component for rangelands. Results indicate that, in general, the model is capable of predicting total infiltration and runoff. However, the model simulates final infiltration (infiltration at the end of one hour) and peak runoff rate with some discrepancy. Comparison of our results with the earlier findings (DeVours and Gifford, 1986; Hutton and Gifford, 1988) indicates that the adjustment of  $K_s$  for canopy and ground cover, crust formation, coarse fragments, and macroporosity had improved the applicability of the Green and Ampt infiltration equation to rangelands. The effect of coarse fragments on soil hydraulic conductivity, however, needs further evaluation.

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