A Rangeland Hydrology and Erosion Model

Haiyan Wei[a], Mark. Nearing[a], Jeffery Stone[a], Ken Spaeth[b], Fred Pierson[a], Mark Weltz[c], and Mariano Hernandez[a]

[a]Agricultural Research Service, Tucson, AZ. [b]Natural Resources Conservation Service, Ft. Worth, TX. [c]Agricultural Research Service, Reno, NV.

Introduction

Soil loss rates on rangelands are considered as one of the few quantitative indicators for assessing rangeland health and conservation practice effectiveness. An erosion model to predict soil loss specific for rangeland applications is needed because existing erosion models were developed from croplands where the hydrologic and erosion processes are different from those found on rangelands.

The Rangeland Hydrology and Erosion Model (RHEM) was designed to fill that need. RHEM represents erosion processes under disturbed and undisturbed rangeland conditions, it adopts a new splash erosion and thin sheet-flow transport equation developed from rangeland data, and it links the model hydrologic and erosion parameters with rangeland plant communities by providing a new system of parameter estimation equations based on 204 plots in 49 rangeland sites distributed across 15 western U.S. states. RHEM estimates runoff, erosion, and sediment delivery rates and volumes at the spatial scale of the hillslope and the temporal scale of a single rainfall event.

Experiments were conducted to generate independent data for model evaluation and the r^2 of runoff and erosion predictions were 0.87 and 0.50 respectively, which indicated the ability of RHEM to provide reasonable runoff and soil loss prediction capabilities for rangeland management and research needs.

What is RHEM?

- **R**angeland **H**ydrology and **E**rosion **M**odel (RHEM) is designed for government agencies, land managers and conservationists who need sound, science-based technology to model and predict runoff and erosion rates on rangelands and to assist in assessing rangeland conservation practices effects.

What is RHEM capable of?

- RHEM estimates runoff, erosion, and sediment delivery rates and volumes at the spatial scale of the hillslope and the temporal scale of a single rainfall event.
- RHEM is also designed so to be used as a runoff and erosion calculator, or "engine", within another model that works on the larger scale, such as KINEROS or SWAT.

What are the main components of RHEM?

- A model core engine that integrates the basic model concepts and essential equations.
- Equations that estimate the hydrology and erosion input parameters as a function of commonly measured soil and plant properties.
- A user-friendly web-based interface.

Model description

Model characters

- RHEM is developed specifically for rangeland applications based on fundamentals of infiltration, hydrology, plant science, hydraulics, and erosion mechanics. It adopts a new splash and sheet erosion equation developed from rangeland soils.
- RHEM models splash erosion and thin sheet-flow transport as the dominant set of processes on undisturbed rangeland sites. For representing erosion on sites with significant disturbances, the model has the capacity to combine splash and sheet erosion with concentrated flow erosion based on the degree of the system disturbance.
- RHEM parameterizes hydraulic and erodibility coefficients for different plant groups based on vegetation cover and soil properties.
- To capture the heterogeneity of rangeland topography, plant types and surface conditions, RHEM uses a larger representative area to measure, model, and parameterize rainfall splash and sheet erosion.

Model equations

Infiltration (Green-Ampt equation):

$$K_e t = F_i - \psi\theta_d \ln\left(1 + \frac{F_i}{\psi\theta_d}\right)$$

where K_e is infiltration rate; t is time after time to ponding, F is the cumulative infiltration depth; ψ is average capillary potential; and θ_d is soil moisture deficit.

Kinematic wave routing equation:

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = v$$

where h is depth of flow; q is discharge per unit width of the plane; and x is distance from top of plane.

Sediment continuity equation:

$$\frac{dG}{dx} = D_{ss} + D_c$$

where G is sediment load; D_{ss} is splash and sheet erosion rate; and D_c is concentrated flow erosion rate.

Splash and sheet erosion:

$$D_{ss} = K_{ss} I^{1.052} q^{0.592}$$

where K_{ss} is the splash and sheet erosion coefficient; and I is rainfall intensity.

Concentrated flow erosion:

$$D_c = K_c(\tau - \tau_c)\left(1 - \frac{G}{T_c}\right)$$

where K_c is the concentrated flow erodibility coefficient; τ is the shear stress of the concentrated flow; τ_c is the critical shear stress for the soil; and T_c is the sediment transport capacity of the flow.

Parameter estimation equations

Estimation equations for the splash and sheet erosion coefficient, K_{ss}	r^2	n
Sod grass		
$K_{ss} = 10$^$(3.54 - 0.85 gcover^{\dagger} - 0.37 cancov)$	0.26	75
Shrub		
$K_{ss} = 10$^$(3.89 - 1.08 rokcov - 1.98 cancov)$	0.54	30
Annual grass and forbs		
$K_{ss} = 10$^$(3.77 - 1.82 clay - 0.29 gcover - 0.25 cancov)$	0.71	22
Bunch grass excluding tall grass prairie and Kentucky Blue		
$K_{ss} = 10$^$(3.30 - 0.57 litter - 0.40 cancov)$	0.27	113
Bunch grass plots that are tall grass prairie and/or Kentucky Blue		
$K_{ss} = 473$		18

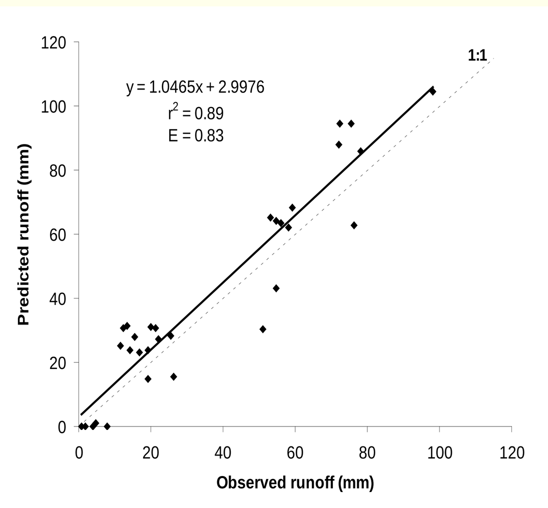
Estimation equations for the Green-Ampt hydraulic conductivity, K_e	r^2	n
All		
$K_e = 10$^$(1.03 - 1.60 clay + 0.45 gcover)$	**0.40**	**184**
Sod grass		
$K_e = 10$^$(1.18 - 1.60 clay + 0.55 cancov)$	0.41	72
Shrub		
$K_e = 10$^$(0.86 - 0.46 clay + 1.01 rokcov + 0.22 gcover)$	0.60	32
Annual grass and forbs		
$K_e = 10$^$(1.88 - 0.28 xhydgrp)$	0.80	10
Bunchgrass		
$K_e = 10$^$(0.07 + 0.89 sand + 0.74 gcover)$	0.40	131

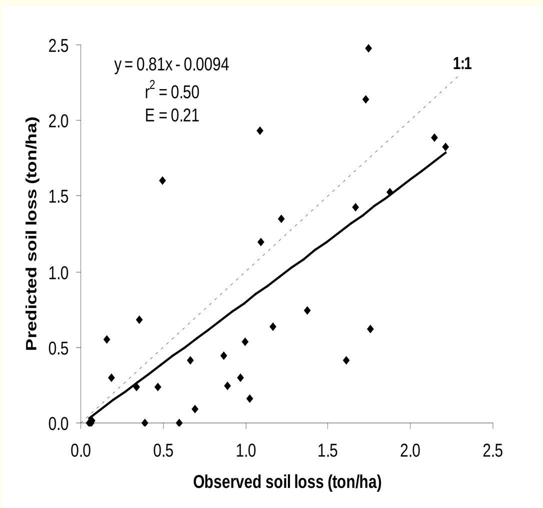
where, *clay* is the clay content of surface soil; *gcover* is total ground cover; *cancov* is the canopy cover; *rokcov* is rock cover; *xhydgrp* refers to the hydrologic group of the soil; *sand* is the sand content of surface soil; and litter is litter cover on soil surface.

Data and experiments

RHEM was developed based on the WEPP-IRWET dataset -- rainfall simulation experimental measurements from 204 plots, 49 rangeland sites located in 15 western states.

Validation





Predicted runoff and soil loss from RHEM vs. observed values from a set of independent rainfall simulation experiments at 6 sites located south of Tucson, AZ. r^2: coefficient of determination; E: Nash-Sutcliffe efficiency coefficient.

Applications in progress

Natural Resources Inventory (NRI)
RHEM was applied to evaluate runoff and erosion at 10,000 NRI ecological sites.

Conservation Effects Assessment Project (CEAP)
RHEM was selected to assess scenarios for various management practices for CEAP goals.

Soil and Water Assessment Tool (SWAT)
RHEM was integrated with SWAT for basin scale assessment.

Kinematic Runoff and Erosion Model (KINEROS)
RHEM was integrated with KINEROS for watershed scale assessment.

RHEM web-interface address:
http://dss.tucson.ars.ag.gov/rhem/