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Spatial variability of cover affecting erosion and sediment yield in overland flow

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Abstract A simple overland flow sediment yield model is applied to an irregular slope to evaluate the influence of varying slope shape, length, and steepness, as well as percent canopy and surface ground cover on sediment yield (mean sediment concentration) along the hillslope. Assuming a uniform distribution of cover along a hillslope profile can result in significant distortions in apparent, or simulated, erosion and sediment deposition rates and thus sediment yield. Therefore, the concept of non-uniformity of cover must be incorporated in simulation models to more accurately describe hillslope erosion and sediment yield processes.

INTRODUCTION

Direct links exist between the form and structure of hillslopes, vegetation composition and patterns, soil and soil surface characteristics, and the interactive processes shaping them. Modern erosion prediction technology (Lane *et al.*, 1992) often represents a hillslope as a single plane, a cascade of plane segments, or a combination of planar and convex or concave segments. Estimated erosion is generally based on spatially-averaged estimates of canopy cover and surface ground cover along the hillslope profile in the direction of flow.

The objectives of this study are (a) to characterize the spatial variability (in the down slope direction) of vegetation canopy cover, surface ground cover (rock, gravel, basal area, litter) referred to as ground cover hereafter, and topography for a small basin on the Walnut Gulch Experimental Watershed in southeastern Arizona, USA; (b) to incorporate this spatial variability into a simple overland flow sediment yield model for rill and inter-rill erosion; (c) to use the sediment yield model to determine the influence of this spatial variability on hillslope erosion processes; and (e) to interpret the erosion model simulation results in the context of stability and disequilibrium of hillslopes.

DESCRIPTION OF THE MODEL

A simple, yet physically-based, sediment yield model is used to evaluate qualitatively the influence of spatial variability in hillslope properties on sediment yield. Though lacking the superior predictive capability of more complex models, the single-event model used has the advantages of an analytic solution, simplified input, and a limited number of parameters. Overland flow on a plane is described by the kinematic wave

$$\frac{\partial h}{\partial t} + \frac{\partial q}{\partial x} = R \tag{1}$$

$$q = kh^{3/2} \tag{2}$$

where h is the local depth of flow (m), t is time (s), q is discharge per unit width ($m^2\ s^{-1}$), x is distance in the direction of flow (m), R is rainfall excess rate ($m\ s^{-1}$), and $k = Cs^{1/2}$, where C is the Chezy coefficient ($m^{1/2}\ s^{-1}$) and s is slope. For this particular formulation, rainfall excess rate is constant and uniform:

$$R(t) = \begin{cases} R & 0 \le t < T \\ 0 & \text{Otherwise} \end{cases} \tag{3}$$

where T is the duration of rainfall excess and the other variables are described above. The continuity equation for sediment is:

$$\frac{\partial (ch)}{\partial t} + \frac{\partial (cq)}{\partial t} = e_i + e_r \tag{4}$$

where c is sediment concentration ($kg\ m^{-3}$), e_i is the inter-rill erosion rate ($kg\ s^{-1}\ m^{-2}$), and e_r is rill erosion or deposition rate ($kg\ s^{-1}\ m^{-2}$).

The inter-rill erosion rate is assumed to be:

$$e_i = k_i R \tag{5}$$

where k_i is the inter-rill coefficient ($kg\ m^{-3}$). The rill erosion/deposition equation is:

$$e_r = k_r[Tc - cq] = k_r[(b/k)q - cq] \tag{6}$$

where k_r is the rill coefficient (m^{-1}), Tc is the transport capacity ($kg\ s^{-1}\ m^{-1}$) and is equal to $(b/k)q$, b is a transport capacity coefficient ($kg\ s^{-1}\ m^{-2.5}$), k is the hydraulic resistance coefficient, c is sediment concentration ($kg\ m^{-3}$), and q is discharge per unit width ($m^2\ s^{-1}$). Equations (1) through (4) (with equations (5) and (6) substituted for the right hand side of equation (4)) are called the coupled kinematic wave and erosion equations for overland flow. The form of equations (5) and (6) was suggested by Foster & Meyer (1972). An analytic solution of the coupled kinematic wave and erosion equations for overland flow during the rising hydrograph only was derived by Hjelmfelt *et al.* (1975). An analytic solution for the entire runoff hydrograph was derived by Lane *et al.* (1988).

The sediment continuity equation can be integrated (Shirley & Lane, 1978) to produce a sediment yield equation for the runoff event as:

$$q_s = q_{vol}(x)\,[(b/k) + (k_i - b/k)\,g(k_r,x)] \tag{7}$$

where q_s is storm sediment yield per unit width of the plane ($kg\ m^{-1}$), q_{vol} is storm runoff volume per unit width ($m^3\ m^{-1}$), x is distance down the plane (m) and g is a function of k_r and x defined as:

$$g(k_r,x) = [1.0 - \exp(-k_r)(x)]/(k_r)(x) \tag{8}$$

This sediment yield equation for a single plane has been extended to irregular slopes to perform the analyses reported herein. Consider a slope composed of n slope segments x_1, x_2, up to x_n where $x_n = L$ = total slope length (m). Hillslope topography can be represented with increasing accuracy by including more segments.

in Fig. 1. Simulated mean sediment concentration based on spatially uniform average canopy and ground cover and measured (spatially varying) canopy and ground cover are shown in Fig. 2. Notice that simulated mean sediment concentration (total sediment yield divided by total runoff volume) varies in the flow direction and assuming average values for canopy and ground cover significantly distorts the spatial distribution of mean sediment concentration along the hillslope profile.

We hypothesize that departures from a uniform mean sediment concentration in the flow direction represent areas of disequilibrium where either net rill erosion (increasing concentration) or net rill deposition of sediment (decreasing concentration) are occurring. Under this hypothesis, the simulation results suggest that, with spatially varying canopy and ground cover, the hillslope profile is near equilibrium from 0 to about 50 m, is subject to increasing erosion from 50 m to about 90 m, and is nearly in equilibrium for the remaining 32 m of the hillslope. In contrast, a simulation based on spatially uniform canopy and ground cover suggests disequilibrium at all points along the profile. Erosion appears to be occurring from 0 to about 85 m, and then deposition for the remaining 37 m.

Gross distortions in estimated erosion and sediment deposition rates, and thus sediment yield, can result if the assumption of average canopy and ground cover values are used in distributed sediment yield models. This suggests a change in conceptualiza-

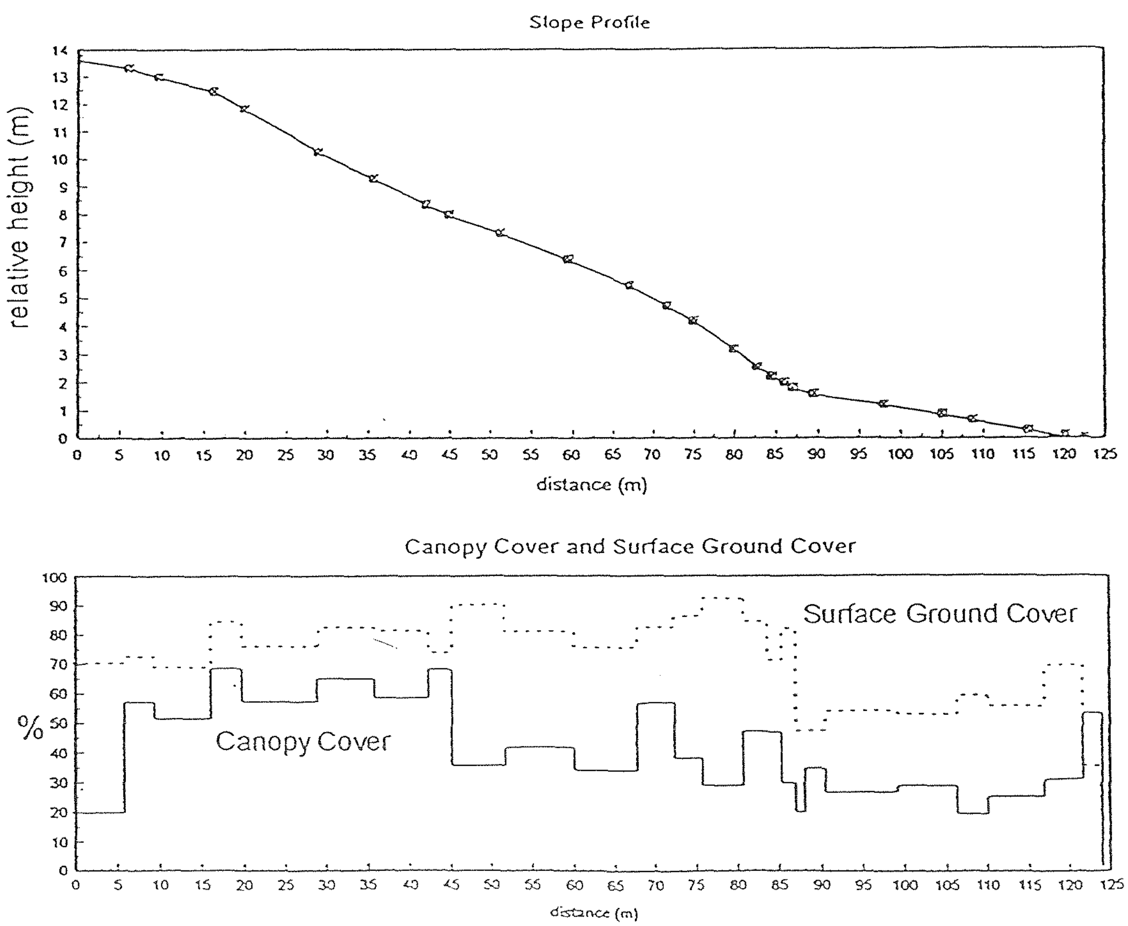

Fig. 1 Representative hillslope profile and measured values of canopy cover and surface

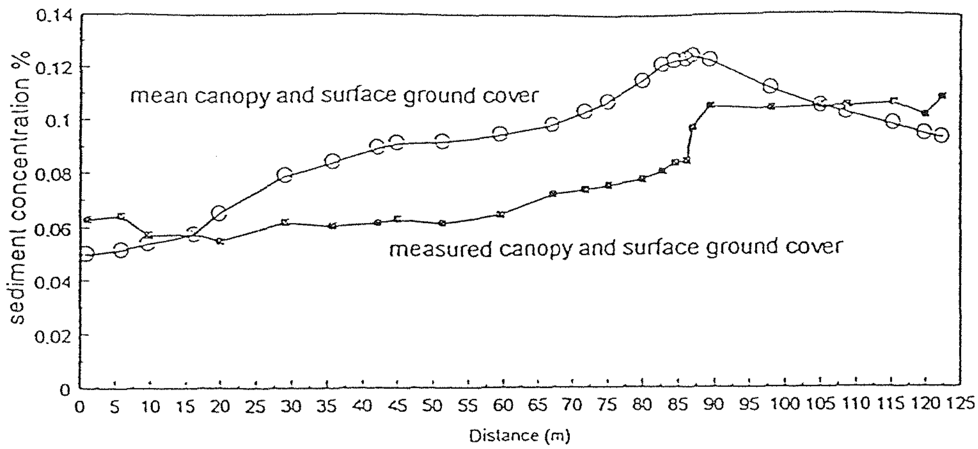

Fig. 2 Simulated mean sediment concentration for the representative hillslope profile on Watershed K2. Simulations with measured values of canopy and ground cover varying along the profile and using average values of canopy and ground cover.

tion of distributed erosion and sediment yield modeling on hillslopes. We recommend a concept of non-uniformity of cover be adopted and question the appropriateness of using overall averages for canopy and ground cover.

DISCUSSION

We have demonstrated that assuming a uniform distribution of cover along a hillslope profile can result in significant distortions in apparent, or simulated, erosion and sediment deposition rates and thus sediment yield. Therefore, the concept of non-uniformity of cover must be incorporated in simulation models to describe more accurately hillslope erosion and sediment yield processes.

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REFERENCES

Bonham, C. D. (1989) *Measurements for Terrestrial Vegetation*. Wiley, New York.

Foster, G. R. & Meyer L. D. (1972) A closed-form soil erosion equation for upland areas. Chapter 12 in: *Sedimentation* (Einstein), (ed. by H. W. Shen). Colorado State University, Fort Collins, Colorado.

Hjelmfelt, A. T., Piest, R. F. & Saxton, K. E. (1975) Mathematical modeling of erosion on upland areas. *Proc. 16th IAHR Congress* (Sao Paulo, Brazil) vol. 2, 40-47.

Lane, L. J., Renard, K. G., Foster, G. R. & Laflen, J. M. (1992) Development and application of modern soil erosion prediction technology — The USDA experience. *Austral. J. Soil Res.* 30, 893-912.

Lane, L. J., Shirley, E. D. & Singh, V. P. (1988) Modelling erosion on hillslopes. In: *Modelling Geomorphological Systems* (ed. by M. G. Anderson), 287-308. John Wiley, Chichester.

Renard, K. G., Lane, L. J., Simanton, J. R., Emmerich, W. E., Stone, J. J., Weltz, M. A., Goodrich, D. C. & Yakowitz

Sellers, W. D. (1964) The climate of Arizona. In: *Arizona Climate* (ed. by C. R. Green & W. D. Sellers), 5-64. University of Arizona Press, Tucson, Arizona.

Shirley, E. D. & Lane, L. J. (1978) A Sediment Yield Equation from an Erosion Simulation Model. In: *Hydrology and Water Resources in Arizona and the Southwest* 8, 90-96.

Simanton, J. R., Johnson., C. W., Nyhan, J. W. & Romney, E. M. (1986) Rainfall simulation on rangeland erosion plots. In: *Erosion on Rangelands: Emerging Technology and Data Base* (ed. by L. J. Lane) (Proc. Rainfall Simulator Workshop, January 1985, Tucson, Arizona), 11-17. Society for Range Management, Denver, Colorado.

Tiscareno-Lopez, M. (1994) A Bayesian-Monte Carlo Approach to Asses Uncertainties in Process-Based, Continuous Simulation Models. PhD dissertation, University of Arizona, Tucson, Arizona.

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