This is not a peer-reviewed paper.

Pp. 412-415 in Soil Erosion Research for the 21st Century, Proc. Int. Symp. (3-5 January 2001, Honolulu, HI, USA). Eds. J.C. Ascough II and D.C. Flanagan. St. Joseph, MI: ASAE.701P0007

Rill Slope: A Pedotransfer Function for Soil Erodibility for Semiarid Rangeland Watersheds

Howard Evan Canfield[1]

Abstract

Rill slope may be used to characterize differences in soil erodibility on semiarid rangeland watersheds at a detail not possible using soil mapping units. This study shows that high-resolution digital elevation models (DEMs) can be used to extract data on rill slope that can be used to characterize differences in soil erodibility. Stream power theory shows that rill slope is related to soil erodibility. The less than 1 mm portion of the sediment was used as a proxy for soil erodibility on the 4.4. Ha Lucky Hills 104 watershed near Tombstone, Arizona. Rill slope was found to be significantly shallower in the finer-grained of three geologic units on a small semiarid rangeland watershed, which indicates that rill slope may be used as a pedotransfer function for soil erodibility.
Keywords. Rill processes, Sediment sources, Semiarid watersheds, High-resolution DEM.

Introduction

Recent advances in mapping, including the widespread availability of digital elevation models (DEMs), have allowed researchers to glean increasingly more information about landscape processes from the landscape form. One of the areas which may benefit from these improved mapping capabilities is estimation of soil erodibility. Often on semiarid watersheds, geologic and pedogenic processes may cause soil texture and erodibility to vary greatly within a soils mapping unit.

Rill slopes may provide better understanding of spatial variability of the erodibility of the underlying materials without detailed soil sampling. For example, at larger watersheds sediment supply may be limited for channels in bedrock, but not limited for channels in alluvium. As such, a threshold can be identified for the maximum possible slope of transport capacity limited channels. Therefore, channel slopes that exceed that threshold can be assumed to be supply limited, and by inference, bedrock channels (Montgomery et al. 1996).

Conceptually stream power presents a way to understand the relationship between soil texture and rill slope. Lane (1955) uses the following characterization:

$$Q_b D_i \propto QS = W \tag{1}$$

where W is stream power, Q_b is the the bedload discharge, D_i is the particle size, Q is the flow rate and S is the slope. In cases where the contributing source areas for rills are equivalent, the runoff (Q) and sediment flux $(Q)_b$are also equivalent for uplands contributing to a rill, so that equation 1 becomes:

$$Di \propto S \tag{2}$$

In other words, for rills with equivalent contributing runoff and sediment, the slope is proportional to the particle size of the bed load being transported. The relative difference between stream power and resistance power is greatest in rills and lower order streams. As such, there is little stored sediment in the rill prior to flow, and the bedload reflects the characteristics of the sediment into which the rill is cut (Bull, 1991). Therefore, rill slope should reflect the characteristics of this underlying sediment.

[1] **Corresponding author**: Howard Evan Canfield, Civil Engineer, USDA-NRCS, St. Michaels AZ.; tel.: (520) 871-4547 ext. 116; fax: (520) 871-4530; e-mail: <evan.canfield@az.usda.gov>.

In this study, data on erodibility was compared with channel slopes derived from a 2.5m x 2.5m DEM to determine if channel slope could be used to recognize differences in sediment erodibility. The objective of this study was to determine if channel slope could be used as an indicator of sediment erodibility (i.e., a pedotransfer function) on small semiarid rangeland watersheds.

Study Location

Lucky Hills 104 is located on the Walnut Gulch Experimental Watershed near Tombstone, Arizona, operated by the USDA-ARS in Tucson. Soils on the watershed are mapped as a single soil type [Luckyhills-McNeal (Ustochreptic Calciorthid; Breckenfield et al., 1995)] with a coarse sandy loam texture.

While contributing areas to initiate rills varies on the Lucky Hills, contributing source areas at the rill head identified in the field averaged 200 m^2 (Canfield, 1998). Previous studies suggest that these sediments are alluvial in origin with pockets and lenses of more fine-grained material.

Methods

DEM Analysis

Landscape form was characterized using a field-derived 2.5m x 2.5m DEM (Canfield, 1998). The TOPAZ (Garbrecht and Campbell, 1997) DEM processing program was used to extract rill locations. Rill slope determined from field survey also agreed well with the slope of rills extracted from the DEM (Canfield, 1998).

Sediment Sampling

Sediment representative of the soils beneath the coarse surficial armoring was sampled at 48 locations on the watershed. Sediment was sieved using sieve sizes in the phi scale classification (Lane et al., 1947) from the -6 phi (64mm) to +4 phi (0.063mm) particle sizes. The less than 1mm portion of the soil sample was used as a proxy for sediment erodibility, because cohesionless sediment less than 1mm in diameter are highly erodible (Hjulstrom, 1935). The sampling indicated a finer-grained geologic unit in the 1364-1366.5 m elevation, with coarser non-cohesive sediment above and below.

Results and Discussion

Ninety-five channel elements were identified in the 4.4 ha watershed using TOPAZ. Forty-nine of these were rills (i.e. first-order channels). Characteristics of the sediment and channels were compared to determine how sediment texture related to channel slope.

Table 1 summarizes differences between channel slope for first order channels, contributing area for first order channels in the three sediment units, and percent of particles less than 1 mm for the three sediment units. Channels are classified based on the elevation at which they initiate. The table shows that the middle unit (i.e. sediment between the elevation of 1364m and 1366.5m) is texturally distinct from the units above and below which have similar characteristics, and that rill slope, too, is shallower in this unit which has a higher percentage of < 1mm sediment.

Statistical t-tests, at the 0.025 level of significance, confirmed that there was a higher percentage of erodible sediment in the layer between 1364m and 1366.5m. The rill slopes in this unit were significantly shallower than the slopes of rills in units above and below this finer-grained unit. The level of significance exceeded 0.01 for the difference in channel slope.

Table 1. Summary statistics for rill slope, upslope drainage area and percent particles less than 1mm for the three geologic units

		<1364m	1364m-1366.5m	>1366.5m
Rill Characteristics				
	N	25	17	6
	Upland Area (sq. m)	263.5	289.06	203.13
	Stdev. Area	102.74	95.43	32.54
	Channel Slope (%)	13.67	9.83	13.45
	Stdev. Slope	3.35	2.39	3.05
Soil Characteristics				
	N	22	15	11
	% < 1mm	52.33	61.78	53.15
	Stdev % 1mm	9.07	10.03	10.96

The slope of first order channels is significantly related to sediment erodibility as characterized by % < 1mm. This observation is further supported in a plot of mean channel slope vs. mean % < 1mm (Figure 1), which suggests a linear relationship between rill slope and % < 1mm.

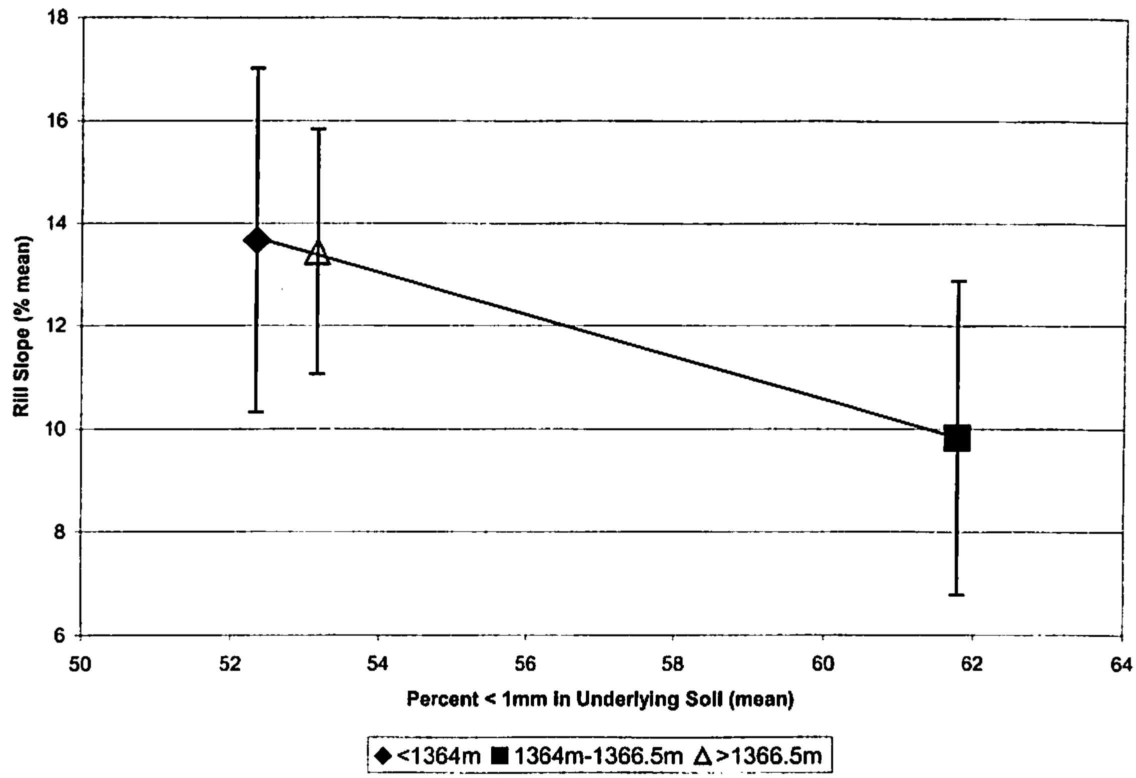

Figure 1. Mean first order channel slope plotted against mean % < 1mm (of the < 64mm portion). Error bars represent one standard deviation. Note that channel slope tends to decrease with increasing % < 1mm.

Such a relationship applies when there are no major differences in cover, infiltration rates etc., so that differences can be attributed largely to underlying sediment characteristics. Still, in this case where there is a statistically significant difference in upslope drainage area for the upper unit, it is remarkable that sediment size and rill slope are proportional

Conclusions

The rill slopes in the finer grained unit were significantly shallower than the rill slopes in coarser units. This indicates that rill slope may be used as a proxy for characterizing spatial variability of soil erodibility. Since high-resolution sediment data may not be readily available, the slope of first order channels derived from a high resolution DEM may, therefore, provide a basis for initial identification of these more erodible units. As high resolution DEM data, such as the 2.5m x 2.5m DEM used in this study, become more readily available, it may be easier to use the slope of rills to identify more erodible units than to sample the units themselves. Such a characterization may make it easier to assess and mitigate erosion hazards.

In this case, a significantly finer-grained unit was present on the Lucky Hills watershed. Identifying this unit was somewhat problematic, because like most alluvial deposits, the unit contained coarser and finer lenses. Furthermore, soils maps do not tend to recognize such these differences in sediment characteristics. For example, this watershed was mapped as a single soil type even though there were significant differences in soil texture. While analysis of the DEM should not serve as a substitute for careful fieldwork, it may provide a preliminary means to begin soils investigations.

References

Breckenfeld D. J., Svetlik, W. A., and McGuire, C. E. 1995. *Soil Survey of Walnut Gulch Experimental Watershed.* United States Department of Agriculture, Soil Conservation Service.

Bull W. B. 1991. *Geomorphic Responses to Climatic Change.* Oxford University Press: Oxford.

Canfield H. E. 1998. Use of Geomorphic Indicators in Parameterizing an Event-Based Sediment-Yield Model. Unpublished Ph.D Thesis. Agricultural and Biosystems Engineering. University of Arizona: Tucson.

Garbrecht J. and Campbell J. 1997. *TOPAZ V1.2: An Automated Digital Landscape Analysis Tool for Topographic Evaluation, Drainage Identification, Watershed Segmentation and Subcatchment Parameterization.* Rpt. GRL #97-4 USDA-ARS Grazinglands Research Laboratory El Reno, Ok

Hjulstrom F. 1935. Studies of morphological activity of rivers as illustrated by the River Fyris. *Bulletin of the Geological Institute University of Uppsala.* 25: 221-527.

Lane E. W. 1955. The importance of fluvial morphology in hydraulic engineering. *Proceedings of the American Society of Civil Engineers.* 81:1-17.

Lane E. W., Brown, C., Gibson, G. C., Howard, C. S., Krumbein, W. C., Mathes, G. H., Rubey, W. W., Trowbridge, A. C., and Staub, L. G. 1947. Report of the subcommittee on sediment terminology, *Transactions of the American Geophysical Union.* 28(6):936-938.

Montgomery D. R., Abbe, T. B., Buffington, J. M., Petersen, N. P., Schmidt, K. M., and Stock, J. D. 1996. Distribution of bedrock and alluvial channels in forested mountain drainage basins. *Nature* 381:587-589.