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Vegetation canopy cover effects on sediment erosion processes in the Upper Colorado River Basin Mancos Shale formation, Price, Utah, USA

Erik M. Cadaret [a], Kenneth C. McGwire [a,*], Sayjro K. Nouwakpo [b], Mark A. Weltz [c], Laurel Saito [b]

[a] Desert Research Institute, Division of Earth and Ecosystem Sciences, Reno, NV, USA
[b] University of Nevada Reno, Department of Natural Resources and Environmental Science, Reno, NV, USA
[c] U.S. Department of Agriculture, Agricultural Research Service, Great Basin Rangelands Research Unit, Reno, NV, USA

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ABSTRACT

This study investigated erosion processes on the highly erosive, saline soils of the Mancos Shale formation in the Price-San Rafael River Basin in Utah, USA. Rainfall simulations were performed at two sites using a Walnut Gulch rainfall simulator with a variety of slope angles and rainfall intensities. The Rangeland Hydrology Erosion Model (RHEM) was calibrated to provide unbiased estimates of discharge and sediment load in runoff at each site. RHEM simulated the inter-plot variability best at the site with higher slope angles, vegetation cover, and sediment loads. The calibrated surface erosion parameters in RHEM (K_{ss}, K_{ω}) were substantially greater than any published in prior studies from non-saline environments. The spatial distribution of vegetation canopy cover was quantified using photogrammetric modeling and landscape pattern metrics. As the patches of vegetation became more contiguous and the tortuosity of the bare soil area increased, RHEM over-predicted sediment output, suggesting that vegetation-driven spatial heterogeneity influenced erosion in a way that is not captured by the model.

1. Introduction

The Colorado River Basin is a primary source of water for seven states in the western United States and the Baja region of Mexico. The U.S. Bureau of Reclamation predicts that climate change, increasing water demand, and water scarcity will exacerbate the current salinity challenges of the Colorado River (USBOR, 2005). The Mancos Shale geological formation spans a wide area in the Upper Colorado River Basin, and its severely eroding rangelands have been identified as a major producer of sediment, salinity, and selenium to the Colorado River (Evangelou et al., 1984; Tuttle et al., 2014a, 2014b). Rasely et al. (1991) estimate that 7–15% of the rangeland areas in the state of Utah (USA) are in a severely eroding condition and are responsible for 75–90% of the increasing sediment and salt yields. Two field sites that represent severely eroding conditions on the Mancos Shale formation were selected for study within the Price and San Rafael River basins in the state of Utah. The Price River contributes <1% of the water to the Colorado River, but approximately 3% of the salt load (Rao et al., 1984). These field sites were located on different members of the formation, providing some insight into the variability of erosion processes within the Mancos Shale. Rainfall simulations were performed to calibrate the Rangeland Hydrology and Erosion Model (RHEM; Nearing et al., 2011) in order to determine what parameter values are required for the erodible saline soils of the Mancos Shale and to investigate how the amount and spatial distribution of vegetation cover may affect sediment loading.

The RHEM simulates hillslope runoff and erosion responses using two process-model components. The hydrology component of the RHEM is based on the KINEROS2 model that incorporates rainfall interception by vegetation, infiltration and overland flow (Smith et al., 1995). The erosion component of RHEM incorporates concentrated flow (Foster, 1982) and splash and sheet flow (Wei et al., 2009) to simulate soil erosion (Al-Hamdan et al., 2015). The current version of RHEM (v2.3) models splash/sheet erosion as the primary driver of erosion, while concentrated flow transports the eroded sediments (M. Hernandez, USDA, pers. comm. 2015). A number of prior studies have successfully used RHEM to model erosion (Al-Hamdan et al., 2012, 2015; Felegari et al., 2014; Hernandez et al., 2013; Zhang et al., 2012; Nearing et al., 2011), but none of these have been performed on the types of saline and sodic soils found in the Mancos Shale formation.

Vegetation canopy cover (VCC) intercepts raindrop impact and reduces runoff by promoting infiltration (Wischmeier and Smith, 1978; Loch, 2000; Branson et al., 1981). Wood et al. (1998) found that at the

Abbreviations: RHEM, Rangeland Hydrology Erosion Model; VCC, Vegetation canopy cover; VDSH, Vegetation-driven spatial heterogeneity; WGRS, Walnut Gulch rainfall simulator; SFM, Structure from motion; MOCOM, Multi-objective complex optimization method; NSE, Nash-Sutcliffe efficiency; RSR, Ratio of root-mean-squared error to standard deviation; FRAC_CV, Coefficient of variation for fractal dimension metric; CONTIG_CV, Coefficient of variation for contiguity index metric.

* Corresponding author at: Desert Research Institute, Division of Earth and Ecosystem Sciences, 2215 Raggio Parkway, Reno, NV 89512, USA.
E-mail address: kenm@dri.edu (K.C. McGwire).

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beginning of a rainfall event, canopies efficiently intercept rainfall within their projected area, until the maximum cumulative interception threshold is exceeded. The amount of time to reach maximum cumulative interception is dependent upon the type of plant and the rainfall intensity (Wood et al., 1998). Proportionally, rainfall lost to vegetation interception is most prominent under conditions of lower rainfall intensities and may strongly influence erosion rates under such conditions (Simanton et al., 1991). Carroll et al. (2000) found that as VCC increases on varying slopes, there is a reduction in runoff electrical conductivity (EC) and sediment loss, and therefore concluded that successful establishment of VCC is an effective way to improve water quality. Bartley et al. (2006) found that even with high mean VCC, small interspaces of bare soil had six to nine times more runoff and 60 times more sediment loss than similar hillslopes that did not contain as much or any interspace patches. In addition, the majority of the sediment load from the hillslopes measured by Bartley et al. consisted of fine suspended load rather than coarse bedload material and the majority of soil loss occurred during the initial runoff event. Bartley et al. (2006) also highlight the importance of having medium to high vegetation cover at the bottom of hillslopes to trap and store sediment.

The distribution of vegetation and interspace areas leads to vegetation-driven spatial heterogeneity (VDSH) in soil development and evolution processes (Puigdefabregas, 2005) that influence sheet runoff and concentrated flow processes. This in turn influences rill and channel development and thereby affects sediment loading along those flow paths (Wilcox et al., 1996; Davenport et al., 1998; Urgeghe et al., 2010). Since the capacity for heterogeneity is constrained when vegetation cover is very low or very high, VDSH is not independent of VCC. If vegetation is sparse and there is little complexity to the pattern of obstacles, runoff tends to concentrate in narrow channels (Al-Hamdan et al., 2012). At moderate levels of vegetation cover, a simple pattern of cover might also concentrate flow while complex cover might interrupt flow and widen channels. This differential response would reflect the existence of a channel network characterized by VDSH (Puigdefabregas, 2005). VDSH may also affect the amount of infiltration (Chartier et al., 2011), soil nutrients, and trapped sediment (Zucca et al., 2011; Howes and Abrahams, 2003). We hypothesize that VDSH may have an effect on sediment erosion processes that is not currently parameterized and therefore not captured by the RHEM.

2. Material and methods

2.1. Site description and plot installation

The study area is located near Price, Utah in the Price-San Rafael River basin (1.1×10^4 km^2). This is a sparsely populated area within the Colorado Plateau that is characterized by an uplifted, eroded, and deeply dissected tableland that contains a salt-desert shrubland ecosystem. The annual mean precipitation at Price is 227 mm yr^{-1} (November = 13.0 mm, September = 29.2 mm), and the annual mean air temperature is 8.2 °C (January = −15.6 °C, July = 32.7 °C). Runoff is primarily from spring snowmelt and high intensity, short duration convectional storms during the summer. The two field sites, named Price and Ferron, were selected for their location on the Mancos Shale formation, varying vegetation cover and slope, accessibility for field operations, and National Environmental Policy Act clearance. The Price site (110° 36′ 26″ W, 39° 27′ 47″ N) is located within the Tununk member of the Mancos Shale formation, 23 km southeast of the city of Price at an elevation of 1700 MASL. The Ferron site (111° 7′ 21″ W, 38° 58′ 23″ N) is located within the Blue Gate member of the Mancos Shale, 74 km south-southwest of Price at an elevation of 1900 MASL (Fig. 1).

The Price field site (Fig. 2A) contains well developed, light gray soil crusts on shallow slopes (0.6%–10%) with sparse vegetation cover (3.3%–17.8%). The soil series found at Price is the Persayo loam (USDA – NRCS, 2013a). The salt-tolerant vegetation includes a mixture of four shrubs (*Krascheninnikovia lanata*, *Chrysothamnus nauseosus*, *Atriplex gardneri*, *Ephedra viridis*), two subshrubs (*Eriogonum microthecum*, *Helianthella microcephala*), and three grass species (*Achnatherum hymenoides*, *Hilaria jamesii*, *Elymus elymoides*). The predominant plant species are *Ephedra viridis*, *Atriplex gardneri*, and *Achnatherum hymenoides*. The Ferron field site (Fig. 2B) contains poorly developed, light-medium gray soil crusts on steep slopes (11.4%–24.5%)

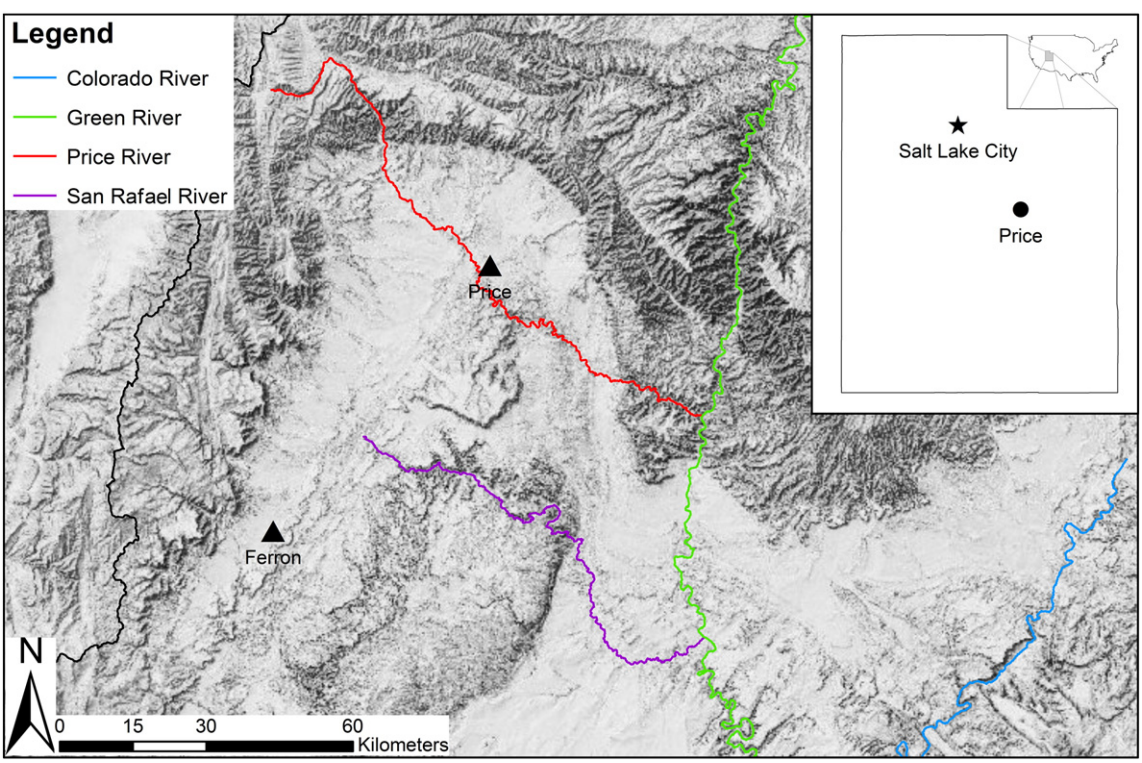

Fig. 1. Map of the field sites relative to rivers in the Upper Colorado River Basin, Utah, USA.