International Soil and Water Conservation Research 4 (2016) 75–86

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

International Soil and Water Conservation Research

journal homepage: www.elsevier.com/locate/iswcr

Review Article

A review of concentrated flow erosion processes on rangelands: Fundamental understanding and knowledge gaps

Sayjro K. Nouwakpo [a,*], Christopher J. Williams [b], Osama Z. Al-Hamdan [c], Mark A. Weltz [d], Fred Pierson [b], Mark Nearing [e]

[a] University of Nevada, Reno, Department of Natural Resources and Environmental Science, 1664 N. Virginia Street, Reno, NV 89557, USA
[b] USDA, ARS, Northwest Watershed Management Research, 800 Park BLVD., STE 105, Boise, ID 83712, USA
[c] Texas A&M University – Kingsville, Department of Civil and Architectural Engineering, Kingsville, TX 78363, USA
[d] USDA, ARS, Great Basin Rangelands Research, 920 Valley Road, Reno, NV 89512, USA
[e] USDA, ARS, Southwest Watershed Research, 2000 East Allen Road, Tucson, AZ 85719, USA

ARTICLE INFO

Article history:
Received 14 March 2016
Received in revised form
24 May 2016
Accepted 25 May 2016
Available online 17 June 2016

Keywords:
Erosion
Rangeland
Concentrated flow
Rill
Gully

ABSTRACT

Concentrated flow erosion processes are distinguished from splash and sheetflow processes in their enhanced ability to mobilize and transport large amounts of soil, water and dissolved elements. On rangelands, soil, nutrients and water are scarce and only narrow margins of resource losses are tolerable before crossing the sustainability threshold. In these ecosystems, concentrated flow processes are perceived as indicators of degradation and often warrant the implementation of mitigation strategies. Nevertheless, this negative perception of concentrated flow processes may conflict with the need to improve understanding of the role of these transport vessels in redistributing water, soil and nutrients along the rangeland hillslope. Vegetation influences the development and erosion of concentrated flowpaths and has been the primary factor used to control and mitigate erosion on rangelands. At the ecohydrologic level, vegetation and concentrated flow pathways are engaged in a feedback relationship, the understanding of which might help improve rangeland management and restoration strategies. In this paper, we review published literature on experimental and conceptual research pertaining to concentrated flow processes on rangelands to: (1) present the fundamental science underpinning concentrated flow erosion modeling in these landscapes, (2) discuss the influence of vegetation on these erosion processes, (3) evaluate the contribution of concentrated flow erosion to overall sediment budget and (4) identify knowledge gaps.

Contents

* Corresponding author.
E-mail address: snouwakpo@cabnr.unr.edu (S.K. Nouwakpo).
Peer review under responsibility of International Research and Training Center on Erosion and Sedimentation and China Water and Power Press.

http://dx.doi.org/10.1016/j.iswcr.2016.05.003
2095-6339/

1. Introduction

Hillslope runoff and soil erosion processes play a vital role in rangeland ecosystem sustainability due to their control on resource mobility (Hassan, Scholes, & Ash, 2005) but they also have significant implications in off-site resource transport. Nichols, Nearing, Polyakov, and Stone (2013) found for example that hillslope processes contributed to 85% of sediment delivery from a 43.7 ha semi-arid shrub-dominated watershed. The influence of vegetation on hillslope runoff and sediment production forms the basis of current hydrology and erosion modeling technologies on rangelands (Nearing et al., 2011). Early attempts to apply empirical soil erosion models derived primarily from cropland data, such as the Universal Soil Loss Equation – USLE and the Revisited Universal Soil Loss Equation – RUSLE, on rangelands yielded unsatisfactory and contested results (Blackburn, 1980; Foster, Simanton, Renard, Lane & Osborn, 1981; Hart, 1984; Johnson, Savabi & Loomis, 1984; Mitchell & Roundtable, 2010; Spaeth, Pierson, Weltz & Blackburn, 2003; Trieste & Gifford, 1980). Weltz, Kidwell, and Fox (1998) point to the lumped nature and rigid structure of these empirical models as a key deficiency when applied to rangelands where biotic and abiotic interactions play a strong control on surficial processes.

The advent of physically-based soil erosion models such as the Water Erosion Prediction Project model-WEPP (Laflen, Lane, & Foster, 1991) offered the opportunity to develop the scientific framework necessary to provide insight into the relationship between hydrologic processes and rangeland condition. These research efforts led to the Rangeland Hydrology and Erosion Model (RHEM) (Al-Hamdan et al., 2015; Nearing et al., 2011), developed from experimental data specifically collected on rangeland sites across the Western U.S. As a process-based erosion model, RHEM models erosion and hydrology using the same fundamental principles as WEPP. Runoff generation and erosion on the hillslope are modeled in response to hydrological inputs and hydraulic parameters that are adjusted based on soil intrinsic properties and land surface conditions.

In both WEPP and RHEM, the hillslope is divided into (1) interrill areas, where rainsplash detachment and sheetflow transport occur and (2) concentrated flow areas where flow is deep and fluvial processes dominate. Accurate partitioning of hillslope erosion into interrill and concentrated-flow-dominated processes has a significant implication on rangeland erosion modeling especially following disturbances. Several studies (e.g, Al-Hamdan, Pierson, Nearing, and Williams (2012b), Pierson et al. (2013a, 2013b); Williams, Pierson, & Spaeth, 2016; Williams et al., 2014a, 2016a, 2016b) have demonstrated a significant increase in concentrated flow erosion when shrub-dominated rangeland are disturbed by fire or woody species encroachment compared to undisturbed conditions.

Concentrated flow erosion is a complex process because flow networks have a dual function of sediment and runoff production and storage as well as that of transport of these resources off-site. These intricately coupled functions are traditionally assumed to be controlled by rill flow hydraulics (Govers, Giménez, & Van Oost, 2007). In fact the presence of rills and gullies and the abundance thereof are key indicators of rangeland health (Pellant, Shaver, Pyke, & Herrick, 2005). As a surface process, concentrated flow erosion is directly influenced by biotic factors such as vegetation, forming feedback mechanisms that are seldom explored.

The aim of this paper is to review published experimental and conceptual research dealing with concentrated flow erosion processes on rangelands. In this paper, the term interrill erosion is used interchangeably with sheet and splash erosion to refer to the process of raindrop splash detachment and subsequent transport in sheetflow. Likewise, the term concentrated flow erosion encompasses a range of processes leading to the formation and erosion of rills and gullies, therefore these two terms were used to refer to specific forms of concentrated flow erosion. In this review we present (1) understanding of the fundamental science underpinning concentrated flow erosion modeling on rangeland with an emphasis on WEPP and advancements of the RHEM model, (2) the influence of vegetation on concentrated flow erosion, (3) the contribution of concentrated flow erosion to sediment budget and (4) knowledge gaps.

2. Physically-based modeling of concentrated flow erosion on rangeland

In physically based erosion models, overland flow in upland areas is a combination of concentrated flow (rill and gullies) and rainsplash sheetflow (interrill) (e.g., Laflen et al. (1991) and Nearing et al. (2011)). Concentrated flow is deeper and faster than overland sheetflow (Julien and Simons, 1985). In most cases the dominant form of overland flow on rangeland with adequate vegetation cover is sheetflow (e.g., Moffet, Pierson, Robichaud, Spaeth, and Hardegree (2007), Pierson et al. (2011, 2013a, 2008b), Pierson, Moffet, Williams, Hardegree, and Clark (2009), Williams et al. (2014, 2014b, 2016a)). However, continuous concentrated flowpaths play a significant role in amplifying soil erosion when they exist, especially on steep slopes or where ground cover is sparse. Therefore, predicting concentrated flow erosion on rangeland is paramount for physically based erosion modeling.

Concentrated flow plays two interactive functions in generating soil erosion. First, it can act as a transport agent for sediments detached by rainsplash and sheetflow. Second, it can act as a soil detachment agent and becomes a sediment source. Hydraulics of concentrated flow plays a key factor in both functions. For instance, flow velocity and rill width are required components to predict sediment detachment, entrainment, and transport (Line, & Meyer, 1988; Nearing, Foster, Lane, & Finkner, 1989). Therefore, modeling concentrated flow erosion requires accurate predictions of the hydraulic parameters. Here we present a description of approaches that have been used for modeling the physics of concentrated flow erosion on rangeland.

2.1. Concentrated flow hydraulics

Many of the physically based erosion models use open channel flow hydraulics concepts such as Manning's equation to model hydraulics in concentrated flow (e.g., De Roo et al. (1994), Foster (1982b), Hairsine & Rose (1992) and Morgan et al. (1998)). In such concepts velocity V (ms^{-1}) of concentrated flow is related to the geometry of the flow channel and the hydraulic roughness of the channel surface:

$$V = \frac{R_h^{2/3} S^{1/2}}{n} \tag{1}$$

where R_h is the hydraulic radius (m) which equals the area divided by the wetted perimeter, S is slope gradient, n is Manning's number which represents the channel surface hydraulic roughness.

Other physically based erosion models use the Darcy–Weisbach roughness coefficient (f) to relate flow rate to flow geometry (i.e., Laflen et al. (1991)):