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Slope Impacts on Concentrated Flow Hydraulics in Rangelands

Osama Z. Al-Hamdan[1,4], Frederick B. Pierson[1], C. Jason Williams[1], Patrick R. Kormos[2], Mark A. Nearing[3], Jan Boll[4]

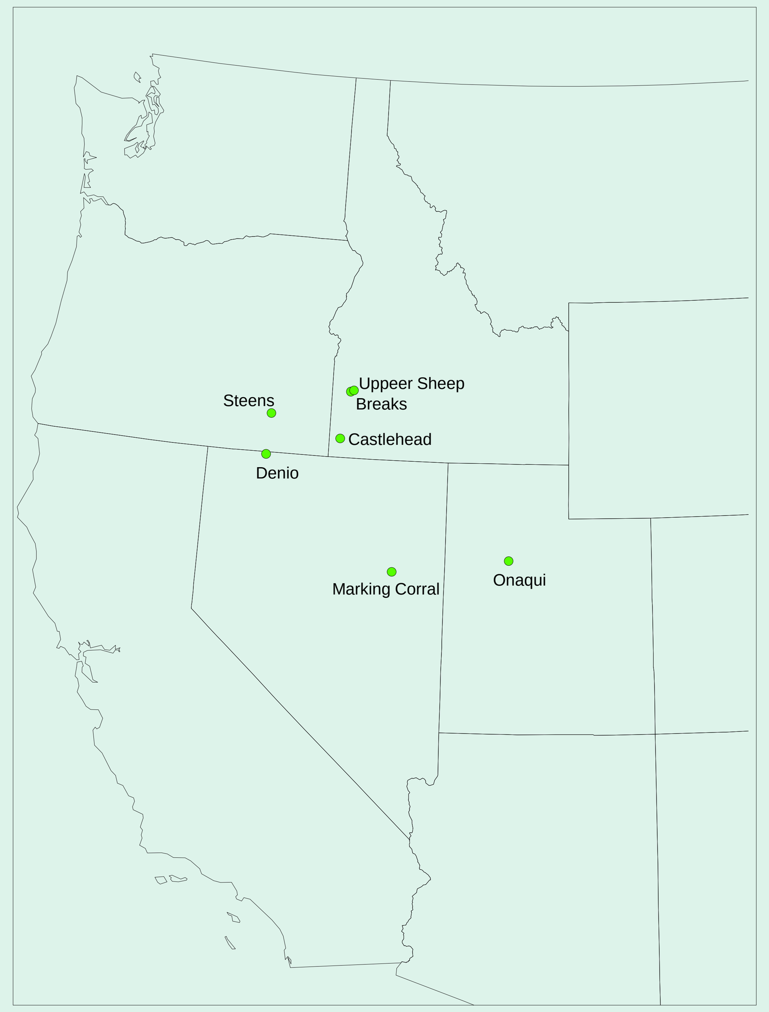
[1]USDA-ARS, Northwest Watershed Research Center, Boise, Idaho – Contact: osama.al-hamdan@ars.usda.gov
[2]Department of Geosciences, Boise State University, Boise, Idaho
[3]USDA-ARS, Southwest Watershed Research Center, Tucson, Arizona
[4]Department of Biological and Agricultural Engineering, University of Idaho, Moscow, Idaho

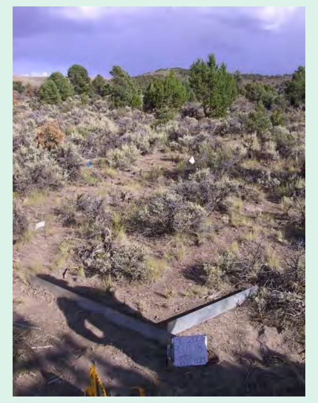
NORTHWEST WATERSHED RESEARCH CENTER
USDA
800 Park Blvd., Suite 105
Boise, Idaho 83712
(208) 422-0700
ars
University of Idaho
Southwest Watershed Research Center Tucson, Arizona
Sagebrush Steppe SageSTEP Treatment Evaluation Project
Joint Fire Science Program
RMRS United States Department of Agriculture – Forest Service Rocky Mountain Research Station

Abstract

Several studies have been conducted to describe rill or concentrated flow hydraulics. However, most of these studies used data obtained from either laboratory experiments or field sites located on gently sloping crop lands. The data sets in the few rangeland field studies conducted did not cover a variety of hillslope angles and generally focused on slope gradients less than 20%. The lack of studies with steeper slopes resulted in misinterpreting the slope gradient impact on concentrated flow hydraulics, as sites with different slopes have different soil and vegetation cover characteristics. This study examines the characteristics of rangeland concentrated flow hydraulics as a function of vegetation and ground cover using field experimental data from diverse vegetated rangeland sites of the western United States. These data span a wide range of slope angles (5.6%-65.8%), soil types, and vegetative cover. Many of the sites exhibit some degree of disturbance, such as wildfire, prescribed fire, tree mastication, and/or tree cutting. The data were divided into two sets, gently sloping (<20%) and steeply sloping (>20%). Analyses were performed on each data set separately as well as on the combined data set. For the complete data set, concentrated flow occurred on less than 26% of the gently sloping plots and on more than 70% of the steep plots. The study shows that when the variation in slopes is large, the slope impact would be too large to be counteracted by the increase in surface roughness due to erosion. The study shows also that in order to understand the hydraulics behavior of concentrated flow in rangelands, the used experimental data should be from diverse vegetated rangelands with a wide range of slopes. Multi regression equations for estimating the width, velocity, and friction factor of the concentrated flow as function of slope, flow discharge, and vegetation cover were developed. Considering the diversity of the field experiment data of this study, as well as, the viability of measuring their variables, the new equations would have the potential to be used in rangelands hydrology and erosion models .

Study Areas




Control Site (untreated)


Burn Site


Uncut Site


Cut Site


Bullhog Treatment Site

Site	State	Treatment	Landscape	Soil Type	Slope (%)
DENIO	NV	Burn, Unburn	Sagebrush Steppe	sandy loam	23.4-65.8
BREAKS	ID	Burn	Sagebrush Steppe	sandy loam	33-55.9
STEENS	OR	Cut, Uncut	Western Juniper	silt loam	15.7-22
ONAQUI	UT	Burn, Cut, Bullhog ,Control	Sagebrush Steppe Juniper	gravelly loam	9-26.1
MARKING CORRAL	NV	Burn, Cut, Control	Pinyon Juniper Sagebrush Steppe	gravelly loam	5.6-21.3
CASTLE HEAD	ID	Burn, Cut, Control	Western Juniper Sagebrush Steppe	stoney loam	13.1-23.4
UPPER SHEEP	ID	Burn, Unburn	Sagebrush Steppe	silt to silt loam	12.4-39.3

Methods


Average slope, ground cover, vegetation cover, and micro topography were measured for each plot (All plots are 2x4 m).


All plots were pre-wet prior to experiments.


Water was released at different inflow rates approximately 4 m upslope of runoff collection point.


For each inflow rate, flow velocity was measured by salt tracer method while the width and depth of each flow path were measured by ruler at several transects.


The outflow discharge rate was determined from timed runoff samples collected during simulations.

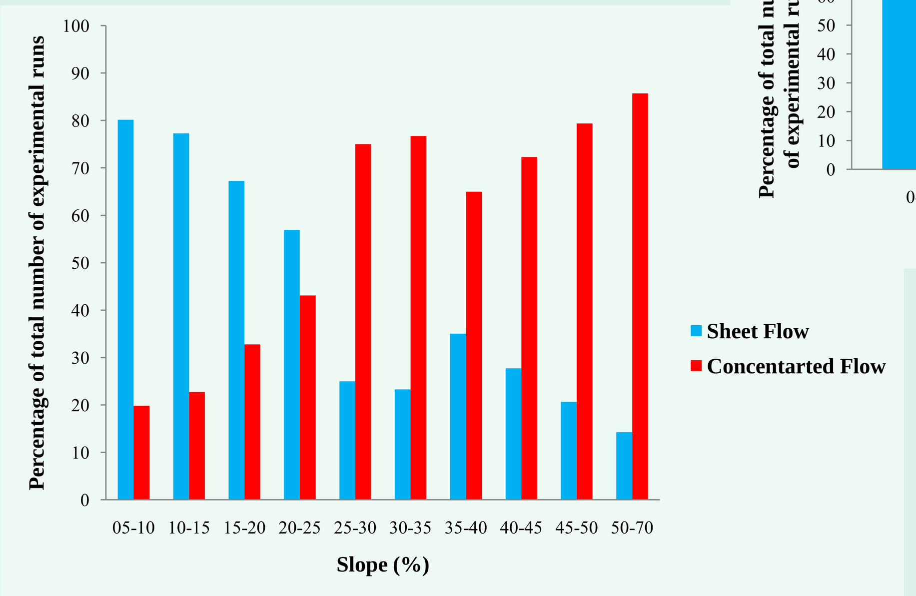
SITE	YEAR	Number of Plots	Plot inflow Rate (L/Min)
DENIO	2000	36	7,12,15,21,24
	2001	36	7,12,15,21,24
	2002	36	7,12,15,21,24
	2003	18	7,12,15,21,24
	2004	44	12,30,48
BREAKS	2002	16	3,7,12,15,21,24
	2003	8	3,7,12,15,21,24
	2004	8	3,7,12,15,21,24,48
	2005	8	3,7,12,15,21,24,48
STEENS	2001	16	3,7,12,15
ONAQUI	2006	36	15,30,45
	2007	32	15,30,45
	2008	16	15,30,45
MARKING CORRAL	2006	24	15,30,45
	2007	24	15,30,45
	2008	18	15,30,45
CASTLE HEAD	2008	30	15,30,45
UPPER SHEEP	2007	20	15,30,45
	2008	12	15,30,45

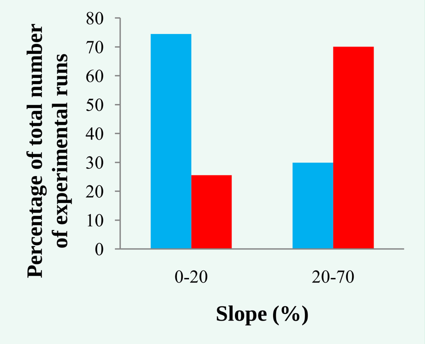
Experimental data Summary

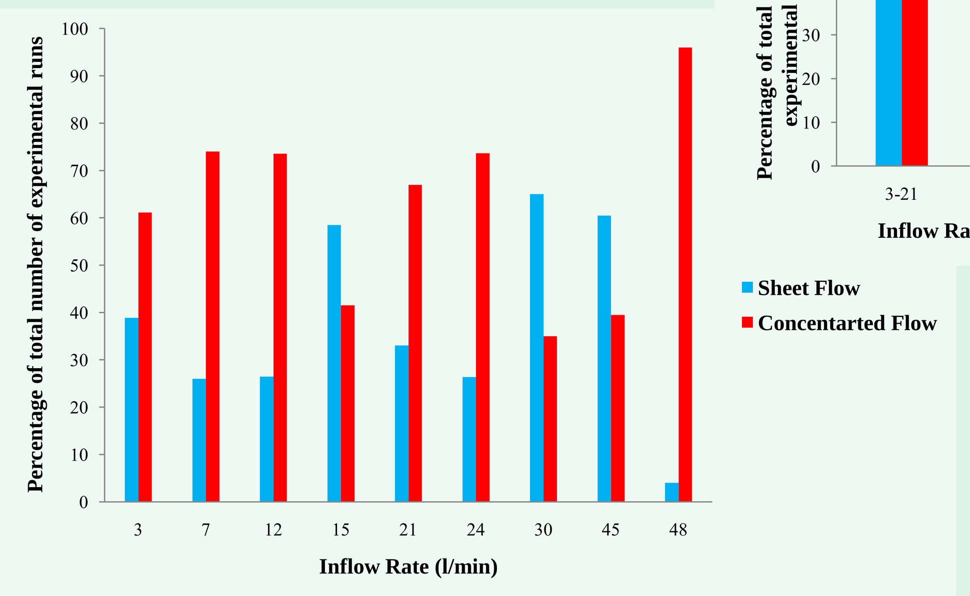
Concentrated Flow vs. Sheet Flow

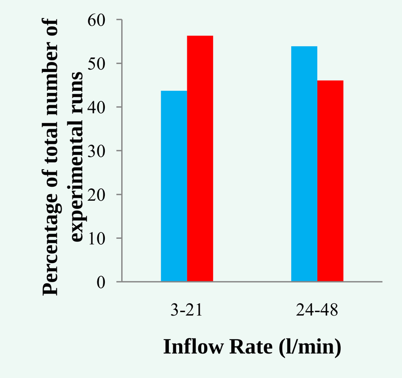

Sheet flow

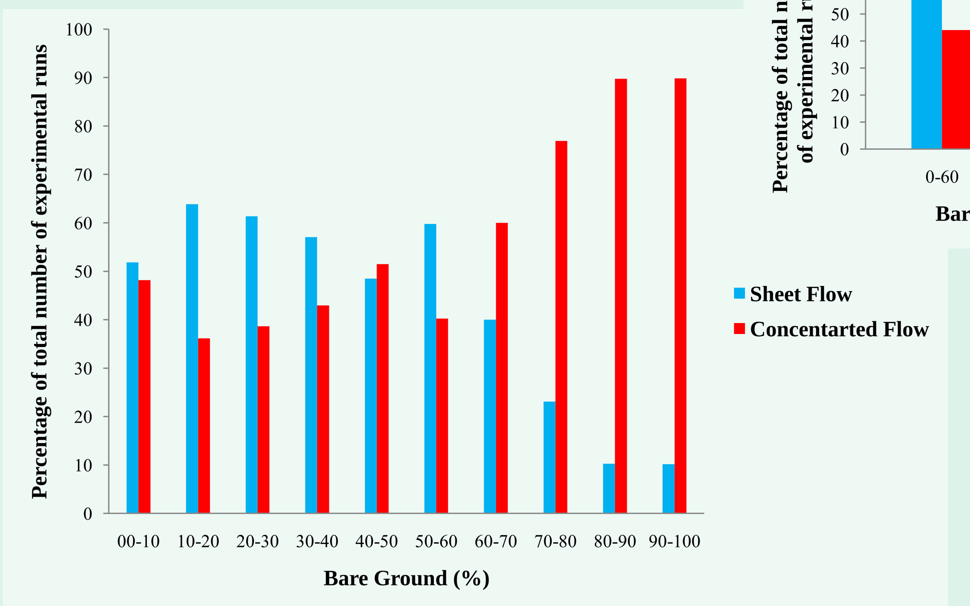

Concentrated flow

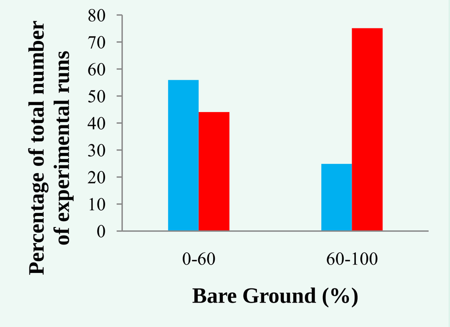




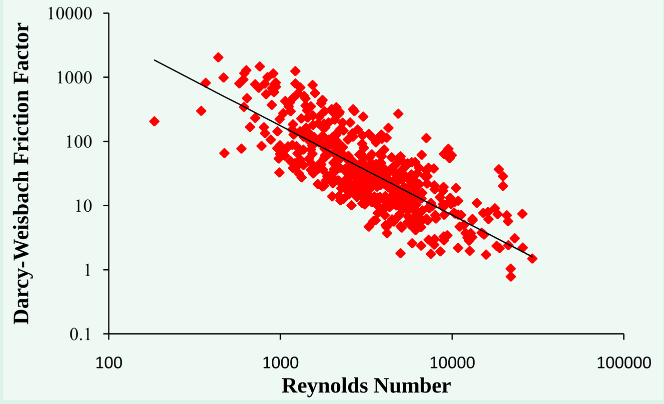


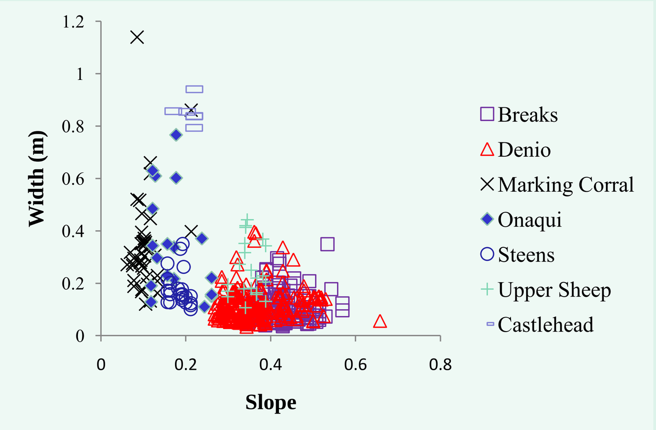


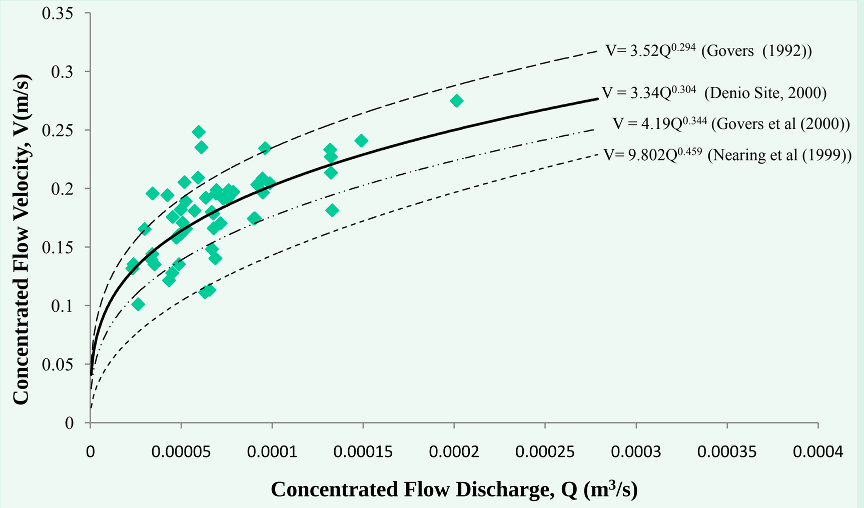




Concentrated Flow Hydraulics







Regression Equation	R^2	Partial R^2 $\log S$
$\log w = 0.04 + 0.338\log Q - 0.647\log S + 0.161 res + 0.218 rock$	0.56	0.19
$\log w = 0.279 + 0.379\log Q - 0.638\log S$	0.54	0.19
$\log w = 0.19 + 0.34\log Q - 0.654\log S + 0.58\log rock$	0.62	0.39
$\log f = 2.06 + 1.1\log S$	0.11	0.11
$\log f = -1.255 + 1.256 res + 1.877 bascry + 1.114 rock - 0.25\log Q + 0.558\log S$	0.57	0.03
$\log V = 0.883 - 0.555 res - 0.89 bascry - 0.55 rock + 0.356\log Q + 0.18\log S$	0.54	0.01

Percentage bare soil	Regression equation	R^2	Partial R^2 $\log S$
0-100%	$\log V = -0.115 + 0.214\log Q$	0.08	-
0-25%	$\log V = -0.33 + 0.218\log Q$	0.08	-
25-50%	$\log V = 0.362 + 0.334\log Q$	0.22	-
50-75%	$\log V = 0.97 + 0.39\log Q + 0.5\log S$	0.6	0.21
75-100%	$\log V = 1.07 + 0.347\log Q + 0.826\log S$	0.73	0.26

Percentage bare soil	Regression equation	R^2
0-100%	$rock = 0.01 - 0.047\log S$	0.02
0-25%	No significant correlation	-
25-50%	$rock = -0.02 - 0.099\log S$	0.16
50-75%	$rock = -0.01 - 0.062\log S$	0.33
75-100%	$rock = -0.02 - 0.054\log S$	0.47

w : Flow width (m).
Q : Flow discharge (m^3/s).
S : Plot average slope (fraction).
$rock$: Rock cover (fraction to the plot total area).
res : Plant dead residue cover (fraction to the plot total area).
$bascry$: Plant Basal and cryptogam cover (fraction to the plot total area).
V :Flow Velocity (m/s).
f :Darcy's Weisbach friction factor.

Summary Points

❑The ability of flow discharge to predict velocity gets better in the absence of non-erodible roughness elements (plant, residue, stones). However, the dependency of velocity on slope also increases as non-erodible roughness elements decreases.

❑In steep rangelands (slope >20%) the slope impact of increasing velocity would be too large to be counteracted by the increase in surface roughness due to erosion.

❑ Because the hydraulics in rangelands are very complex, it is important to use data with a wide range in slope and vegetation cover to develop empirical concentrated flow velocity equations.

❑ The characteristics of rangelands and crop lands are different especially in slope gradient impact on ground cover. Hence, implications of crop land studies on rangelands would be misleading.

❑New equations for predicting the hydraulic parameters such as velocity, Darcy-Weisbach friction factor, and width of concentrated flow in rangelands were developed. Considering the diversity of the field experiment data of this study, as well as, the viability of measuring their variables, the new equations have the potential to be used in rangelands hydrology and erosion models.

Acknowledgements

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