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Estimating concentrated flow erodibility parameters from pre- and post-fire rangeland field data for physically-based erosion modeling

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Abstract

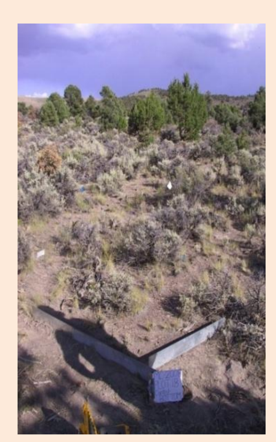
In physically based soil erosion models a concentrated flow erodibility parameter is necessary to run the model. This parameter is usually set to a relatively insignificant value when applying models on rangeland ecosystems as soil erosion induced by concentrated flow on these ecosystems tends to be low compared with those on cropland. However, after a fire, concentrated flow is often the dominant source of water erosion especially on steep slopes. Hence, the erodibility parameter becomes a very important factor in estimating the erosion rate after such disturbance. In this study, we estimated the concentrated flow erodibility using field experimental data over diverse rangeland landscapes within the Great Basin Region, United States. The vegetation community ranges from sagebrush steppe to pinyon-juniper woodland. Many of the sites exhibit some degree of wildfire or prescribed fire. The erodibility parameters were measured before and after fire. In some sites erodibility was measured one, two, and three years after fire. The results show that, in general, concentrated flow erodibility increased significantly after fire. In some sites, erodibility continued to increase until the second year after fire where erodibility began to decline. The results also show that concentrated flow erodibility was not constant within each experimental run, where in most cases erodibility had a high value at the beginning and then declined due to reduction of sediment availability. Using the data in this study we developed an empirical equation to predict the change of erodibility as a function of cumulative unit discharge. The empirical function can be used for parameterizing the concentrated flow erosion component of physically based models on burned rangeland.

Objectives

1) To characterize the relationship between concentrated flow detachment capacity and commonly derived hydraulic parameters for different rangeland environmental conditions.
2) To develop a model that predicts soil erodibility changes within a runoff event.
3) To investigate the effects of fire disturbance on magnitude and temporal variability in soil erodibility.
4) To develop empirical equations for estimating concentrated flow soil erodibility based on readily measureable ecological sites, soils, and vegetation data.

Study areas

Site	State	Landscape	Soil type	Slope (%)
Denio	NV	sagebrush steppe	sandy loam	23.4-65.8
Breaks	ID	sagebrush steppe	coarse sandy loam	33.0-55.9
Onaqui	UT	sagebrush steppe – Utah juniper	gravelly loam	9.0-26.1
Marking Corral	NV	pinyon-juniper – sagebrush steppe	gravelly loam	5.6-21.3
Castlehead	ID	western juniper – sagebrush steppe	stony loam	13.1-23.4
Upper Sheep	ID	sagebrush steppe	silt or silt loam	12.4-39.3


Control site (untreated)


Burned site

Theory

$$D_{cf} = K_{HP}\left(HP - HP_c\right)^{\alpha}$$

$$D_{cf} = K_{HP}\,(HP - HP_c)$$

$$D_{cf} = K_{HP}(HP)$$

$$\tau_s = \left(\frac{f_s}{f_t}\right)\gamma R_h \sin\left[tan^{-1}(S)\right]$$

$$\omega = \gamma S q$$

D_{cf} : Detachment rate of concentrated flow (kg s^{-1} m^{-2})
HP : Hydraulic parameters (τ_s , ω)
K_{HP} : The soil erodibility factor based on the hydraulic parameter (*HP*)
HP_c : The threshold value where D_{cf} is insignificant before *HP* exceeds it
α : The power constant
τ_s : Shear stress (kg s^{-2} m^{-1})
ω : Stream power (kg s^{-3})
q : Unit width flow discharge (m^2 s^{-1})
S : Slope
γ : The specific weight of water (kg m^{-2} s^{-2})
R_h : The hydraulic radius (m)
f_s : The hydraulic friction due to the soil grains
f_t : The total Darcy-Weisbach friction factor

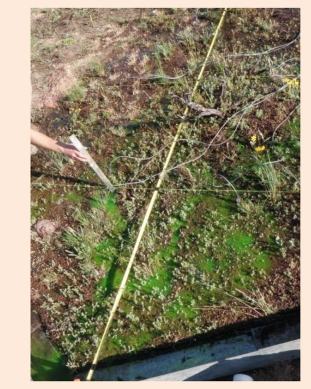
Methods

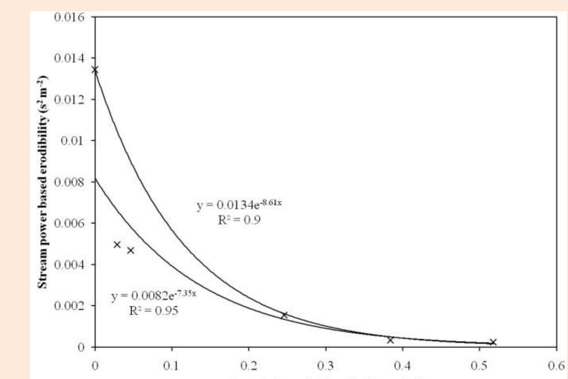

1. Average slope, ground cover, vegetation cover, and micro-topography were measured for each plot (all plots are 2x4 m).


2. All plots were pre-wet prior to experiments.

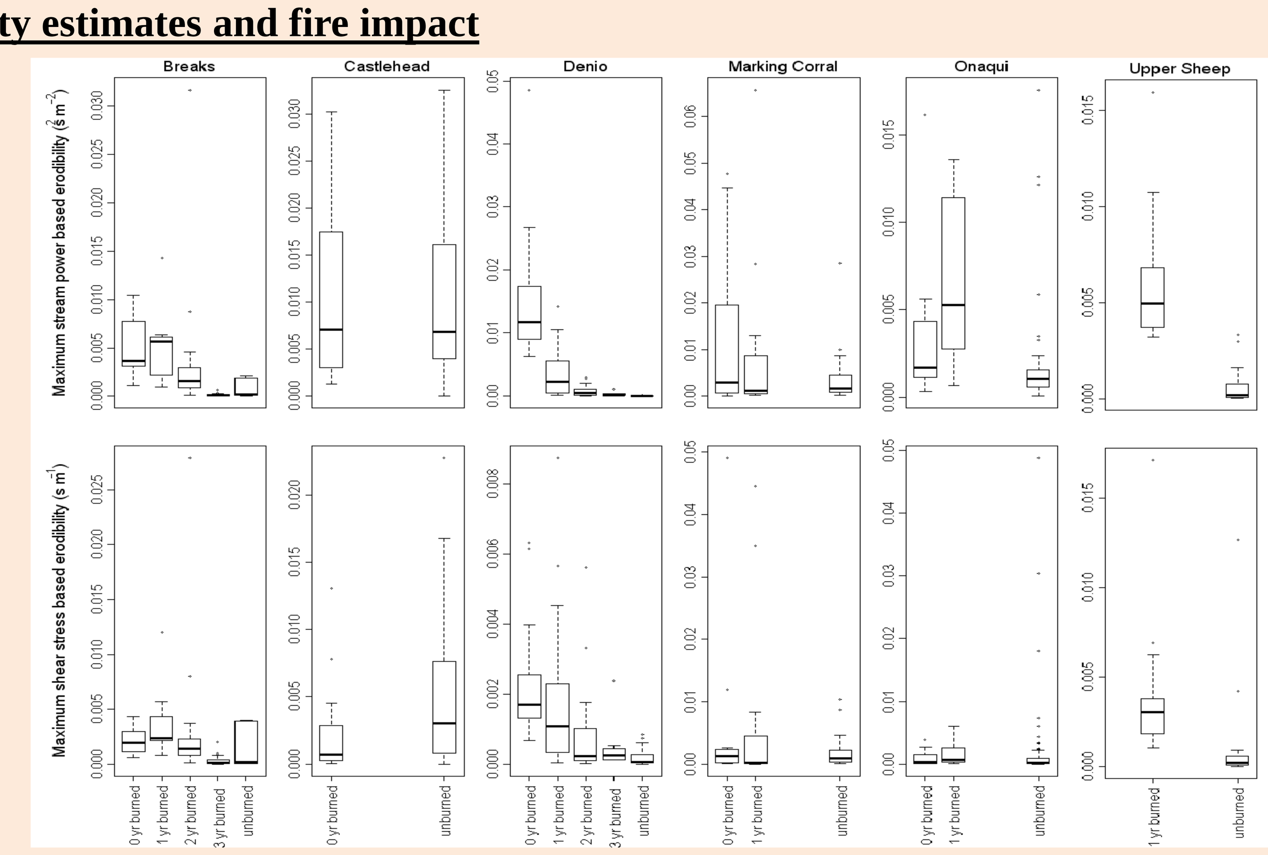

3. Water was released at different inflow rates approximately 4 m upslope of runoff collection point.

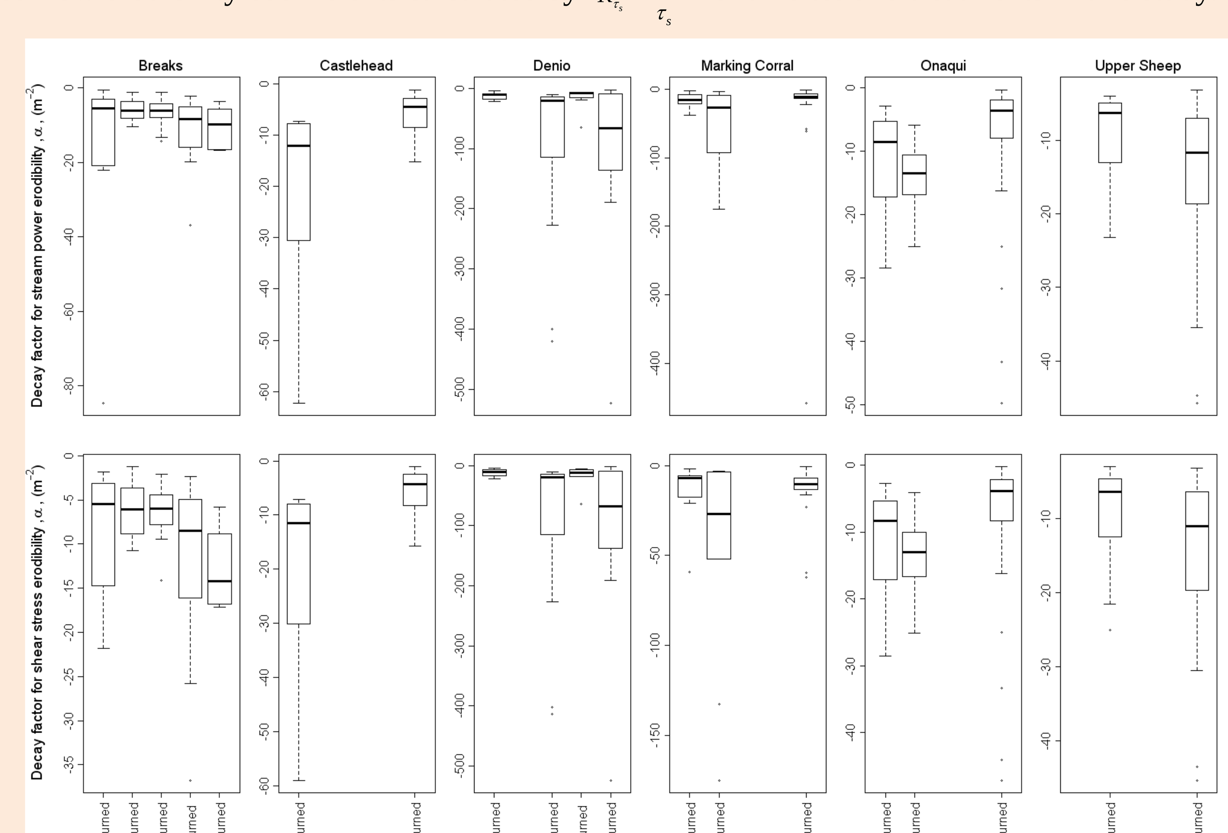

4. For each inflow rate, flow velocity was measured by salt tracer method while the width and depth of each flow path were measured by ruler at several transects.


5. Total outflow discharge rate was determined from timed runoff samples collected during simulations. The samples were oven-dried and then weighed in order to determine sediment concentration.

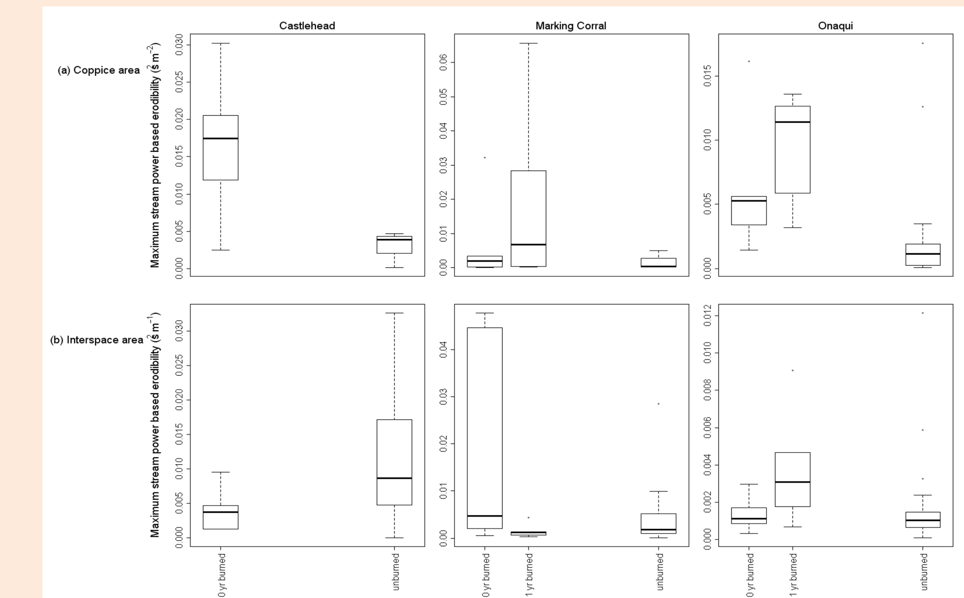

6. Values of *K* at each time step (i.e. time at which runoff samples were collected) within each flow release experiment was calculated (e.g. $K_{\omega} = \frac{D_{cf}}{\omega}$). Then, the decay factor was calculated as the slope of the relationship between the values of log transformed *K* and the values of cumulative flow discharge (*q*) to form the decay function: $K = K_{(Max)}\exp(\alpha q)$.

Erodibility estimates and fire impact

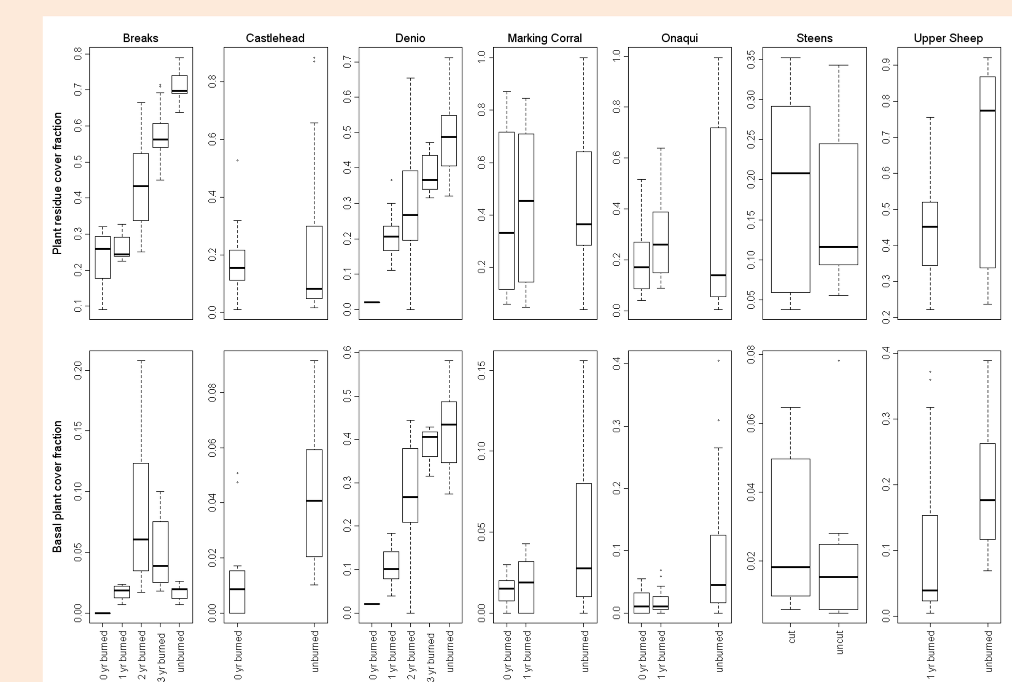

Maximum stream power concentrated flow erodibility coefficients calculated by $K_{\omega} = \frac{D_{cf}}{\omega}$ and maximum soil shear stress concentrated flow erodibility coefficients calculated by $K_{\tau_s} = \frac{D_{cf}}{\tau_s}$ for all sites and treatments in this study.


Decay factor (α) of stream power based concentrated flow erodibility, in $K = K_{(Max)}\exp(\alpha q)$, for all sites and treatments in this study.

Erodibility estimates and fire impact


Maximum stream power concentrated flow erodibility coefficients calculated by $K_{\omega} = \frac{D_{cf}}{\omega}$ for Castlehead, Marking Corral, and Onaqui sites where data were divided into two microsites (a) Coppice area and (b) Interspace area.

Describing temporal variability of erodibility within recovery period


Plant residue cover and basal plant cover for each site and treatment in this study.

Equation	n	R^2
Breaks		
$K_{\omega(Max)} = 10^{-1.65-3.17res}$	64	0.53
$K_{\tau_s(Max)} = 10^{-2.34-1.96res+6.75rock}$	64	0.3
Castlehead		
$K_{\omega(Max)} = 10^{-1.81-14.65bascry}$	28	0.29
$K_{\tau_s(Max)} = 10^{-2.9+1.5rock}$	28	0.14
Denio		
$K_{\omega(Max)} = 10^{-1.86-2.86res-3.12bascry}$	86	0.8
$K_{\tau_s(Max)} = 10^{-2.61-1.68res-1.68bascry}$	86	0.45
Marking Corral		
$K_{\omega(Max)} = 10^{-1.85-1.31res-1.8rock}$	58	0.25
$K_{\tau_s(Max)} = 10^{-2.88}$	58	
Onaqui		
$K_{\omega(Max)} = 10^{-2.75-1.91bascry}$	80	0.25
$K_{\tau_s(Max)} = 10^{-3.11+0.58res}$	80	0.11
Upper Sheep		
$K_{\omega(Max)} = 10^{-0.78-2.84res-4.46bascry}$	36	0.63
$K_{\tau_s(Max)} = 10^{-3.07}$	36	

Multiple regressions equations for estimating the average and maximum values of concentrated flow erodibility coefficients as a function of basal plant cover (*bascry*), plant litter (*res*), and rock cover (*rock*) for each site in this study.

Conclusions

- Concentrated flow erodibility was not constant within each experimental run.
- Concentrated flow erodibility increased significantly when a site was exposed to a fire.
- Fire not only altered erodibility, it also increased the erosive energy of overland flow and its impact by exposing the soil surface.
- Fire impacts can vary among sites depending on the inherent characteristics of the site as well as on fire severity.

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