Comparison of Field Jet Erosion Tests and WEPP-Predicted Erodibility Parameters for Varying Land Cover

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Introduction

Hydrologic models are used to evaluate the effect of land cover changes on erosion. The excess shear stress equation is often applied to determine the erosion rate:

$$\varepsilon_r = k_d(\tau - \tau_c)^a \qquad (1)$$

where ε_r = erosion rate of soil (cm/s), k_d = erodibility coefficient (cm³/Ns), τ = applied shear stress (Pa), τ_c = critical shear stress (Pa), a = constant assumed to be 1. Therefore, the effect of land cover on the two main parameters of this equation (k_d and τ_c) needs to be investigated. Many times empirical equations are used to predict these two parameters which may not account for vegetation effects or do so with coefficients that are very broad characterizations. Using an *in situ* test such as the Jet Erosion Test (JET) provides a mechanistic way to determine these two parameters that incorporates all the variability of the field, including land cover, which cannot be easily measured or included in empirical equations. The hydrologic model WEPP, the Water Erosion Prediction Project, was used in this study to compare the predicted erodibility parameters to parameters measured in field with JETs.

In this study, several small watersheds with dominant land cover consisting of either native grassland or 20-yr stands of Eastern Redcedar (*Juniperus virginiana*) were identified. The k_d and τ_c were estimated at various locations using *in situ* JET tests and also using measured soil texture in empirical equations. This study highlights the need to use *in situ* testing to determine erodibility of a field site to better encompass the effects of land cover when predicting erosion in hydrologic modeling.

Methods

Cross Timbers Experimental Range (CTER)

- Four individual watersheds were identified at CTER with contrasting vegetative land cover: two grassland and two Eastern Redcedar (Figure 1)

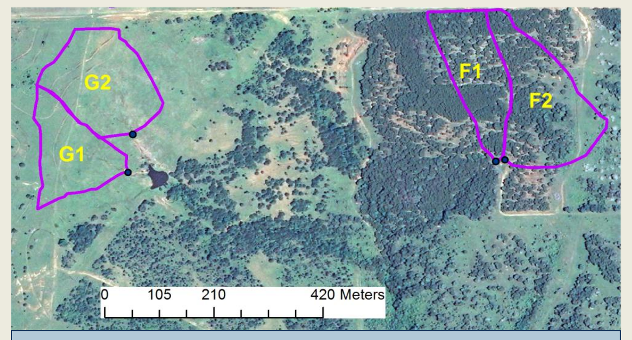


Figure 1. CTER field site including two grassland (G1, G2) and two encroached (F1, F2) watersheds

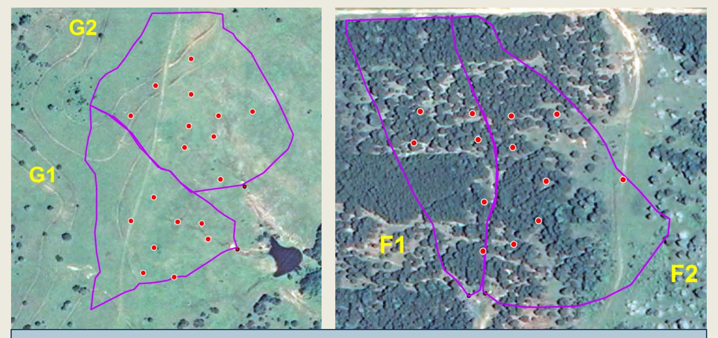


Figure 2. Aerial image of experimental watersheds displaying JET locations which were chosen to contain each soil type present

Soil Sampling and Processing

- 20 to 30 soil samples were taken at five depths (127, 381, 635, 889, and 1143 mm) throughout each watershed in a grid sampling pattern 25-35 m apart
- Samples were composited into one sample per depth per watershed and tested for soil texture and organic matter
- Hydrometer method was used to determine clay and very fine sand content at the individual locations where JETs were conducted

JET Estimation of Erodibility

- Five to ten JETs were conducted in each watershed (Figure 2)
- In a JET test, a submerged jet of water impinges on the soil surface and erodes a scour hole. The scour depth over time is measured with a depth gauge (Figure 3)
- The scour depth over time and the head pressure for each JET is entered into a macro-enabled Excel spreadsheet which uses an iterative solver routine to determine k_d and τ_c
- Two solution techniques were used to find k_d and τ_c: the Blaisdell and scour depth solutions described by Daly et al. (2013)

Figure 3. Controlled-burn truck used to provide water to field site (left), head tank that delivers constant pressure to JET and recycle loop to send water back to tank (middle), and JET device employed in the field with both intake and waste hose (right)

WEPP Modeling

The Water Erosion Prediction Project (WEPP)

- Developed by the USDA-ARS National Soil Erosion Research Laboratory (NSERL) to estimate soil loss along a hillslope or within a small watershed
- Four main input parameters: climate, slope, soil and land management
- Sediment detachment and transport is modeled using the excess shear stress and Yalin equations (Foster et al., 1995; Stone et al., 1995)
- Rill erodibility (k_d) and critical shear stress (τ_c) are determined by empirical equations derived from field experiments by Elliot et al. (1989)

WEPP Estimation of Erodibility

- The baseline rill erodibility (k_{db}) is calculated as a function of the percent of very fine sand content (*vfs*) and organic matter (*orgmat*) in the top 20 cm of the soil:

$$k_{db} = 0.00197 + 0.030 * vfs + 0.03863\, e^{(-184 * orgmat)} \qquad (2)$$

- The baseline critical shear stress (τ_{cb}) is calculated as a function of the percent of clay and very fine sand (*vfs*) in the top 20 cm of soil:

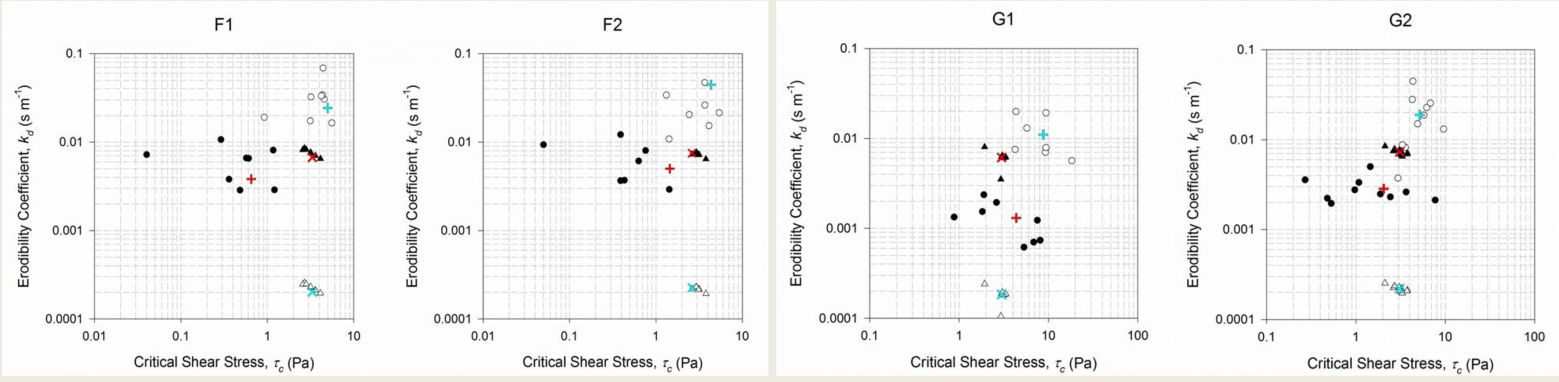
$$\tau_{cb} = 2.67 + 6.5 * clay - 5.8 * vfs \qquad (3)$$

- Adjustment factors are multiplied by k_{db} and τ_{cb} to give adjusted rill erodibility (k_{dadj}) and adjusted critical shear stress (τ_{cadj}) which accounts for aspects that change over time such as incorporated residue, roots, sealing and crusting, and freezing and thawing.

Results

Comparison of Erodibility Parameters from WEPP and JETs

- WEPP baseline k_d and τ_c were calculated using equations (2) and (3) for the composited soil sample from each watershed and additionally for each soil sample corresponding to the JET test locations



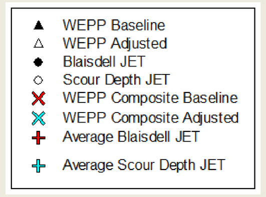


Figure 4. Erodibility coefficient and critical shear stress comparisons for each individual JET location in each watershed as determined by two JET solution techniques (Blaisdell and scour depth solutions) and by WEPP using both baseline and adjusted equations. The average of the JET values is shown by a plus and the WEPP-predicted values from the composite soil textures are shown by an x.

- Adjusted estimates from WEPP were smaller than the baseline values by an order of magnitude (Table 1). The adjusted k_d predicted by WEPP for all watersheds is less than JET-measured data (Figure 4)
- Forested: τ_c from the scour depth solution better matched the τ_c estimated from WEPP. However, the k_d from the Blaisdell solution was more similar to the k_d from WEPP Composite Baseline (Figure 4)
- Grassland: WEPP Composite Baseline k_d matched the scour depth solution better than the Blaisdell but was on the lower end of the scour depth solution values. The WEPP Composite τ_c was closer to the Blaisdell but most τ_c values were within the same order of magnitude (Figure 4)
- F1 and G1 have similar soils and similar WEPP-calculated k_d values (the same holds true for F2 and G2)
- The mean JET-measured k_d and τ_c appear more similar among land cover types than soil texture
- The grassland sites had a k_d that was up to two times smaller than the forested sites as measured with scour depth solution and four times smaller with the Blaisdell solution (Table 1)

Table 1. WEPP and JET values for k_d and τ_c in each watershed shows relationship of erodibility parameters compared to soil texture and vegetation type.

	F1	F2	G1	G2
Top Soil Texture (0-20cm)	Loam	Sandy Clay Loam	Loam	Sandy Loam
WEPP Adjusted k_d (s/m)	1.97E-04	2.14E-04	1.95E-04	2.42E-04
WEPP Erodibility Adjustment Factor	0.03	0.03	0.03	0.03
WEPP Baseline k_d (s/m)	6.57E-03	7.13E-03	6.50E-03	8.07E-03
Blaisdell JET k_d (s/m)	6.46E-03	6.31E-03	1.73E-03	2.90E-03
Scour Depth JET k_d (s/m)	3.27E-02	2.75E-02	1.41E-02	1.96E-02
WEPP Baseline τ_c (Pa)	3.32	3.23	3.37	3.04
Blaisdell JET τ_c (Pa)	0.60	0.63	4.37	2.65
Scour Depth JET τ_c (Pa)	4.26	3.70	8.76	5.69

Results

Two Sample t-tests

Statistical difference (α=0.05) in erodibility parameters determined from both WEPP and JETs when comparing:

- Table 2: Land cover types (Grassland vs. Forest)
    - JET erodibility parameters all showed a significant difference but the WEPP values did not
- Table 3: Soil textures (Greater than or less than 50% sand)
    - No significant difference for any erodibility parameters

Table 2. Two sided t-test between grassland and forest watersheds

Grassland vs. Forest t-test	p-value	DF
WEPP Baseline k_d (s/m)	0.116	27
Blaisdell JET k_d (s/m)	**0.001**	14
Scour Depth JET k_d (s/m)	**0.008**	20
WEPP Baseline τ_c (Pa)	0.605	26
Blaisdell JET τ_c (Pa)	**0.003**	16
Scour Depth JET τ_c (Pa)	**0.006**	20

Table 3. Two sided t-test between soil textures based on % sand

Soil Texture t-test	p-value	DF
WEPP Baseline k_d (s/m)	0.503	17
Blaisdell JET k_d (s/m)	0.664	23
Scour Depth JET k_d (s/m)	0.832	19
WEPP Baseline τ_c (Pa)	0.876	23
Blaisdell JET τ_c (Pa)	0.185	18
Scour Depth JET τ_c (Pa)	0.071	15

Soil Texture Relationships

- The empirical equations used in determining k_d and τ_c in WEPP are both dependent on the percent very fine sand (*vfs*) but no such relationship is present among JET k_d and τ_c (Figure 5)

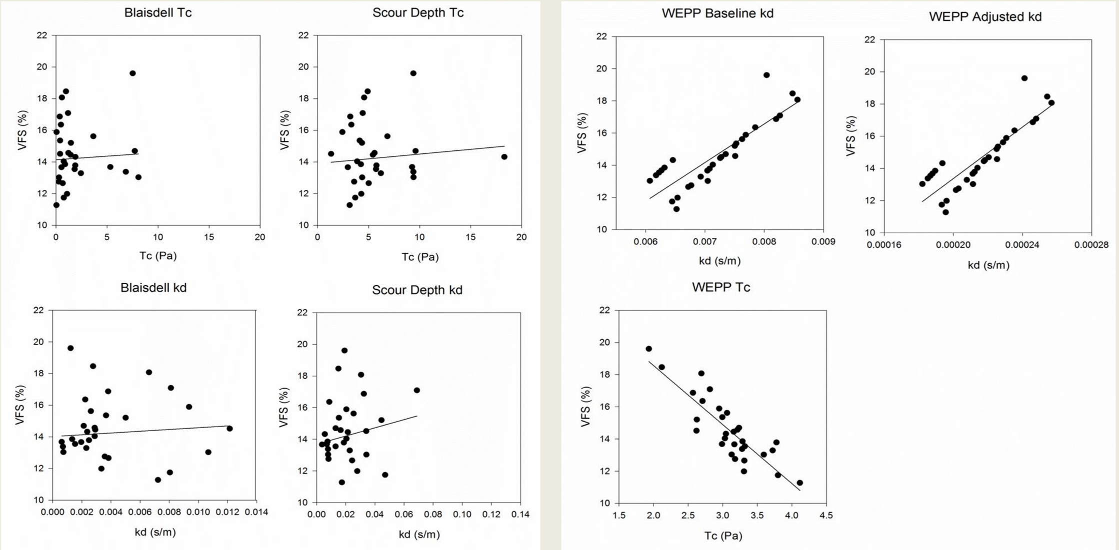


Figure 5.The k_d has an increasing linear relationship with *vfs* content and the τ_c has a linear decreasing relationship with *vfs*. When analyzing the relationship between *vfs* and JET-measured k_d and τ_c no linear relationship was apparent.

Conclusions

- All WEPP adjusted values were less than JET values by an order of magnitude
- JET erodibility parameters showed the influence of land cover: grassland watersheds mean k_d values were two-four times smaller than the forested k_d values
- T-tests showed that JETs show a significant difference between land cover but WEPP does not show any significant difference. Also, there were no significant differences among soil textures
- There is no linear relationship among erodibility parameters derived from JETs

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