USE OF THE REVISED UNIVERSAL SOIL LOSS EQUATION ON AN EVENT-BY-EVENT BASIS

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BIOGRAPHICAL SKETCH

Kurt Kelsey is a graduate student at the University of Wisconsin-Stevens Point. Kurt's master degree work involves an evaluation of the Revised Universal Soil Loss Equation on small erosion plots under simulated rainfall. His interest in the erosion control industry began with a 1999 summer internship at American Excelsior Company's ErosionLab, where he has worked for the past three summers. Kurt eagerly anticipates joining the soil/water work force following the completion of his education in spring 2002. Mr. Kelsey plans to become CPESC certified in the near future.

ABSTRACT

Key Words: RUSLE, NPDES Permits, Hillslope Erosion

In March 2003, the US EPA will require National Pollutant Discharge Elimination System (NPDES) permits for construction sites as small as .405ha (one acre). The exact methodology of this process has yet to be released, but some form of the Revised Universal Soil Loss Equation (RUSLE) will most likely be used as a guideline for the NPDES permits. Since most construction disturbances last less than one year, an accurate event-by-event predictor may be needed. The RUSLE was designed to estimate soil loss amounts on an average annual basis rather than on a single event basis. The equation's accuracy may be altered when used on a single event basis causing inaccurate soil loss estimates. This study assessed use of the RUSLE parameters on small erosion plots under simulated rainfall on an event-by-event basis. Measured soil loss from the plots was compared to predicted amounts by RUSLE under the same conditions.

A series of tests were conducted on bare soil plots composed of sandy loam, loam, and silty clay loam soils to develop a baseline dataset. Loam plots closely followed predicted soil loss amounts by RUSLE ($p=.678$), while silty clay loam plots were over-predicted ($p=.008$). RUSLE under-predicted sandy loam plots, but the difference between measured and predicted soil loss was not significant because of variability within the data set ($p=.110$).

An erosion control blanket and blown straw were also tested across the three soil types. Tests involving the erosion control blanket showed significant differences between measured and predicted soil loss values on the silty clay loam plots ($p=.008$). Blown straw tests on the sandy loam plots also showed significant differences ($p=.007$).

Overall, the RUSLE was found to be a suitable predictor of soil loss from single events. Where significant differences were recognized, the equation over-predicted soil loss amounts. Although not exact, the over-predicted soil loss amounts can help prevent

costly repairs to erosion control projects, which may result from under-predicted soil loss amounts in the early planning stages.

Introduction

Estimates of soil loss are important in issues of land and water management. Much of the soil loss information in erosion control is based on the use of the Revised Universal Soil Loss Equation (RUSLE). RUSLE, previously the Universal Soil Loss Equation (USLE), was developed to estimate average annual sediment loss from agricultural fields. The full equation is: A=RKLSCP, where R is the rainfall-runoff erosivity factor, K is a soil erodibility factor, LS is a slope length and steepness factor, C is a cover management factor, P is a conservation support factor, and A is estimated soil loss. This project assessed use of RUSLE as a soil loss predictor on small erosion plots on an event-by-event basis.

Background

According to the USDA-ARS National Sedimentation Lab, RUSLE is used by numerous government agencies and private businesses and individuals to assess the magnitude of rill erosion, to pin point situations where erosion is serious, and to guide development of plans to control soil erosion. RUSLE is the tool currently used by the U.S. Environmental Protection Agency (EPA) and other government agencies to predict erosion losses from disturbed sites. These estimated erosion levels will most likely be used as thresholds when the agencies issue National Pollutant Discharge Elimination System (NPDES) permits for disturbed sites as small as .405ha (one acre) starting in March 2003. NPDES permits for construction sites will require the owners and operators to implement programs and practices to control polluted storm water runoff. In addition to RUSLE's use for NPDES permits, land planners also utilize the equation. These various users of RUSLE might use the equation on an event-by-event basis, but it may not be an accurate predictor when used that way.

Why RUSLE is Commonly Used

RUSLE is widely used for several reasons. The equation is believed to be applicable wherever factor values are available (Renard et al., 1997). According to the National Sedimentation Laboratory, RUSLE is the best available tool for erosion prediction from specific field sites and contains a large database supported by numerous top scientists and the USDA-NRCS. In addition, the equation combines interrelated physical and management parameters such as soil type, rainfall pattern, and topography that influence the rate of erosion. These parameters are represented through RUSLE's five factors whose site-specific values can be expressed mathematically (Foster et al., 1999).

Utilizing RUSLE

There is a large pool of information regarding the proper use of RUSLE;

however, RUSLE continues to be used outside the context of its intended purpose. RUSLE is not intended to predict soil loss from individual storms nor estimate the probability of soil erosion by event or season. In everyday use, the equation is commonly used this way because users of the equation need to predict soil losses over periods of time less than one year. Measurements should be made over a minimum of three years when a range of soil loss and weather condition occurred. In addition, soil loss predictions from slopes over 22 percent are believed to be over-predicted by the equation. Lastly, RUSLE should not be considered absolute, rather the equation should be used as a guide (Foster et al., 1999).

Problems With Field Studies

Assessments of the accuracy of RUSLE are impeded by many factors. Field studies are costly, labor intensive, and time consuming, which may lead to few replications. Variability in data caused by differences in plot preparation or soil characteristics can result in misleading conclusions. It is hard to find hillslopes without variation in soil properties where numerous tests can be replicated (Foster et al., 1999).

RUSLE on a Single Event Basis

Few previous studies have assessed the accuracy of USLE/RUSLE compared to event-by-event field measured soil losses. Wischmeier and Smith (1978) suggest that USLE/RUSLE may be used for periods of less than one year, such as construction activities. The portion of the annual R-factor occurring over the time period is used in place of the annual average R-factor when calculating soil losses.

Erosion Control Products and RUSLE

Erosion control products are represented within RUSLE under the C-factor. Current C-factor values for erosion control products may be uncertain. The uncertainty associated with the C-factor's derivation may be attributed to limited testing on an event-by-event basis. Long-term averages are helpful, but the products may need to be tested at events with magnitudes greater than the average annual value.

Objective

The objective of this study was to evaluate the accuracy of the Revised Universal Soil Loss Equation on small erosion plots on an event-by-event basis.

Study Site

Fieldwork for this study was completed at American Excelsior Company's ErosionLab™ during the months of May through October in 1999 and 2000. The lab is a state-of-the-art outdoor erosion control research and development facility located in Rice Lake, WI. This study used the Rainfall Erosion Facility (REF), the simulated rainfall portion of the lab. REF follows the procedures provided in American Society for Testing and Materials (ASTM) ASTM D-6459, "Standard Test Method for Determination of Erosion Control Blanket (ECB) Performance in Protecting Hillslopes from Rainfall-Induced Erosion". The facility contains 12 erosion plots that were created at an approximate 33 percent slope. Three soil types are replicated four times each across the plots. All 12 plots are 12.2m (40ft) long by 2.4m (8ft) wide and are separated from one another by a 4.9m (16ft) wide buffer of vegetated soil. Each plot contains either a 265L (70gal.) or 843L (223gal.) tank buried at the bottom of the plot. V-shaped metal flashing at the bottom of each plot directs the materials leaving the plot into the collection tanks.

Simulated Rainfall

Water is pumped to rainfall risers from an on-site 2ha (5acre) pond. Eleven 3m (10ft) high risers are located around the plots in fixed positions, which were predetermined to insure optimal plot coverage. Gate valves located on each of the risers control the amount of water flowing through the rainfall simulator system. Pressure gauges on the risers in combination with the gate valves allow the system to be operated at specified pressures. Through a calibration process operating pressures were determined to achieve target intensities of 5.1, 10.2, 15.2, and 20.3cm/hr (2,4,6,&8in/hr). Four sprinkler heads located at the top of each riser control the amount of water that leaves the riser. An approximate 5.1cm/hr event is produced with one sprinkler head open on each of the risers:

2 heads open on each riser = 10.2cm/hr
3 heads open on each riser = 15.2cm/hr

and the maximum potential of the rainfall simulator of 20.3cm/hr is achieved when all forty-four sprinkler heads are opened. Simulated rainfall testing was performed when winds were less than or equal to 8 km/hr (5mph) to insure uniform plot coverage.

Soil Types Tested

Chetek sandy loam is the native soil on site and contains a grain size distribution of 82.3 percent sand, 2.8 percent silt, and 14 percent clay. An imported topsoil was also tested. The material has a grain size distribution of 43.6 percent sand, 30.4 percent silt, and 10.5 percent clay, which categorizes the material as a loam soil according to the USDA textural triangle. The remaining four plots also contain an imported material. The grain size distribution of this material is 1 percent sand, 61.6 percent silt, and 37.4 percent clay, which is classified as a silty clay loam according to the USDA textural triangle. This “clayey” material as well as the “topsoil” material, were originally added as 45.7cm (18in) veneers when the site was constructed. Additional material is added to the erosion plots as needed from on-site stockpiles.

Dependent Variable Measured

Total soil loss per simulated rainfall event was the dependent variable in this study. Soil losses were measured to the nearest half pound due to the available instrumentation’s precision.

Independent Variable

The only independent variable measured in this study was rainfall intensity. Six rain gauges were randomly placed throughout the plots during each 20-minute increment. The accumulation of rainfall measured and the duration of the test were used to determine the storm’s intensity. There is no variability associated with the rainfall variable since exact rainfall levels are not necessary for this study. As with most studies, there are other variables that could have influenced the results.

Surface Covers Tested

A series of bare soil tests were conducted to develop a baseline dataset where no surface cover was added to the plots. Blown oat straw was one surface cover best management practice (BMP) applied to the plots at a rate of 459kg/ha (2500lb/acre) and tested. Aspen excelsior blankets weighing 0.40kg/m^2 (.73lbs/yd^2) were also installed and tested. *Figures 1-3* illustrate the three cover types tested.

Figure 1. Loam Test Plot Following Storm Series Under Bare Soil Conditions.

Figure 2. Chetek Sandy Loam Plot Covered With Blown Straw Following Storm Series.

Figure 3. Chetek Sandy Loam Plot Covered With Excelsior Blanket Prior to Testing.

Storm Events

Each bare and excelsior blanketed plot experienced events having intensities of approximately 5.1cm/hr (2in/hr), 10.2cm/hr (4in/hr), and 15.2cm/hr (6in/hr) for a duration of 20 minutes each. The blown straw series did not include the 15.2cm/hr (6in/hr) 20-minute event. All intensities were only target intensities. Exact intensities were not necessary since the EI units of each event were determined. Depending on cover type, the two or three 20-minute increments per plot were combined into single events lasting forty or sixty minutes.

Data Collection

Total soil loss measurements were collected following each 20-minute simulated rainfall event. The soil was transferred from the collection tanks into pre-weighed pails. The pails were then weighed to determine soil loss on a wet basis. A sample of the runoff was taken to determine the soil moisture content so the equivalent dry basis soil loss could be determined. The samples were immediately analyzed, or refrigerated when they were not analyzed on the same day the test was conducted. The six rain gauges were also recorded after each 20-minute increment.

RUSLE Factors

R-Factor

The R-factor was determined by calculating the EI units for each 20-minute segment of the events based on the rain gauge readings. The following equations were taken from Agriculture Handbook 703.

$$R=\Sigma EI_{30}(10^{-2})$$

where:

R=Rainfall-runoff erosivity
E=Total storm kinetic energy
I_{30}=Maximum 30-min. rainfall intensity

and

$$EI_{30}=\left[\sum_{K=1}^{m} e_r \Delta V_r\right] I_{30}$$

where:

e_r =Rainfall energy per unit of rainfall {MJ/ha*mm} (foot*tonf/acre*inch) for the r^{th} increment of the storm, and

Δv_r=Depth of rainfall for the rth increment of the storm hyetograph which is divided into m parts, each with essentially constant rainfall intensity {mm} (in)

Unit energy, e, is a function of rainfall intensity and is computed as

$$e_k=1099[1-0.72 \exp(-1.27 i_r)]$$

where:

$$i_r=\Delta V_r/\Delta t_r$$

where:

Δt_r=Duration of the increment over which rainfall intensity is considered to be constant (h), and
i_r=Rainfall intensity (in/hr)

I_{30}=The maximum intensity over 30 consecutive minutes {mm/h}(in/h). If the duration of the test is greater than or equal to 30 minutes, the measured intensity is used.

When the incremental duration is less than 30 minutes, data must be combined from two incremental periods. Most tests lasted 20 minutes in this study. To figure the maximum intensity over 30 minutes (I_{30}) from two increments, the first 10 minutes are figured to have come from the lower intensity test and the last 20 minutes are from the higher intensity test. The following equation from Clopper et. al. (2001) was applied:

I30=[A*(.33h/.5h)]+[B*(.5h-.33h)/.5h]

Where:

A=Larger rainfall intensity of the two 20-minute increments of interest {mm/hr} (in/hr)
B=Smaller rainfall intensity of the two 20-minute increments of interest {mm/hr} (in/hr)

K-Factor

The K-factors for the three soil types used in this study were derived from the soil erodibility nomograph (Wischmeier and Smith, 1978). This procedure is possible since all three soils contain less than four percent organic matter content (Renard et al., 1997).

LS-Factor

Table 4-3 from Agriculture Handbook Number 703 was interpolated to determine the LS factor. Since the horizontal slope length of 12.2m (37.8ft) and slope gradient of 33 percent are uniform for all 12 plots, the plots share the same LS value.

C-Factor

Published C-factor values were used in RUSLE to obtain predicted soil loss values. The C-factor values came from two sources. American Excelsior Company provided the value for the excelsior blanket tested. Table values from Wischmeier and Smith (1978) were used for blown straw cover, because the straw was not anchored by any means. By definition, the C-factor equals one for bare soil conditions.

P-Factor

P equaled one for all tests since no support practices were applied to the plots.

Table 1. Summary of RUSLE values used

RUSLE Parameter	Value
*R	Unique to each increment. Based on the rain gauge readings and the storm duration
**K	Chetek sandy loam (Csl)=.004(.03) Loam(l)=.02(.15) Silty Clay Loam(scl)=.065(.49)
***LS	2.81
C	Bare Soil=1 Blanket:Csl=.01,l=.018,scl=.222 Blown Straw:Csl=.17,l=.17,scl=.24
P	=1 for all tests

*SI units=MJ*mm/ha*event, US Customary units= hundreds of foot*tonf*inch/acre*h*event
**SI units=t*ha*h/ha*MJ*mm, US Customary units=ton*acre*hour/hundreds of acre*foot*tonf*inch
***LS,C,&P factors are unitless

Laboratory Methods

Runoff samples were used to determine the moisture content of the soil lost from the plots. The Microwave Method, ASTM #4643, was followed (ASTM D420, 2000). After the moisture content of the sample was known, the ratio of dry to wet soil was used to calculate the equivalent amount of dry soil that was collected during the test. This was necessary because RUSLE computes soil loss on a dry basis.

Statistical Analysis

Erosion studies performed on simulated rainfall plots have unexplained error associated with them. It is not uncommon for adjacent plots under similar conditions to have a 30 percent difference in soil loss values. These differences tend to be unexplainable by soil, plot preparation, or plot condition differences (Foster et al., 1999).

Some of the data obtained during this study were not normally distributed. The Wilcoxon Signed Ranks test was used to analyze the difference between soil loss measured from the plots to soil loss predicted by RUSLE under the same conditions. Each cover/soil type test series was replicated three times on each soil type.

Results/Discussion

Table 2 provides the associated significance levels between the measured and RUSLE predicted soil loss amounts for all soil and cover type combinations tested. Three significant differences were recognized as a result of the statistical analysis performed on the dataset.

Table 2. Significance Levels (p) Comparing Measured Soil Loss to Amounts Predicted by RUSLE Under the Same Conditions

α=.05	*Soil Type*		
Cover Type	Chetek sandy loam	loam	Silty clay loam
Bare Soil	.110	.678	.008
Excelsior Blanket	.260	.440	.008
Blown Straw	.007	.345	.463

RUSLE over-predicted soil loss on the silty clay loam plots for bare soil tests and tests involving the excelsior blanket. A soil erodibility factor back-calculated from the bare soil dataset on the silty clay loam yielded a value of .008 t*ha*h/ha*MJ*mm compared to the predicted soil nomograph value of .065. Thus, the silty clay loam in the test plots acted less erodible under the testing conditions than the soil nomograph predicted. This discrepancy in K-factor values is a potential reason why RUSLE over-predicted soil loss values on the silty clay loam plots under bare soil conditions and while covered with excelsior blankets.

It should be noted that soil loss measured following the blown straw tests on the silty clay loam plots also differed from RUSLE predicted values although the differences were not recognized statistically. The equation over-predicted four of the six tests in the series, but grossly under-estimated the other two tests where mass wasting of saturated soils occurred. The blown straw was observed to have created small dam-like structures on the plots during the simulated rainfall events. This damming effect slowed the water allowing it to infiltrate into the plots, which created a near-saturated condition. It is believed that saturated conditions occurred during the two mass wasting events where soil slid down the plot in large slugs.

RUSLE over-predicted soil loss amounts from the Chetek sandy loam plots covered with blown straw. Chetek sandy loam soils are somewhat excessively drained and have a permeability rate of 15-51mm/hr in the upper 41cm of the soil. Once again the blown straw is believed to have slowed the water and thus promoted infiltration. The RUSLE does not account for the infiltration capacity of soils.

Soil loss amounts from bare Chetek sandy loam plots were under-predicted by RUSLE, but the difference between measured and RUSLE predicted amounts were not statistically significant. The difference was not recognized as significant because of the large variability within the bare Chetek sandy loam data set. A tumbling effect by the large sand particles was noted during some of the higher intensity tests. RUSLE does not account for "snow-balling" effects as experienced during this study.

Conclusions

Many soil loss studies produce data that are non-normally distributed because of the inherent variability associated with the nature of the studies. When non-normal distributions are found, nonparametric statistical tests should be used to analyze the data (Freund and Simon, 1997). Nonparametric tests may not recognize the same statistical differences as parametric tests would. This is question of concern involving soil loss studies.

The following conclusions are based on data utilizing RUSLE parameters that are site-specific for the conditions present at the study site and should not be considered directly applicable to all sites.

With NPDES permits for construction sites as small as .405ha (one acre) coming in the near future, an accurate predictor of soil loss on small sites over time periods of less than one year is needed. The RUSLE was found to be a reliable predictor of soil loss on an event-by-event basis over the course of this study on loam soil. The RUSLE's ability to predict soil loss on a single event basis was questionable on the sandy loam soil and became less reliable on the silty clay loam soil. The equation over-predicted soil loss amounts in the three situations where significant differences were recognized between measured and RUSLE predicted soil loss amounts. The equation was not found to be an exact predictor of soil loss when used this way, rather the equation was found to be a "safe" tool since it over-predicted rather than under-predicted for the instances where statistically significant differences were recognized.

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