3.0 PREDICTING SOIL LOSS

Introduction

Construction project personnel may find it very helpful to estimate soil loss at specific site locations during various stages of construction. These soil loss estimates can help with EPSC measure planning and can help show which project stages have the largest predicted soil losses. There are many computer models that can be used to estimate soil losses on project sites. However, these computer models do not replace EPSC measure design procedures. It is also important to recognize that all computer models include assumed conditions and are not applicable to all situations. Knowing how to properly use the model and how to correctly interpret the model's results are critical for success.

One of the most well-known models for estimating long-term soil loss is the Universal Soil Loss Equation (USLE) and later revisions and updates to the original USLE method. One reason for the popularity of the USLE family of models is that there are few required inputs, and the inputs have remained user-friendly. This section will discuss using the Revised Universal Soil Loss Equation 2 (RUSLE2), which is a more recent update for the USLE model family. The References at the end of this section include other RUSLE2 references for more in-depth information about the model's development and use.

There are also other computer models that also allow users to estimate eroded sediment amounts for a target area (slope, watershed, etc.). However, many of the other models usually require using more model inputs for the model to run than the USLE family of models. Some of the other models incorporate some version of one of the USLE models. The section also provides a brief introduction for other computer models that may be used for estimating construction site soil loss. The References at the end of this section include further reference information about the models discussed in this section.

3.1 RUSLE2 MODEL

The RUSLE2 model and other related support materials are available through the United States Department of Agriculture's Agricultural Research Service (USDA-ARS) official RUSLE2 website here:

http://fargo.nserl.purdue.edu/rusle2_dataweb/RUSLE2_Index.htm

This section discusses the basics of the methodology behind and use of RUSLE2, and how RUSLE2 results relate to construction sites. It does not include detailed information about how to use the model's Windows interface or how to set up a RUSLE2 model run. The references at the end of the section provide supplemental information on how to set up and use RUSLE2.

The RUSLE2 model calculates long-term sediment loss on slopes from rill and interrill erosion. Rainfall and runoff actions cause soil particle removal during rill and interrill erosion. The interrill erosion process starts with raindrop impact detaching soil particles and allowing these particles to move across the soil surface. Detached soil particles will be referred to as sediment. Interrill erosion may also be called sheet erosion. Interrill erosion runoff collects and forms rills on the hill slope. Sediment is then transported through the rills down the slope until the runoff flow slows down enough to allow the sediment to be deposited on either the land surface or in concentrated flow areas such as channels.

RUSLE2 Model Applicability

The RUSLE2 model can be used to help with EPSC and construction planning for construction sites. Some scenarios where RUSLE2 can be used as a planning tool are listed below:

- Calculating a baseline estimated soil loss to use for comparison with other scenarios;
- Comparing slope erosion rates at different construction stages;
- Comparing effect of erosion control measures in reducing erosion (rank practices for evaluating performance, cost-benefit);
- Calculating estimated sediment yields for phased and timed projects to minimize soil exposure to erosive rain events;
- Diverting runoff away from potentially high-erosion areas;
- Reducing overland flow path length where erosion control practices do not provide desired control (e.g., shorten overland flow path length, reduce steepness and more favorable slope shape);
- Showing the effects of stabilizing disturbed areas with vegetation, mulch or gravel soon after soil exposure;
- Selecting local environment vegetation types for long-term erosion control and management practices;
- Adding flat segments at end of overland flow paths to allow for deposition; and
- Using sediment trapping devices.

All computer models involve assumed conditions and calculations that help in defining to which situations the model is (or is not) applicable. The RUSLE2 computer model can be used to calculate rill and interrill erosion for slopes with mineral soils. However, there are situations where RUSLE2 is not applicable. The model developers do not recommend using RUSLE2 results directly for EPSC measure design procedures, but RUSLE2 output may be used to evaluate relative effectiveness of different EPSC measures. RUSLE2 does NOT apply for the scenarios in the following list:

- Concentrated flow areas (e.g., gullies, ditches, streams);
- Undisturbed forestland;
- Erosion by piping;
- Erosion caused by snowmelt;
- Erosion by mechanical processes (mass movement such as landslides, movement by tillage operations);

- Organic soils;
- Slope lengths longer than 1000 feet (maximum slope length used for deriving RUSLE2 data was 650 feet);
- Slope steepness greater than 100% (data used to derive RUSLE2 included very little slope data for slopes above 30%);
- Sediment basins beyond small, very simple sediment basins; and
- Sediment basin and diversion engineering designs

RUSLE2 Model Equation

To use RUSLE2, the user inputs climate, soil, slope, landuse and management information and the model output is the net average annual sediment loss. The equation format for RUSLE2 is the same as the equation format for most of the USLE family of models, and is shown in Equation 3.1. Each factor in the equation will be briefly introduced.

Equation 3.1 RUSLE2 Equation.

$$A = RKLSCP$$

A = average soil loss from rill and interrill erosion caused by rainfall and associated overland flow (tons/acre/time) – timeframe for loss calculations may be set by the user.
R = climate erodibility
K = soil erodibility for standard condition
L = slope length
S = slope steepness
C = cover management factor
P = support practices factor

Average Soil Loss (A)

The RUSLE2 model output (A) gives the average soil losses for the user-specified timeframe and is actually a net loss amount because the model allows for deposited sediment to be removed from the average soil loss. The RUSLE2 model involves some calculation differences from the calculations used in the USLE and RUSLE1. The USLE and RUSLE1 are used to calculate annual average soil losses, but cannot calculate average soil losses for shorter timeframes.. RUSLE2 includes daily soil loss calculations that allow the user to better refine soil loss estimates for a user-specified timeframe. The daily loss calculations are summed to get the loss for the user-specified timeframe as well as for annual loss estimates. Therefore, RUSLE2 model output for A may be based on a shorter timeframe (i.e., per day, week or month) as well as on an annual basis. More information about how RUSLE2 calculations are computed and how the RUSLE2 factors are calculated can be found in the reference materials.

The average loss can also be viewed as the net sum of soil losses related to the following four processes:

- soil loss on the eroding portion the slope;
- soil detachment on the entire slope;
- conservation planning soil loss; and
- sediment delivery for the slope length.

The soil loss on the eroding slope portion and the soil detachment on the entire slope describe the rill and interrill erosion processes. Conservation planning soil loss allows the user to include specific measures or practices that reduce slope erosion losses. Sediment delivery for the slope length gives a net amount of sediment that is not lost to sediment deposition along the slope.

Another way to view the model calculation process **.**can be summarized with Equation 3.2. The net annual soil loss may also be referred to as the sediment yield.

Equation 3.2. Net soil loss relationship equation

$$Net\ Soil\ Loss = Soil\ Loss - Deposition$$

Climate Erodibility (R)

The climate erodibility factor (R-value) is also known as an erosivity index and accounts for rainfall amount and intensity for the specified location. Temperature is also included in this factor since temperature can indirectly affect erosion by affecting decomposition rates for vegetation and other organic materials used for erosion control. This R value is allowed to vary by month to account for seasonal variations. However, RUSLE2 is not equipped to account for other seasonal vegetation growth and variations. Climate data for the R-value may be obtained from the national RUSLE2 databases and supplemented as needed based on local conditions.

The R factors for RUSLE2 for an area are typically developed on an average annual basis similar to the methods used for USLE. For the daily calculations performed by RUSLE2, the average annual R factor is multiplied by the fraction that occurs on a given day. This fraction is based on seasonal variations in temperature and rainfall.

Soil Erodibility (K)

The soil erodibility factor (K-value) is set based on how susceptible the soil is to erosion. The K factor are determined empirically based on specific slope conditions known as a RUSLE2 unit plot. The unit plot method allows the K factor to be set using consistent conditions for various soil types and conditions. The unit plot is 72.6 feet long, 9% steep, maintained in a continuous fallow (no vegetation) and has a seedbed that is tilled up and down slope. Using the unit plot method as a common basis for testing soils produces K-factors that are independent of other variables such as ground cover, management practices, etc. that also affect erosion on slopes. These other variables are accounted for with other RUSLE2 variables.

The K-factor is based on a combination of soil and site properties. The soil texture is the most important soil information included in the K-factor. The soil texture is based on the distribution (percentages) of clay, silt and sand particles in the soil. The soil's type is specified by the percentages of each of these soil particle types. K-factors can also be affected by seasonal changes (e.g., soil moisture content, freeze and thaw cycles) and local variations.

In general, soils with higher clay content have lower K-values because clay particles produce strong forces between soil particles that help the soil particles resist being detached by raindrop impact and by overland flow. Soils with high sand content also have lower K-values because sandy soils have higher infiltration rates that lead to reduced runoff and erosion. Soils with high percentages of silt particles are the soils most likely to be eroded because silt particles can be easily detached by raindrops and by runoff, and silty soils also produce more runoff for a given rainfall amount than sandy soils.

Most non-disturbed soils in the United States have a K-value assigned that can be located in the Natural Resources Conservation Service's (NRCS) national RUSLE2 database. For highly disturbed soils where the soil layers have been mixed, K-values are not predetermined. This highly disturbed condition can exist on construction sites, and should be considered when performing RUSLE2 calculations. RUSLE2can help with estimating K-values for highly disturbed soils, but the user may have to collect and analyze soil samples to help with developing these input estimates. For determining the K-factor for highly disturbed soils, the RUSLE2 user's manual suggests first looking for a suitable soil within the NRCS database. The selected soil and the disturbed soil should match well for the following variables: erodibility factor K-value, soil texture for upper 4 to 6 inches of soil, hydrologic soil group and rock cover on the soil surface.

Slope Length (L) and Slope Steepness (S)

The slope length (L-value) and slope steepness (S-value) factors are often referred to in combination since both help define the overland flow path and topography used in RUSLE2. Some models within the USLE family of models treat these as a combined "LS" factor rather than as two separate factors. The three main topographic factors in RUSLE2 that define the overland flow path re average steepness, overland flow path length and flow path profile (slope) shape. The slope length is defined as the distance from where overland flow begins to occur to where flow becomes concentrated or to where deposition begins. However, this definition can be too simplified for certain complex slopes. As slope steepness increases, erosion also increases. Erosion also increases for longer overland flow path lengths because more runoff accumulates over the longer length. The overland flow path length contributes more to erosion on steep slopes than on areas with flatter slopes. The profile or slope shape also affects erosion and net soil loss. RUSLE2 allows users to input the following four main types of slope shapes:

- Uniform;
- Convex;
- Concave; and
- Complex.

Figure 3.1 shows examples of the different types of slope shapes. Uniform slopes have consistent steepness, soil and cover management conditions throughout the whole slope with no variations. Concave slopes are slopes where the steepness increases along the slope, and can produce higher erosion rates at the end of these slopes. Convex slopes have decreased steepness along the slope, and can have sediment deposition areas at the end of the slope if the end of the slope is flat enough to slow down runoff and allow sediment to deposit. Complex slopes are used where conditions along a slope are variable. Complex slopes include slopes that involve a combination of concave and convex sections as well as slopes where soil and land use conditions vary along a slope. RUSLE2 allows the user to break a slope into multiple segments for complex slopes, and to specify properties for each slope segment.

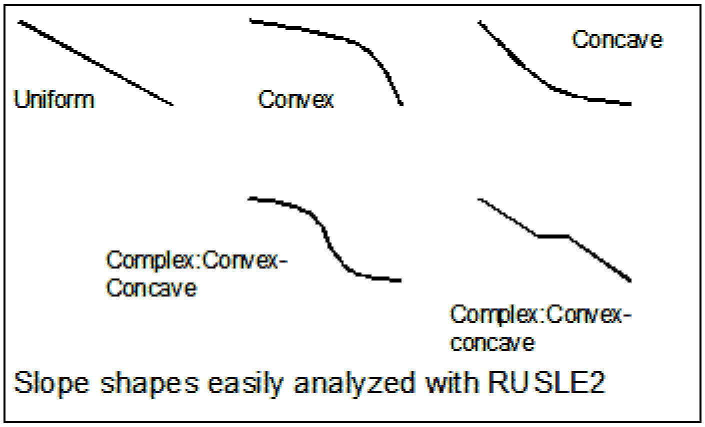

Figure 3.1. The four main types of RUSLE2 slope shapes

Cover Management Factor (C) and Support Practices (P)

The cover management factor (C-value) includes land use conditions for the slope and the support practices factor (P-value) allows the user to specify what support practices may be in use on the slope. These two factors are inter-related, but are two different factors in RUSLE2.

The C-value depends on vegetation type and growth, application of surface and buried materials (e.g., mulch, manure), crop rotation, conservation tillage and random roughness. The C factor is split into subfactors in earlier USLE models. RUSLE2 includes subfactors for the following items:

- Canopy;
- Ground cover (e.g., vegetation, mulch, rock);
- Surface roughness;
- Ridges;
- Below ground biomass (e.g., roots);
- Soil consolidation; and
- Antecedent soil moisture.

These subfactors are independent of landuse and can interact with one another. For example, the user must avoid "double counting" the same vegetation areas toward both canopy and ground cover subfactors. RUSLE2 uses equations to determine how these subfactors interact and how the subfactors affect soil loss. Further information about subfactors and how these affect RUSLE2 calculations is available in the reference materials. The user's manual notes that for temporary (1-year) disturbed condition runs, it is important to select "NO" for crop rotation – this prompts RUSLE2 to set initial conditions for cover-management. For disturbed land, initial condition is important because erosion depends on previous land use conditions. Users should also note that RUSLE2 does not adjust vegetation-related factors for local conditions.

Examples of P factor practices include contouring, strip systems (e.g., buffer strips, filter strips), terrace/diversions, small impoundments such as small sediment basins and tile drainage. More information about these practices and modeling the practices in RUSLE2 can be found in the reference materials. One RUSLE2 output that can be linked with the P factor practices is critical slope length.

Users should be careful when specifying cover management and supporting practice factor inputs. As mentioned earlier, avoid inadvertently "double counting" for the cover management subfactors. Practice installation is also sensitive to installation and location. Overland flow practices modeled in RUSLE2 such as silt fence and grass strips are assumed to be installed right on the contour. For installations that are not well aligned with the contour, sediment deposition decreases and concentrated flow occurs sooner (i.e., the practice's effectiveness is reduced). The model developers do not recommend using grass strips for steep slopes since RUSLE2 will greatly reduce sediment yield for the slopes beyond what would be observed in an actual installation.

Model Output

RUSLE2 provides multiple model outputs that can be used for gauging model performance and for planning different management scenarios. One output value is the average soil loss for the user-specified timeframe. Soil loss values can be compared for different management scenarios and different timeframes to determine if construction project EPSC measures and/or construction timing can help reduce estimated soil losses. RUSLE2 also gives a critical slope length output that gives the maximum slope length before the contouring management practice begins to fail. If the actual slope length is greater than the critical slope length, the slope may be more vulnerable to EPSC failures. Cover management systems that increase slope roughness and/or ground cover can be implemented to increase the critical slope length. Other measures such as grass strips or terraces may also be used to increase the critical slope length. It is desirable for the actual slope length to be less than the critical slope length for erosion control applications. Model users should carefully review RUSLE2 model input and output information to check that the model inputs and results are reasonable and consistent with accepted values from the model's user's manual.

Model Summary

Table 3.1.1 gives a brief summary of some key properties, abilities and limitations for using RUSLE2. Users should consult the RUSLE2 user's manual and other related references for more detailed information.

Table 3.1-1 RUSLE2 Model Summary

Model Description	Model Information
Model Area Scale	• Slope-based or watershed-based
Model Time Scale	• Range covers daily to long-term (annual and multi-year)
Key Equations Included	• RUSLE2 equation
Model Format	• Computer-based (Windows program)
GIS Compatibility	• ArcMUSLE add-on tool • Model inputs such as drainage area, slopes, etc. can be calculated using GIS, typically using gridded data such as digital elevation models (DEMs)
Key Assumptions/Limitations	• User's understanding of how to perform Q and q_P calculations will greatly affect model's results • Watershed-based and slope-based calculations will depend on the user's knowledge of condition of slopes (steepness, amount of cover, slope type, etc.)
Pros	• Ease of use (does not require computer analysis)
Cons	• Users need more knowledge than for RUSLE2 use (need to know how to calculate Q and q_P) • Model contains empirical parts

3.2 OTHER MODELS

Other computer models are also available that can be used to calculate soil loss for slopes and for larger areas. Brief overviews for several of these models are presented in this section.

MUSLE

The Modified Universal Soil Loss Equation (MUSLE) was developed as an alternative to the USLE that allowed the user to calculate sediment yield from rill and interrill erosion and to apply the model to single storm events. The MUSLE method was originally developed by Williams and Berndt, 1976. In MUSLE, the RUSLE2 rainfall energy factor (R) is replaced with a runoff factor (Q x q_P). The MUSLE equation is presented below:

Equation 3.2-1 MUSLE

$$T = 95(V \times Qp)0.56 \times K \times LS \times C \times P$$

Where:

T = sediment yield per storm event in tons
V = volume of runoff per storm event in acre-feet
Qp = peak flow per storm event in cubic feet per second
K, LS, C, and P are RUSLE factors

Values for V and Qp are determined from the sites drainage analysis.

The runoff volume (V) is calculated using the commonly used NRCS curve number method found in NRCS National Engineering Handbook Section 4: Hydrology (NEH-4). The peak discharge (Q_P) can be calculated using the graphical peak discharge method that is described in the user's manual for NRCS model Technical Release 55 (TR-55). The graphical peak discharge calculation requires the user to determine travel times for both sheet flow and shallow concentrated flow to calculate a time of concentration (Tc).

Table 3.2-1 MUSLE Model Summary

Model Description	Model Information
Model Area Scale	• Watershed-based (V and Q_P calculations require watershed parameters)
Model Time Scale	• Single storm events (V and Q_P calculations for single storm events)
Key Equations Included	• MUSLE • NRCS curve number method for V calculation • NRCS graphical peak discharge method and travel time equations for q_P calculation
Model Format	• Equation-based • Does not require computer calculations, but use can be expanded to larger areas with computer calculations
GIS Compatibility	• ArcMUSLE add-on tool • Model inputs such as drainage area, slopes, etc. can be calculated using GIS, typically using gridded data such as digital elevation models (DEMs)
Key Assumptions/Limitations	• User's understanding of how to perform V and QP calculations will greatly affect model's results • Watershed-based and slope-based calculations will depend on the user's knowledge of condition of slopes (steepness, amount of cover, slope type, etc.)
Pros	• Ease of use (does not require computer analysis)
Cons	• Users need more knowledge than for RUSLE2 use (need to know how to calculate V and QP) • Model contains empirical parts

REFERENCES

Integration of Modified Universal Soil Loss Equation (MUSLE) into a GIS Framework to Assess Soil Erosion Risk. Y. Zhang, J. Degroote, C. Wolter and R. Sugumaran. 2009. *Land Degradation and Development.* Volume 20, pp. 84-91.

RUSLE2 User Manual for Highly Disturbed Lands: Construction, Reclaimed, Mined, Landfills, Military Training Grounds, and Similar Lands. George R. Foster and Terry Toy. 2005. USDA – Agricultural Research Service.

Soil-Loss Estimation for Construction Lands Using RUSLE 2.0. Terrence Toy, Ph.D., CPESC and George Foster. Ph.D. February 2007. IECA Training Course.