THE REVISED UNIVERSAL SOIL LOSS EQUATION, VERSION 2

D.K. McCool[A], G.R. Foster[B] and D.C. Yoder[C]
[A] Research Leader, Land Management and Water Conservation Research, USDA-ARS, Pullman, Washington.
[B] Hydraulic Engineer (Retired), National Sedimentation Laboratory, USDA-ARS, Oxford, Mississippi.
[C] Professor, Dept. of Biosystems and Environmental Science, University of Tennessee, Knoxville, Tennessee.

Abstract
Version 2 of the Revised Universal Soil Loss Equation (RUSLE2), the second generation of RUSLE, estimates soil loss, sediment yield, and sediment characteristics from rill and interrill erosion caused by rainfall and associated overland flow. RUSLE2 uses factors that represent the effects of climatic erosivity, topography, cover-management, and support practices to compute erosion. Like other models, it uses a system of equations implemented in a computer program to estimate erosion. RUSLE2 database and its rules and procedures are used to describe a site-specific condition. RUSLE2 can be used to guide conservation planning, inventory erosion rates over large areas, and estimate sediment production on upland areas that might become sediment yield in watersheds. It can be used on cropland, pastureland, rangeland, disturbed forestland, construction sites, mined land, reclaimed land, landfills, military lands, and other areas where mineral soil is exposed to raindrop impact and surface overland flow produced by rainfall intensity that exceeds infiltration rate (Hortonian overland flow). RUSLE2 is a new model with new capabilities and features. It is much more powerful, has improved computational procedures, and provides more output useful for conservation planning than does RUSLE1. It uses a modern graphical user interface and can operate in either US customary or SI units.

Additional Keywords: erosion, modeling, conservation planning, transport, deposition

Introduction
Version 2 of the Revised Universal Soil Loss Equation (RUSLE2) is a new model with new features and capabilities that estimates soil loss, sediment yield, and sediment characteristics from rill and interrill (sheet and rill) erosion caused by rainfall and its associated overland flow. RUSLE2 uses factors that represent the effects of climate (erosivity, precipitation, and temperature), soil erodibility, topography, cover-management, and support practices to compute erosion. RUSLE2 is a mathematical model that uses a system of equations implemented in a computer program to estimate erosion rates. A major component of RUSLE2 is a database containing an extensive array of values that enable the user to describe a site-specific condition so RUSLE2 can compute erosion values that directly reflect conditions at a particular site. By using fundamental variables to represent cover-management effects, RUSLE2 can be applied to cropland, rangeland, disturbed forestland, construction sites, reclaimed mined land, landfills, military training sites, and other areas where mineral soil is exposed to the forces of raindrop impact and surface overland flow produced by rainfall intensity exceeding infiltration rate. RUSLE2 is used to evaluate potential erosion rates at specific sites, guide conservation and erosion control planning, inventory erosion rates over large geographic areas, and estimate sediment production on upland areas that might become sediment yield in watersheds.

RUSLE2 uses a modern, powerful graphical user interface instead of the text-based interface of RUSLE1. RUSLE2 can operate in either US customary units or SI units and can globally switch between the two systems of units, or the units on individual variables can be changed to one of several units. RUSLE2 can also manipulate attributes of variables, which includes graphing, changing units, and setting number of significant digits.

Theory and Assumptions:
RUSLE2 considers detachment, transport, and deposition of soil along an overland flow path. Detachment is estimated and soil is then transported by runoff estimated by the NRCS Runoff Curve Number technique. Deposition is estimated when slope flattens or flow is retarded by support practices or other causes.

Detachment
RUSLE2 detachment theory assumes that detachment is due to the forces of raindrop impact and surface overland flow produced by rainfall intensity in excess of infiltration rate. RUSLE2 uses an equation structure similar to the

Universal Soil Loss Equation (USLE) and RUSLE1 to compute average annual soil loss (detachment) on each day of the year as:

ai = ri ki li S ci pi [1]

where: ai = average annual soil loss for the ith day of the year, ri = erosivity factor, ki = soil erodibility factor, li = soil length factor, S = slope steepness factor, ci = cover-management factor, pi = supporting practices factor, all on the ith day. The slope steepness factor S is the same for every day and thus has no subscript. Values for these factors are average annual for a particular day of the year—not average values for the year. RUSLE2 is based on the assumption that net detachment caused by a single storm is directly proportional to the product of a storm's energy E and its maximum 30-minute intensity I_{30}. The relationship between detachment and storm erosivity EI is linear, which means that individual storm EI values can be summed to determine monthly and annual values. This linear relationship also means that average annual erosion can be mathematically computed for each day of the year as represented by Equation 1 even though erosion does not actually occur on every day.

Runoff, Transport, and Deposition

RUSLE2 computes sediment transport and deposition by using the Runoff Curve Number technique to estimate runoff using a 24-hour, 10-year recurrence interval storm. Deposition is computed when sediment load exceeds transport capacity in a segment of an overland flow path.

RUSLE2 uses the 10 year-24 hour storm in the Runoff Curve Method to compute storm erosivity and runoff values that are used to compute factor values for contouring, critical slope length for contouring, sediment transport capacity, and the effect of ponding on reducing erosivity. Sediment transport capacity is used to compute deposition by runoff entering slope segments with a concave shape, dense vegetation, high ground cover, or rough of this storm value and placed in the NRCS national RUSLE2 database by county and precipitation zone. Hydrologic soil group designations are available by map unit and component in the NRCS soil survey database. The USDA-NRCS hydrology manual provides information on assigning hydrologic soil group designations for those soils not included in the NRCS soil survey.

Base Computational Unit

The base RUSLE2 computational unit is a single overland flow path along a hill slope profile. An overland flow path is defined as the path that runoff follows from the origin of overland flow to where it enters a major flow concentration. Major flow concentrations are locations on the landscape where sides of a hill slope intersect to collect overland flow in defined channels. Ephemeral or classical gully erosion occurs in these channels. These defined channels are distinguished from rills in two ways. Rills tend to be parallel and are sufficiently shallow that they can be obliterated by typical farm tillage or grading operations that are a part of construction activities. When the rills are reformed, they occur in new locations determined by microtopograpy left by soil-disturbing operations like tillage. In contrast, concentrated flow areas occur in the same locations, even after these channels are filled by tillage. Location of these channels is determined by macrotopography of the landscape. The overland flow path (profile) that represents the 1/4 to 1/3 most erodible part of the area is often the profile selected for applying RUSLE2. RUSLE2 is used to estimate erosion for this profile that is used in conservation planning to choose a management practice that adequately controls erosion.

Climate

Storm erosivity EI is the product of a storm's total energy E and its maximum 30-minute intensity I_{30}. The EI product for storm erosivity captures the effects of the two most important rainfall variables that determine erosivity; how much it rains (rainfall amount) and how hard it rains (rainfall intensity).

Erosivity density is the ratio of the monthly erosivity to monthly precipitation. The erosivity density method used to derive erosivity values was developed to maximize the precipitation data that could be used to compute erosivity values and to provide a consistent set of erosivity values for conservation and erosion control planning. Erosivity density values were computed across the US at about 1610 stations. Statistical analysis showed that erosivity density is independent of elevation, which means that the erosivity density could be smoothed and mapped using GIS techniques for the entire continental US as a spatial unit.

Three types of erosivity inputs can be used in RUSLE2. The preferred method is to enter values for erosivity density. Erosivity density values were recently determined from analysis of modern weather data as a part of the RUSLE2 development. The second method is to enter monthly erosivity values. The third method is to enter an average annual erosivity value along with an erosivity distribution curve for the EI zone containing the site where RUSLE2 is being applied. This latter method is the same as that described in AH703 for RUSLE1. RUSLE2 computes a monthly erosivity by multiplying monthly erosivity density by monthly precipitation. Annual erosivity is computed as the sum of the monthly erosivity values.

Soil

Soils vary in their inherent susceptibility to erosion. The soil erodibility K factor is a measure of erodibility for the unit plot condition. The unit plot is 72.6 ft (22.1 m) long on a 9 percent slope, maintained in continuous fallow, tilled up and down hill periodically to control weeds and break crusts that form on the soil surface. Unit plots are plowed, disked, and harrowed, much like for a clean tilled row crop of corn or soybeans except no crop is grown.

The unit plot procedure determines empirical K values for specific soils where the effect of cover-management on soil erodibility has been removed. The soil erodibility factor K represents the combined effect of susceptibility of soil to detachment, transportability of the sediment, and the amount and rate of runoff per unit rainfall erosivity for unit plot conditions. The RUSLE2 soil erodibility factor is an empirical measure defined by the erosivity variable EI_{30} (product of storm energy and maximum 30 minute intensity) used in RUSLE2. It is not directly related to specific erosion processes, and it is not a soil property like texture. RUSLE2 K values are unique to this definition, and erodibility values based on other erosivity measures, such as runoff, must not be used for K. Soil erodibility K values vary during the year. The values tend to be high in early spring during and immediately following thawing and other periods when the soil is wet. The values tend to be low in late summer when soil moisture and runoff is low because of increased soil evaporation caused by high temperatures.

Topography

The slope length effect in RUSLE2 is a function of rill erosion relative to interrill erosion. Interrill erosion is assumed to be caused by raindrop impact and therefore independent of location along the overland flow path, assuming that the variables that affect interrill erosion are constant along the overland flow path. Rill erosion is assumed be caused by surface runoff and to vary linearly along the overland flow path because of the accumulation of runoff. The slope length exponent m is defined in the equation:

$$m = \beta / (1+\beta) \qquad [2]$$

where β is the ratio of rill to interrill erosion varies between 0 and 1 and reflects the relative contribution of rill and interrill erosion. The exponent m is near zero when almost all of the erosion is by interrill erosion, such as on a flat slope, and m is near one when almost all of the erosion is from rill erosion, such as on a bare, steep slope. Slope steepness, cover-management, and soil affect the RUSLE2 slope length effect because of their different effect on rill erosion relative to interrill erosion. The RUSLE2 slope length effect varies daily as cover-management conditions change. The USLE slope length factor is independent of the other USLE factors, except for slope steepness. The slope steepness S factor should be a function of the soil and cover-management similar to slope length. However, neither the empirical data nor theory is sufficient for incorporating those effects into RUSLE2.

Cover-Management Factors

A sub-factor method used in RUSLE2 to compute values for the cover-management factor ci gives RUSLE2 its land use independence. This method uses sub-factors that are universally important in how any cover-management system affects rill and interrill erosion. The RUSLE2 sub-factors are canopy, ground cover, soil roughness, ridge height, soil biomass, and soil consolidation. RUSLE2 computes a value for each sub-factor and their product for each day to compute a daily ci factor value for use in equation 1. Cover-management variables also affect the RUSLE2 topographic and support practice factors. Thus, the topographic, cover-management, and support practice factors must be examined to see the entire effect of land use and management on RUSLE2 erosion estimates.

Canopy effects

Canopy is live and dead vegetative cover above the soil surface that intercepts raindrops but does not contact the surface runoff. The portion of the above ground plant biomass touching the soil surface is treated as live ground cover. The two canopy variables of canopy cover and effective fall height are used to describe the effect of canopy on erosion.

Ground Cover

Ground cover, which is material in contact with the soil surface, slows surface runoff and intercepts raindrops and water drops falling from canopy. Ground cover includes all material that touches the soil surface. Ground cover is probably the single most important variable in RUSLE2 because it has more effect on erosion than almost any other variable, and applying ground cover is the simplest, easiest, and most universal way of controlling erosion.

Ground cover reduces erosion by protecting the soil surface from direct raindrop impact, which reduces interrill erosion. Ground cover also slows surface runoff and reduces its detachment and transport capacity, which reduces rill erosion. If ground cover is low (less than about 15%) and ground cover pieces are long and oriented across slope, ground cover reduces soil loss by causing deposition in small ponds above ground cover pieces. As ground cover increases, deposition ends and ground cover reduces runoff detachment capacity, which reduces rill erosion. The effectiveness of ground cover varies with the site-specific condition. For example, a 50% ground cover can reduce soil loss by 95% under some conditions while only reduce soil loss by 65% under other conditions. In RUSLE2, the effect of cover varies daily with the ratio of rill to interrill erosion.

Operation Database Component

The operation descriptions in the operations component of the RUSLE2 database contain the information that RUSLE2 uses to describe how operations affect erosion. An operation is an event that affects the soil, vegetation, and/or residue. Operations are discrete events that change properties of vegetation, residue, and/or the soil that affect erosion.

Examples of operations include tilling, planting, harvesting, grazing, burning, frost, ripping, and blading. Operations are described using a sequence of processes. Both the processes themselves and their sequence determine an operation effect. Additional variables are used to describe some processes.

A very important difference between RUSLE2 and RUSLE1 is that tillage operations in RUSLE2 include a flattening ratio that describes the mechanical flattening of standing residue prior to its burial, and a resurfacing ratio that accounts for material returned to the surface by a tillage operation. These options differ from those used in RUSLE1 and other models, and preclude their direct use in RUSLE2.