

THE REVISED UNIVERSAL SOIL LOSS EQUATION

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ABSTRACT

The Universal Soil Loss Equation has been revised to more accurately estimate soil loss from both crop and rangeland areas. The revision includes data not available at the time Agriculture Handbook 537 was completed in 1978. All factors R, K, LS, C and P have received attention. R-values for the western United States were developed from hourly precipitation data. A time-variant K factor was included for the eastern United States. New length and steepness (LS) factor relationships were developed. C factors are now computed by a subfactor approach, and P factors were developed using the CREAMS model. The model has been computerized for use on personal computers with a DOS operating system. The program is available for purchase from the Soil and Water Conservation Society.

INTRODUCTION

In 1985, at a meeting of the United State Department of Agriculture (USDA) and university erosion researchers, it was decided that two concurrent efforts were needed to improve the erosion prediction technology used in USDA conservation planning: 1) revise the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) to incorporate technology developed after 1978; and 2) develop technology which would address interrill and rill erosion, as well as sediment transport and deposition associated with concentrated flow and ponded areas, the Water Erosion Predictions Project (WEPP). Both of these projects are nearing fruition. This paper discusses the changes incorporated in the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1995).

RUSLE DESCRIPTION

RUSLE maintains the basic structure of the USLE, namely:

$$A = R K L S C P \quad (1)$$

where A is the computed soil loss, R is the rainfall-runoff erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the cover-management factor, and P is the supporting practices factor. This empirically based equation,

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derived from a large mass of field data. computes combined interrill and rill erosion using values representing the four major factors affecting erosion. These factors are: climatic erosivity represented by R, soil erodibility represented by K, topography represented by LS, and land use and management represented by C and P. Whereas the basic USLE structure has been retained, the algorithms used to calculate the individual factors have been changed significantly in RUSLE. Perhaps most important has been the computerization of the technology to assist with the determination of individual factors. This allows computation of the soil loss ratio (SLR) by 15-day intervals rather than by longer crop stage periods, and improves estimates of the factors affecting the SLR, such as surface roughness, crop growth and residue decomposition.

R-factor

Ideally, the R-factor is determined by analyzing long-term breakpoint precipitation data and calculating EI, the product of energy and maximum 30-minute intensity of each storm meeting certain characteristics, summing the EI for the entire period of record and dividing the value by the number of years. This process was used in developing the original R map for the eastern United States (U.S.). This procedure is very time consuming and requires breakpoint data, which are unavailable for much of the western U.S.. In the western U.S., new R values have been calculated using over 1,000 point values of EI developed from a relationship between 60-minute and 15-minute precipitation data (Istok et al., 1986):

$$(EI)_{15} = b(EI)_{60} \quad (2)$$

where

$(EI)_{15}$ = EI calculated from 15-minute data

$(EI)_{60}$ = EI calculated from 60-minute data

b = regression parameter.

A b value was obtained for each climatically homogeneous area in the western U.S.. The $(EI)_{15}$ values were then adjusted to an equivalent breakpoint basis using $EI = 1.0667 (EI)_{15}$ and $R = 1.0667 (R)_{15}$ (Weiss, 1964). Some changes were also made in the location of lines of equal erosivity in the eastern states (east of the 105th meridian). Another change in the R-factor was to reduce R values where flat slopes occur in regions of long intense rainstorms. Pondered water on the soil surface reduces the erosivity of the rain. Finally, an R equivalent approach is being used in the Pacific Northwest area to reflect the combined effect of rain and snow melt on partly thawed soil. These R equivalent relationships were developed from 10 years of erosion measurements (McCool et al., 1987a).

Part of the R-factor calculation involves a seasonal distribution to permit weighting of the soil erodibility value, K, and the cover-management factor, C, by the percent of annual R occurring during each 15-day computation interval. To facilitate these calculations, climate data files have been developed (called a city code) for climatically homogeneous areas. These computer files require information such as the frost-free duration, monthly precipitation and temperature, and 15-day distributions of R. Typical values are included in the computer program for at least one station in each of 119 climatic regions of the contiguous 48 United States plus numerous stations in Hawaii.

K-factor

The K-factor is a measure of the inherent erodibility of a given soil under the standard condition of the USLE unit plot maintained in continuous fallow. Values for K typically range from about 0.013 to 0.059 SI units, (0.10 to 0.45 U.S. customary units) (Foster et al., 1981), with high-sand and high-clay content soils having the lower values and high-silt content soils having the higher values. Users in the U.S. have little difficulty choosing a K-factor value because the U.S. Natural Resource Conservation Service (NRCS) has identified K values for all major soil mapping units in the U.S. However, the site-specific K-value, and its seasonal variation, can be quite different from the K-value given in soil survey information.

The soil erodibility nomograph (Wischmeier et al., 1971) is a popular tool for estimating K values, but it does not apply to some soils. Updating the K-factor for RUSLE involved developing guides so the user could identify soils where the nomograph does not apply and estimate K using alternative methods. Erodibility data from around the world have been reviewed, and an equation has been developed that gives a useful estimate of K as a function of an "average" diameter of the soil particles. Only soils with less than 10% of rock fragments were considered. The equation in SI units (Foster et al., 1981) can be expressed as:

$$K = \left\{ 0.0034 + 0.0405 \exp \left[-\frac{1}{2} \left(\frac{\log (Dg) + 1.659}{0.7101} \right)^2 \right] \right\}$$

where

$$Dg(mm) = \exp \left[0.01 \sum_{i=1}^N f_i \ln m_i \right]$$

Here, f_i is the primary particle size fraction in percent, and m_i is the arithmetic mean of the particle size limits of that size (Charas and Boersma, 1984). K-values for volcanic soils of Hawaii are also estimated with an alternative algorithm to the erodibility nomograph (El-Swaify and Dangler, 1976).

RUSLE also varies K seasonally. Experimental data show that K is not constant but varies with season, being highest in early spring when the soil is wet and lowest in mid-fall when the soil is dry. The seasonal variability is addressed by weighting the instantaneous estimate of K in proportion to EI (the percent of annual R) for 15-day intervals. Instantaneous estimates of K are made from equations relating K to the frost-free period and the annual R-factor.

An additional change incorporated in RUSLE is to account for rock fragments on and in the soil, a common occurrence on western U.S. rangelands and croplands in many areas of the world. Rock fragments on the soil surface are treated like mulch in the C-factor, while K is adjusted for rock in the soil profile to account for effects on runoff. RUSLE also provides a procedure for identifying soils that are highly, moderately, or slightly susceptible to rill erosion compared with their susceptibility to interrill erosion.

L and S factors

RUSLE uses four separate slope length relationships. Three are functions of slope steepness as in the USLE, and of the susceptibility of the soil to rill erosion relative to interrill erosion. A separate slope length relationship was developed specifically for the dryfarmed cropland region of the Pacific Northwest of the U.S. (McCool et al., 1989; 1993).

More questions and concerns have been expressed over the L-factor than any of the USLE factors. One reason is that the choice of a slope length involves judgment; different users choose different slope lengths for similar situations. RUSLE includes improved guides for choosing slope length values to give greater consistency among users. The attention given to the L-factor is not always warranted, because soil loss is less sensitive to slope length than to slope steepness. For typical slope conditions, a 10% error in slope length results in a 5% error in computed soil loss.

Revised slope steepness relationships were developed from data from a large number of historical and current research plots (McCool et al., 1987b). A separate relationship was developed specifically for the dryfarmed cropland region of the Pacific Northwest U.S. (McCool et al., 1993).

Soil loss is much more sensitive to changes in slope steepness than to changes in slope length. In the USLE, a 10% error in slope steepness gives about a 20% error in computed soil loss. Thus, special attention should be given to obtaining good estimates of slope steepness. RUSLE has a closer to linear slope steepness relationship than the USLE. Computed soil loss for slopes less than 20% are similar in USLE and RUSLE. However, on steep slopes, computed soil loss is reduced almost in half with RUSLE. Experimental data and field observations, especially on rangelands, do not support the USLE quadratic relationship when extended to steep slopes.

In most practical applications, a slope segment previously estimated as a single plane or uniform slope can be a poor representation of the topography. In RUSLE and its computer program, complex slopes can be readily represented to provide a better approximation of the topographic effect.

C-factor

The C-factor is perhaps the most important USLE/RUSLE factor because it represents conditions that can most easily be managed to reduce erosion. Values for C can vary from near zero for a very well-protected soil to 1.5 for a finely tilled surface that produces much runoff and leaves the soil highly susceptible to rill erosion.

Values for C are a weighted average of soil loss ratios that represent the soil loss for a given condition at a given time, to that of the unit fallow plot. Thus, soil loss ratios vary during the year as soil and cover conditions change. To compute C, soil loss ratios are weighted according to the distribution of erosivity during a year (i.e., from the information in the city code climate data).

In RUSLE, a subfactor method is used to compute soil loss ratios as a function of four subfactors (Laflen et al., 1985) given as:

$$C = PLU * CC * SC * SR \quad (5)$$

where PLU is prior land use subfactor, CC is crop canopy subfactor, SC is surface or ground cover (including erosion pavement) subfactor and SR is the surface roughness subfactor.

The prior land use subfactor (PLU) expresses the influence on soil erosion of (1) prior cropping, (2) dominant tillage practice, (3) soil consolidation, (4) time, and (5) biological activity. These components account for the residual effects of cropping.

The canopy cover subfactor (CC) expresses the effect of vegetative canopy on reducing rainfall energy impacting the soil surface. While most rainfall intercepted by crop canopy eventually reaches the soil surface, it usually does so with much less energy than non-intercepted rainfall. These intercepted raindrops either fracture into smaller drops with less energy, drip from leaf edges or travel down crop stems to the ground.

Surface cover affects erosion by reducing transport capacity of runoff water (Foster, 1982), by causing deposition in ponded areas (Laflen, 1983), and by decreasing the surface area susceptible to raindrop impact. It is perhaps the single most important factor in determining soil erosion. Surface cover includes crop residue, rocks, cryptogams, or other nonerodible material that are in direct contact with the soil surface (Simanton et al., 1984; Box, 1981; and Meyer et al., 1972). The effect of surface cover on soil erosion is given by a negative exponential relationship, $SC = e^{-bm}$, between the surface cover subfactor, SC, and the fraction of the land area covered by surface cover, m. The coefficient b indicates the effectiveness of surface cover in reducing soil erosion. Laflen et al. (1980) and Laflen and Colvin (1981) found that b values ranged from 3.0 to 7.0 for row crops, while Dickey et al. (1983) found b values of 2.4 to 3.2 in a rainfall simulation study on small grains. Within the Pacific Northwest, b values greater than 5.0 have been found for small grain (McCool, 1985; 1989 - personal communication).

Surface roughness has been shown to affect soil erosion (Cogo et al., 1984). They showed that the random roughness, an index of surface roughness (Allmaras et al., 1966), can be used to predict soil erosion. A rough surface, expressed by a large surface roughness index, has many depressions and barriers. During a rainfall event, these trap water and sediment, and erode at lower rates than do smooth surfaces under similar conditions. Increasing surface roughness decreases transport capacity and detachment of runoff by reducing flow velocity. Consolidation because of rainfall decreases surface roughness over time.

P-factor

Of the USLE/RUSLE factors, values for the P-factor are the least reliable. The P-factor mainly represents how surface conditions affect flow paths and flow hydraulics. For example, with contouring, tillage marks are credited with forcing runoff to flow around the slope at much reduced grades. However, slight changes in grade can greatly change the erosivity of runoff. In experimental field studies, small changes in such features as row grade and their effect on erosion are difficult to document, leading to much scatter in measured data. For example, the effectiveness of contouring in field studies conducted on a given slope have ranged from no

reduction in soil loss to a 90% reduction. Likewise, identifying these subtle characteristics in the field is difficult when applying RUSLE. Thus, P-factor values represent broad, general effects of such practices as contouring.

In RUSLE, extensive data have been analyzed to reevaluate the effect of contouring. The results have been interpreted to give factor values for contouring as a function of ridge height, furrow grade, and climatic erosivity. New P-factor values for the effect of terracing account for grade along the terrace while a broader array of strip cropping conditions are considered in RUSLE than in USLE. The CREAMS model (Knisel, 1980) was used in developing the new P-factor values.

Finally, P factors in RUSLE have been developed to reflect conservation practices on rangelands such as pitting, ripping, root plowing and land imprinting. Evaluation of the practices requires estimates of surface roughness and runoff reduction. Some of the P-factor values are slope dependent.

SUMMARY

The USLE has been revised to reflect new technology and analysis of data required since 1978 when Agriculture Handbook 537 was completed. The RUSLE (Renard et al., 1995) is available in handbook form or on disc for use with a personal computer. The computer version is available for purchase from the Soil and Water Conservation Society. Currently, all computations are in U.S. customary units. Conversions to SI units can be made readily using factors developed by Foster et al. (1981).

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