RUSLE

Revised universal soil loss equation

By Kenneth G. Renard, George R. Foster, Glenn A. Weesies, and Jeffrey P. Porter

THERE are many changes for estimating erosion by water in RUSLE, the revised universal soil loss equation. The changes include the following:

► Computerizing the algorithms to assist with the calculations.

► New rainfall-runoff erosivity term values (R) in the western United States, based on more than 1,200 gauge locations.

► Some revisions and additions for the eastern United States, including corrections for high R-factor areas with flat slopes to adjust for splash erosion associated with raindrops falling on ponded water.

► Development of a seasonally variable soil erodibility term (K).

► A subfactor approach for calculating the cover-management term (C), with the subfactors representing considerations of prior land use, crop canopy, surface cover, and surface roughness.

► New slope length and steepness (LS) algorithms reflecting rill to interrill erosion ratios.

► The capacity to calculate LS products for slopes of varying shape.

► New conservation practice values (P) for rangelands, stripcrop rotations, contour factor values, and subsurface drainage.

History of the USLE

Although the universal soil loss equation (USLE) is a powerful tool that is widely used by soil conservationists in the United States and many foreign countries, research and experience since the 1970s have provided improved technology that is incorporated in the new, revised USLE.

The USLE was developed by W. H. Wischmeier, D. D. Smith, and others with

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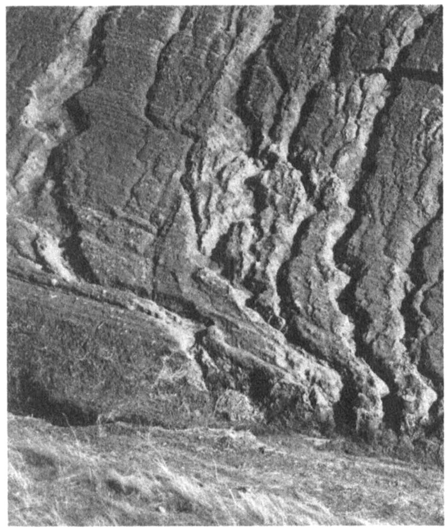

the U.S. Department of Agriculture (USDA), Agricultural Research Service (ARS), Soil Conservation Service (SCS), and Purdue University in the late 1950s. Its field use began in the Midwest in the 1960s.

In 1965, *Agriculture Handbook 282* was published, which served as the main reference manual for USLE until it was revised in 1978 as *Agriculture Handbook 537* (*4*).

In the decade since the publication of handbook 537, experts have improved the USLE significantly and extended it to several new applications. In 1987, ARS, SCS, and several cooperators began a project to revise the USLE and its documentation.

The USLE is as follows:

$$A = RKLSCP \qquad [1]$$

where A is computed soil loss, R is the rainfall-runoff erosivity factor, K is a soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is a cover-management factor, and P is a supporting practices factor. This empirically based equation, derived from a large mass of field data, computes sheet and rill erosion using values representing the four major factors affecting erosion. These factors are:

► Climate erosivity represented by R.

► Soil erodibility represented by K.

► Topography represented by LS.

► Land use and management represented by CP.

These same factor values are retained in the RUSLE.

Applications of the USLE

The USLE was developed initially as a tool to assist soil conservationists in farm planning. A conservationist used the USLE to estimate soil loss on specific slopes in specific fields. If the estimated soil loss exceeded acceptable limits, the USLE was used to guide the conservationist and farmer in choosing a practice or practices that would control erosion adequately while meeting the needs and wishes of the farmer. Thus, the USLE helped to tailor erosion control practices to specific sites.

In the 1970s the USLE became an important tool for estimating sheet and rill erosion in national inventories and assessments to formulate and implement public policy on soil conservation. Such inventories, involving erosion estimates at more than one million sample points on nonfederal land across the United States (*3*), produced an immense amount of information on the nation's soil resources. This information has been used for studies that neither developers of the USLE nor those conducting the inventories anticipated. For example, G. R. Foster and colleagues at the Los Alamos National Laboratory used the data to evaluate how rapidly plutonium fallout would leave the landscape by erosion and reach outlets of major rivers in the United States.

In the Food Security Act of 1985, the USLE is being used to identify highly erodible land and develop farm plans for compliance with the act. This use of the equation in policy implementation is new and uncertain and will likely subject the equation to legal and administrative challenges on its validity and application. We expect the USLE to successfully withstand these challenges, despite its application for situations beyond those for which it was developed.

Originally, the USLE was developed for use on cropland. By the early 1970s it was being applied to rangeland and disturbed forest land, often stimulating controversy. Other land uses where the USLE has been applied include urban construction areas, recreational sites, highway embankments, mine tailings, and even coal piles. Such widespread application results from the technical soundness and the lack of alternative models for planning conservation programs to control soil erosion by water.

Wise use of prediction technology like the USLE/RUSLE requires that the user be aware of a procedure's limitations. The USLE/RUSLE is an equation that estimates average annual soil loss by sheet and rill erosion on those portions of landscape profiles where erosion, but not deposition, is occurring. It does not estimate deposition like that at the toe of concave slopes, and it does not estimate sediment yield at a downstream location. Also, it does not include ephemeral gully erosion. Furthermore, the USLE/RUSLE does not provide information on sediment characteristics, such as those needed in many water quality initiatives.

An important scientific limitation of the USLE/RUSLE as an empirically based equation is that it does not represent fundamental hydrologic and erosion processes explicitly. For example, the effect of runoff, as might be reflected in a hydrologic model, is not represented directly in the USLE/RUSLE. If the USLE is modified to account for a runoff effect, every term must be considered. Fundamental erosion processes and their interactions are not represented explicitly. An example where the USLE does not give the proper result is the deposition of sediment in furrows on flat grades. Analysis of any single data set may show significant differences between estimates with the USLE/RUSLE and observed data.

Such limited comparisons are not at all an indication of the overall performance of the USLE/RUSLE. As an empirical equation derived from experimental data, the USLE/RUSLE adequately represents the first-order effects of the factors that affect sheet and rill erosion.

The revised equation

In the meantime, the USLE remains the most powerful, widely used, and practical tool for estimating sheet and rill erosion. The current project to revise and update the USLE is nearing completion and will strengthen the technology. The update is based on an extensive review of the USLE and its data base, analysis of data not previously included in the USLE, and theory describing fundamental hydrologic and erosion processes. This update of the USLE is so substantial that the result is referred to as RUSLE—the revised USLE. Following is a brief description of some of the improvements being made to the USLE factors in the RUSLE.

R factor. The R factor represents the input that drives the sheet and rill erosion process, and differences in R values represent differences in erosivity of the climate. For example, in Illinois, all other factors being the same, nearly twice as much erosion is expected in southern Illinois than in the northeast because of differences in climatic erosivity at the two locations.

The erosivity of rains is not distributed uniformly throughout the year. Many of the most erosive rains occur in the spring when row-cropped land is bare and ready for planting, so the soil is most susceptible to erosion when the most erosive rains occur. Thus, in assessing erosion, the magnitude of the R factor and its seasonal distribution must be addressed in relation to the cropping system.

Of the USLE factors, R is the one most exactly computed from input data: rainfall amounts and intensities. However, these data are not always available, especially in isolated areas of foreign countries. Suggestions are presented for relating R to precipitation data.

One of the major improvements in the RUSLE is a greatly improved isoerodent map for the western United States. Data from more than 1,000 locations have been analyzed to prepare the new map. The previous isoerodent map was based on a few point calculations and a procedure that related the annual R to the two-year frequency, six-hour duration precipitation amount. The current map produced point estimates in the western United States that are seven times as large as those in *Agriculture Handbook 537*.

Another change in the R factor is to reduce R values where flat slopes occur in regions of long, intense rainstorms (such as in the southeastern United States). Ponded water on the soil reduces the erosivity of raindrdop impact. Finally, an R equivalent approach is being used in the Pacific Northwest to reflect the combined effect of thawing soil and rain on snow or partly frozen soil.

K factor. The K factor is a measure of the inherent erodibility of a given soil under the standard condition of the unit USLE plot maintained in continuous fallow. Values for K typically range from about 0.10 to 0.45 (customary English units), with high-sand and high-clay content soils having the lower values and high-silt content soils having the higher values.

Because of its great range in possible values, the K factor may be of slightly greater importance, from a sensitivity point of view, than is the R factor. Users have little difficulty choosing a K-factor value because SCS has identified K values for all major soil mapping units. However, the site-specific K value can be quite different from the K value given in soil survey information.

The erodibility nomograph is the most commonly used tool for estimating K values, but it does not apply to some soils. The updating of the K factor for RUSLE involves developing guides so that the user can identify soils where the nomograph does not apply and then estimate K using alternative methods. Erodiblity 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.

Use of this function, however, is only recommended where the nomograph or another procedure does not apply. K values for the volcanic soils of Hawaii are estimated with an alternative algorithm to the erodibility nomograph (*1*).

The RUSLE also varies K seasonally. Experimental data show that K is not constant but varies with season, being highest in the spring with soil fluffing from freeze-thaw actions and lowest in mid-fall and winter following rainfall compaction or a frozen soil. The seasonal varibility is addressed by weighting the instantaneous estimate of K in proportion to the 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 the RUSLE is to account for rock fragments on and in the soil. 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 rock effects on permeability and, in turn, runoff. (Updating of the K factor values is led by M.J.M. Römkens, ARS, Oxford, Mississippi, and R. A. Young, ARS, Morris, Minnesota.)

L and S factors. More questions and concerns are expressed about the L factor than any of the other USLE factors. One reason is that the choice of a slope length involves judgment, and different users choose different slope lengths for similar situations. The RUSLE includes improved guides for choosing slope length values to give greater consistence among users.

The attention given to the L factor is not always warranted because soil loss is less sensitive to slope length than to any other

USLE factor. For typical slope conditions, a 10 percent error in the slope length results in a 5 percent error in computed soil loss.

The RUSLE uses three separate slope length relationships. They include (a) a function of slope steepness, as in the USLE, (b) a function of the susceptibility of the soil to rill erosion relative to interrill erosion, and (c) a slope length relationship specifically for the Palouse region in the Pacific Northwest. A guide helps the user identify the appropriate relationship for the particular field conditions.

Soil loss is much more sensitive to changes in slope steepness than to changes in slope length. In the present USLE, a 10 percent error in slope steepness gives about a 20 percent error in computed soil loss. Thus, special attention should be given to obtaining good estimates of slope steepness.

The RUSLE has a more nearly linear slope steepness relationship than the USLE. Computed soil loss for slopes less than 20 percent are similar in the USLE and RUSLE. However, on steep slopes, computed soil loss is reduced almost by half with the RUSLE. Experimental data and field observations, especially on rangeland, do not support the USLE quadratic relationship when extended to steep slopes. The RUSLE also provides a slope steepness relationship for short slopes subject primarily to interrill erosion and a steepness relationship for the Palouse region.

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 the RUSLE complex slopes can be represented readily to provide a better approximation of the topographic effect. (Updating of the L- and S-factor values is led by D. K. McCool, ARS, Pullman, Washington).

C factor. The C factor is perhaps the most important USLE factor because it represents conditions that can be managed most easily to reduce erosion. Values for C can vary from near zero for a very well-protected soil to 1.5 for a finely tilled, ridged 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 (SLRs) that represent the soil loss for a given condition at a given time to that of the unit plot. Thus, SLRs vary during the year as soil and cover conditions change. To compute C, SLRs are weighted according to the distribution of erosivity during a year.

In the RUSLE, a subfactor method is used to compute SLRs as a function of four subfactors: prior land use, canopy, ground cover, and within-soil effects. Ground cover affects erosion the most. But after too much attention is given to ground cover without considering the within-soil effects, such as those associated with root mass and tillage. For example, 30 percent cover after planting is the criterion frequently used for conservation tillage. A 30 percent cover reduces soil loss about 72 percent, according to the USLE. For comparison, the soil loss from a slope freshly plowed out of highly productive meadow is only 25 percent of that from the unit plot. Thus, within-soil effects can be substantial.

In the RUSLE, the subfactor relationship is given by the equation:

$$C = PLU \cdot CC \cdot SC \cdot SR \qquad [2]$$

where PLU is the prior land use subfactor, CC is the canopy subfactor, SC is the surface cover subfactor, and SR is the surface roughness subfactor.

The effect of surface ground cover on erosion has been observed to vary greatly in research studies. In some studies a 50 percent cover reduced soil loss by about 65 percent. In other studies a 50 percent cover reduced soil loss by 95 percent. To deal with this varied effectiveness in the RUSLE, the following equation is used:

$$SC = \exp(-b\ M) \qquad [3]$$

where SC is the mulch or ground cover subfactor value and M is the percentage of ground cover. The b coefficient is assigned a value of either 0.025, the value in the present USLE; 0.035, the new "typical" value in the RUSLE; or 0.050 for certain conditions. The value of b is increased as the tendency for rill erosion to dominate over interrill erosion for the soil increases. Guidelines are provided on choosing the b value.

Subfactor values (PLU and SR) for the within-soil effect are calculated from the amount of biomass in the soil that accumulates from roots and incorporation of crop residue. The RUSLE computes biomass decomposition on and in the soil using a residue decomposition model (2). Characteristics of tillage operations are important in computing estimates of subfactor values for SLRs. Values for SLRs in the RUSLE for conservation tillage likely will be less than those of the USLE because RUSLE computes greater effectiveness for ground cover.

One reason for the subfactor approach in the RUSLE is for applications where SLR values are not available. For example, no experimental erosion data exist for many vegetable and fruit crops, such as asparagus and blueberries. Developing SLR values using the subfactor method in the RUSLE is easier and more accurate than making comparisons with values in table 5 of *Agricultural Handbook 537* when none of the crops listed in the table closely matches the characteristics of the crop for which new values are needed.

The RUSLE has computer routines for many tillage operations and crops. In other instances, the user must input new data reflecting the amount of residue incorporated by a tillage operation and the roughness residual following tillage. For crops not available in the computer program, data are needed to reflect canopy characteristics and root mass in the upper four inches of the soil profile. Thus, the user must specify the crops in a rotation; crop yield; and the dates of operations, such as tillage and harvest. The computer calculates SLRs and the average annual C-factor.

Grazing effects on rangeland, pasture, and meadow are reflected in the effect of canopy height, ground cover, and root biomass. Finally, ground cover as used in the USLE reflected vegetation and litter; in the RUSLE, ground cover is given as 1.0 minus the amount of bare soil that reflects the addition of litter in the form of rock and stone besides the conventional vegetative litter. (Updating of the C-factor values for cropland is led by J. M. Laflen, ARS, West Lafayette, Indiana; J. P. Porter, SCS, Flint, Michigan; and J.R. Simanton, ARS, Tucson, Arizona).

P factor. Of all the USLE 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 directing runoff around the slope at much reduced grades. However, slight changes in grade can change runoff erosivity greatly. In experimental field studies, small changes in such features as row grade and their effect on erosion are difficult to document, leading to appreciable scatter in measured data. For example, the contouring effectiveness in field studies conducted on a given slope have ranged from no reduction in soil loss to a 90 percent reduction. Likewise, identifying these subtle characteristics in the field is difficult when applying the RUSLE. Thus, P-factor values represent broad, general effects of such practices as contouring.

In the 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 stripcropping conditions are considered in the RUSLE.

Finally, P factors have been developed to reflect conservation practices on rangeland. The practices require estimates of surface roughness and runoff reduction. Some of the practice values are also slope-dependent.

A comparison

To illustrate some of the differences between RUSLE and USLE soil loss estimates, calculations were made for a continuous corn field with conventional tillage near Indianapolis, Indiana, and for rangeland near Tombstone, Arizona (see table).

For these illustrations, the changes in R values are relatively insignificant. K-factor changes using the time and varying factor in the RUSLE led to a smaller K value in Indiana and a larger value in Arizona, a trend observed frequently in our experience to date. Breaking a 300-foot-long slope at eight percent into three segments (top of slope to the bottom) of 100 feet at six percent, 150 feet at 10 percent, and 50 feet at six percent (the same total elevation change) produced greatly different LS values.

At the Indianapolis location, the 1.72 LS value in the USLE increased to 1.94 in the RUSLE, whereas the LS value for the the RUSLE rangeland location decreased to 1.52, from 1.72, indicating the reduced rill to interrill erosion ratio on rangeland over that for cropland.

The C-factor values in both instances were lower for the RUSLE estimates when compared to the values from *Agriculture Handbook 537*. In still other instances, higher C-factor values have been observed from the RUSLE than from the USLE.

The estimated soil loss for these two illustrations are both less with RUSLE than with USLE estimates. This should not be considered the case for all locations, however.

Of greatest significance is that C-factor values can be estimated with the RUSLE for crops where SLRs were not available, that is, there were no data in tables 5 and 10 of *Agriculture Handbook 537* to cover the particular crop and operation. Given that a user can obtain data for developing a crop file to cover the specific conditions encountered in his or her climatic conditions (data to describe at intervals after planting the root mass in the upper four inches of soil, canopy cover, fall height, carbon-to-nitrogen ratio, residue-to-yield ratio, and characteristics of the residue stem), SLRs with which to calculate a C factor can be made for any crop. Furthermore, new tillage implements can be added to the operations file to cover an infinite range of activities with which to simulate their effect on soil loss.

Delivery of documentation

Drafts of the docmumentation on the RUSLE are being reviewed by technical specialists in USDA, along with other cooperators. Review of the RUSLE computer program also is nearing completion. (The programming of RUSLE is led by J. P. Porter, SCS, Flint, Michigan, formerly ARS, West Lafayett, Indiana, and Daniel Yoder and David Whittemore, ARS, West Lafayette, Indiana.) The documentation and the program should be available for widespread use in the immediate future. Close contacts with user agencies have been maintained throughout the development of RUSLE, so we feel the technology is user-oriented. The program is designed to run on a personal computer with a DOS or UNIX operating system.

In summary

The USLE is a powerful tool that has been used by soil conservationists for almost three decades for on-farm planning of soil conservation practices, inventorying and assessing the regional and national impacts of erosion, and developing and implementing public policy related to soil conservation. Over the last three years, a cooperative effort between scientists and users to update the USLE is nearing completion and will produce a revised version of the USLE known as the RUSLE.

Some of the improvements in the RUSLE will include:

► A greatly expanded erosivity map for the western United States.

► Minor changes in R factors in the eastern United States.

► Expanded information on soil erodibility.

► A slope length factor that varies with soil susceptibility to rill erosion.

► A nearly linear slope steepness relationship that reduces computed soil loss values for very steep slopes.

► A subfactor method for computing values for the cover-management factor.

► Improved factor values for the effects of contouring, terracing, stripcropping, and management practices for rangeland.

The RUSLE will be implemented using a computer program that, along with documentation, will be available soon.

Differences in soil loss estimates between the RUSLE and USLE vary from more to less erosion for individual locations depending on specific factor value changes.

Summary of RUSLE and USLE soil loss estimates for two locations

	Location			
	Continuous Corn Indianapolis, Indiana		Rangeland Tombstone, Arizona	
Factor	RUSLE	USLE	RUSLE	USLE
R	180	175	65	70
K*	0.32	0.37	0.32	0.26
LS†	1.94	1.72	1.52	1.72
C	0.236‡	0.252§	0.014#	0.038‖
P	1.0	1.0	1.0	1.0
A	26.4	28.1	0.44	1.19

*Used a Miami silt loam in Indianapolis and a Stronghold gravelly sandy loam in Tombstone.

†Used a 300-foot slope length at 8 percent in the USLE and a 3 segment, 100-foot at 6 percent, 150-foot at 10 percent, and 50-foot at 6 percent in the RUSLE.

‡Used continuous corn with 8-inch deep moldboard plowing on 4/10, tandem disk on 4/15, row planter on 4/20, row cultivator on 5/15, and harvest on 10/13 with 120 bushels/acre yield.

§Used continuous corn with SLRs from line 1 of table 5 in AH537.

#Used 0.8 roughness, 60 percent ground cover, 25 percent canopy cover, 4,000 pounds/acre root biomass in the upper 4 inches and a canopy height of 1-foot.

‖Used table 10 of AH537 with grass, 25 percent cover, and 60 percent ground cover.

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