Calculating Revised Universal Soil Loss Equation (RUSLE) Estimates on Department of Defense Lands: A Review of RUSLE Factors and U.S. Army Land Condition-Trend Analysis (LCTA) Data Gaps

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ABSTRACT

The Revised Universal Soil Loss Equation (RUSLE) is a revision and update of the widely used Universal Soil Loss Equation (USLE). RUSLE retains the factors of the USLE to calculate annual sheet and rill erosion from a hillslope; however, changes have been made for each factor. Each RUSLE factor is briefly described and examined in terms of required inputs to the model. Inputs not currently collected as part of the Army's Land Condition-Trend Analysis (LCTA) program are identified. The application of RUSLE using LCTA data from the Yakima Training Center, Washington, resulted in a significant decrease in soil loss estimates compared to the USLE. The development, implementation, and support of standardized data collection methods is important if RUSLE is to be used to determine erosion status and trends at Army installations.

The Revised Universal Soil Loss Equation (RUSLE) computes sheet and rill erosion from rainfall and the associated runoff for a landscape profile. As a revision and update of the Universal Soil Loss Equation (USLE)[1], RUSLE incorporates data from rangeland and other research sites in the United States to significantly improve erosion estimates on untilled lands. RUSLE can be used to compute soil loss on areas where significant overland flow occurs, but is not designed for lands where no overland flow occurs, such as undisturbed forest lands[2]. Since a significant proportion of military lands is comprised of rangeland communities and disturbed forest lands, an improved erosion estimation model should be of interest to installation natural resource managers. This paper focuses on the time-invariant cover management factor (C) module, which is designed for pasture and rangeland applications where the plant community changes little over the course of a year. This module is appropriate for land areas not subject to intense rotational grazing by livestock or other agricultural uses. When mechanical soil disturbance is extensive or the plant community changes significantly over a year, the time-variant module should be applied (e.g., construction sites, mine spoils, tracked vehicle maneuver areas, vehicle staging areas, and excavation sites, where a single disturbance is followed by long-term stabilization).

The soil loss computed by RUSLE is the amount of sediment lost from a landscape profile described by the user. A landscape profile is defined by a slope length, which is the length from the origin of overland flow to the point where the flow reaches a major flow concentration or a major area of deposition. The soil loss is an average erosion rate for the landscape profile. Erosion can vary widely even on a uniform slope, depending on slope position and configuration of the slope profile. RUSLE does not estimate the amount of sediment leaving a field or watershed, but estimates soil movement at a particular site. RUSLE uses the same factorial approach employed by the USLE:

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[1] Agriculture Handbook No. 703: <u>Predicting soil erosion by water - a guide to conservation planning with the revised universal soil loss equation (RUSLE)</u> (Renard et al.) has not yet been published. Unpublished copies may be available through the Soil and Water Conservation Society office in Ankeny, IA or through George Foster, RUSLE Project Leader, USDA-ARS National Sedimentation Lab, Oxford, MS. When published, Agriculture Handbook No. 703 will supersede Agricultural Handbook No. 537, "Predicting Rainfall Erosion Losses: A Guide to Conservation Planning" (Wischmeier and Smith, 1978), and will be available for purchase from the National Technical Information Service.

[2] For the application of RUSLE to disturbed forest lands, see Dissmeyer and Foster (1980), SWCS (1995), and USDA (1995).

A = R*K*LS*C*P

where
A = annual soil loss from sheet and rill erosion in tons/acre
R = rainfall erosivity factor
K = soil erodibility factor
LS = slope length and steepness factor
C = cover and management factor
P = support practice factor

Each factor has been either updated with recent information, or new factor relationships have been derived based on modern erosion theory and data. Unlike the Water Erosion Prediction Project (WEPP), RUSLE does not explicitly consider runoff or the individual erosion processes of detachment, transport, and deposition.

Major changes to the USLE incorporated into RUSLE include:

R factor: new and improved isoerodent maps and erodibility index (EI) distributions for some areas
K factor: time-variant soil erodibility which reflects freeze-thaw in some geographic areas
LS factor: new equations to account for slope length and steepness
C factor: additional sub-factors for evaluating the cover and management factor for cropland and rangeland
P factor: new conservation practice values for cropland and rangeland

The factors discussed in this review are used to compute RUSLE estimates in the RUSLE software program Version 1.04[3]. Individual factor values can be entered directly into the formula or calculated from information provided by the user. The following section briefly describes each RUSLE factor and lists required inputs for the time-invariant (average annual values) module.

Erosivity (R) Factor

The R factor for a given location is derived from precipitation records, placed on an isoerodent map, and published in Natural Resources Conservation Service (NRCS) Soil Surveys. Local R values can be taken directly from isoerodent maps or from the CITY database in the RUSLE software program. In the eastern U.S., a single R value location is usually sufficient for applying RUSLE in a county. However, in large counties or in mountainous areas (large elevation differences), especially in the western U.S., several locations in a county may be needed. Generally, local variations in rainfall erosivity ($\pm$5%) can be represented with a single R value. R values can be calculated for specific locations from rainfall intensity data. However, this is a very time and labor-intensive process requiring erodibility index (EI) calculations for each storm event greater than 0.5 inches for each rain gauge over a period of years (see USDA Handbook 703, Appendix B). "Equivalent" R values have been developed for the Northwest Wheat and Range Region, where erosivity can vary greatly during the year due to rainfall and/or snowmelt on thawing soils. The effect of the distribution of R over the year is incorporated into the model in the computation of the C factor.

The isoerodent maps presented in Agriculture Handbook 703 (RUSLE) are a significant improvement over those presented in Agriculture Handbook 537 (USLE), especially for the western U.S.. In addition to being used to calculate time-variant erosion estimates, the annual distribution of the local erodibility index can be useful when scheduling or planning soil-disturbing activities. The EI distribution (as a percentage of the annual value) for twenty-four 15-day periods has been updated through RUSLE for 120 geographic areas in the continental U.S. and Hawaii (Renard et al. 1996). The annual EI distribution curves for three geographic locations are presented in Figure 1.

[3] RUSLE software ($295) can be purchased from the Soil and Water Conservation Society, 7571 Northeast Ankeny Rd., Ankeny, IA 50021-9764.

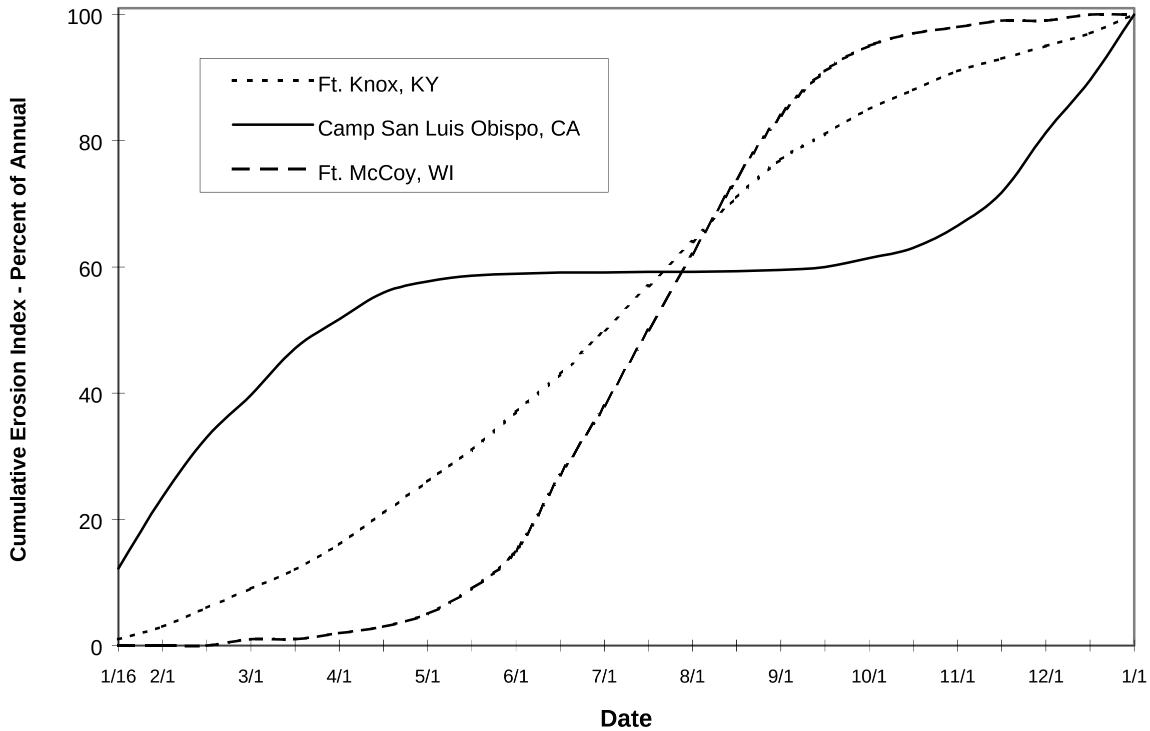

Figure 1. EI distribution curves for three Army installation locations.

Soil Erodibility (K) Factor

The K factor represents both susceptibility of soil to erosion and the amount and rate of runoff. Soil texture, organic matter, structure, and permeability determine the erodibility of a particular soil. K values for various soil types are presented in Table 1.

Table 1. Soil Characteristics Associated with K Values.

SOIL TYPE	ERODIBILITY	K VALUE RANGE
fine-textured; high in clay	low	0.05 - 0.15
course-textured; sandy	low	0.05 - 0.20
medium-textured; loams	moderate	0.25 - 0.45
high silt content	high	0.45 - 0.65

Soil organic matter reduces erodibility. However, extrapolation of the K factor nomograph beyond an organic matter of 4% is neither recommended by the NRCS nor allowed by RUSLE software. The USLE also uses this organic matter limit. Addition or accumulation of increased organic matter through management is represented within the C value. Soil structure affects both susceptibility to detachment and infiltration. Permeability of the soil profile affects K because it affects runoff. Where published K values are not available, a value can be estimated using the published soil erodibility nomograph (Wischmeier and Smith 1978, Renard et al. 1996). Erodibility index (EI) zones have been developed for some geographic areas which allow the use of time-varying K factor calculations. The annual distribution of rainfall erosivity directly influences seasonal values of K.

Slope Length and Steepness (LS) Factor

The LS factor represents erodibility due to combinations of slope length and steepness relative to a standard unit plot. Slopes of non-uniform steepness require dividing the slope into segments. Usually, five segments comprised of slope length and steepness are sufficient to define a non-uniform slope profile. RUSLE uses one of four equations to compute LS values (Table 2). The choice of LS equation is based on existing conditions including surface cover at the site. LS equations one and two would be applicable to military lands that are relatively undisturbed or receive moderate use. LS equation three would be applicable to areas receiving heavy use from excavation, staging, bivouac, demolition, munitions testing, off-road maneuvers, and other inherently destructive military land uses. Equation four is reserved for use on thawing soils.

Table 2. Guide for LS Equation Selection

Typical Applications	Rill:Interrill Ratio	Select LS Equation
rangelands, pasture, other consolidated soils with cover	low	1
row-cropped agricultural and other moderately consolidated soil conditions with little to moderate cover	moderate	2
mine spoil, construction sites, other highly disturbed soil conditions with little or no cover	high	3
Northwest Wheat and Range Region; thawing soils where erosion is caused by surface flow	N/A	4

Cover and Management (C) Factor

The C factor represents the effect of plants, soil cover, below-ground biomass, and soil-disturbing activities on soil erosion. Both time-variant (cropping/rotation scenario) and time-invariant (average annual values) modules have been constructed.

The time-variant option is used when plant and/or soil conditions change enough to significantly affect erosion during the year, during a rotation cycle, or over an extended period. This option is typically applied to croplands; rangelands where cover changes significantly during the year such as from grazing, burning, or herbicide application; sites regenerating following soil-disturbing activities on forest lands; and recovery following construction or earth moving activities.

The time-invariant option is used where constant conditions can be assumed, which is often the case on range and pasture land. The time-invariant option is applicable to large portions of military installations across the U.S.. User inputs required for the time-invariant option:

1. Effective root mass in top 4" of soil (lb./acre) or estimate of annual site production potential (lb./acre) to generate a root mass value for a given plant community
2. Percent canopy
3. Average fall height (ft)
4. Surface roughness value (index of average micro-elevation): generally ranges from 0.3 to 1.5
5. Percent ground cover (rock + litter, excluding plant basal cover)
6. Surface cover function expressed as B value: represents the relative effectiveness of surface cover for reducing soil loss. The choice of B value is based on the ratio of rill/interrill erosion under bare soil conditions. Some typical B-values are presented in Table 3.

Table 3. Examples for B-Value Selection.

Examples/Field Conditions	Rill:Interrill Ratio (bare soil)	B Value	B-Value Code
flat and short slopes, where soil is resistant to erosion by flow, consolidated lands (e.g., pasture)	low	0.025	2
moderate slopes and slope lengths with moderate disturbance	moderate	0.035	1
steep and long slopes where soil is highly disturbed and where soil is susceptible to erosion by flow	high	0.045	3
southwestern range lands, where runoff tends to be low and affected by cover	high	0.045	3
long term no-till cropping, especially where no-till significantly reduces runoff	high	0.050	3

Support Practices (P) Factor

The supporting effects of practices like contouring, strip cropping, and terraces are described by the P factor. Most often this variable is set to equal 1 in military land management applications. However, various P factor scenarios can be run to predict the effects of different management options on soil-loss estimates.

LCTA Data Gaps

The U.S. Army Land Condition-Trend Analysis (LCTA) program is a standardized method for natural resource data collection, analysis, and reporting (Tazik et al. 1992). The program was initiated in 1984 in response to growing concerns about deterioration in the condition of U.S. Army natural resources due to the increased use of training lands (Diersing and Severinghaus 1984, Goran et al. 1983, Johnson 1982, Severinghaus and Goran 1981). Permanent plots are established using stratified random sampling based on soil and landcover types. LCTA methods were designed in part to collect information necessary to calculate soil erosion potential based on the USLE. LCTA methods and data are examined in light of changes to the USLE and data required by RUSLE. The following data is not currently collected or part of the standard LCTA database; additional field data collection (**FC**) or information gathering (**IG**) is required to calculate RUSLE estimates for LCTA plots.

R Factor

- consult updated R value maps or consult with local NRCS staff (IG).

K Factor

- no additional data required.

LS Factor

- choose appropriate LS equation based on topography, land use, rill/interrill ratios (FC).

C Factor

- estimate effective root mass in top 4” of soil (lb./acre) or annual site production potential (lb./acre) to generate a root mass value for a given plant community [IG (e.g., soil survey) and/or FC]. A potential productivity condition rating could be developed which adjusts for site condition.

- surface roughness value (index of micro-elevation in inches): generally ranges from 0.3 to 1.5 (FC).

- surface cover function B-value code: represents the relative effectiveness of surface cover for reducing soil loss. The choice of B value is based on the ratio of rill/interrill erosion under *bare* soil conditions (IG).

P Factor

- collect information on conservation practices in place (FC).

Case Study: Yakima Training Center, WA

The Revised Universal Soil Loss Equation (RUSLE) was examined as an improved method for estimating sheet and rill erosion at the Yakima Training Center (YTC), Washington. The YTC, located in the shrub-steppe zone east of the Cascade Mountains in Washington, is comprised of approximately 130,000 hectares with rolling to steep topography. Soils are mostly of basaltic origin with wind-deposited material forming the surface soil horizon in many areas. Major vegetation components include bluebunch wheatgrass (*Agropyron spicatum*) and big sagebrush (*Artemisia tridentata*). Annual precipitation averages approximately 200 mm; most effective precipitation occurs between October and May.

Using RUSLE software version 1.04, erosion estimates were generated for 202 Land Condition-Trend Analysis (LCTA) core plots stratified across soil and landcover types. LCTA data from the initial 1989 plot inventory were used for slope and slope length, percent ground cover, canopy cover, canopy drip height, and percent bare ground. RUSLE estimates were subsequently compared to USLE estimates calculated by the LCTA Front End Software Program.

RUSLE inputs used for the time-invariant module typically used for rangeland applications:

-R value = 10

-Slope length and steepness values for the 0 meter transect location.

-Assumed no mechanical disturbance.

-Surface roughness value = 0.5, a moderate value for rangeland field conditions[4].

-Soil consolidation period = 7 years.

-LS Table 1 was used for all transects.

-Surface cover function B values were based on the following criteria:
Code 2 was used for sites with little or no disturbance and relatively flat slopes.
Code 1 was used for sites with moderate disturbance and/or moderate slopes.

-Plant community code = pasture/bunchgrasses (#12) -- this choice probably overestimated root mass for some plots resulting in underestimated values for C.

-Annual site production potential (lb./acre) values were obtained from the YTC Draft Soil Survey; average production values were used.

-P (conservation practice) value = 1 for all sites. This assumes no conservation practice is employed.

Results

Results of the comparison of RUSLE and USLE values are presented in Table 4.

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[4] December 15, 1995 personal communication with Donald McCool, Agricultural Engineer and RUSLE contributor, USDA-ARS, Land Management and Water Conservation Research Unit, Washington State University.

Table 4. RUSLE values expressed as average percentage change from USLE values.

	R value	K value	LS value	C value	Estimated soil loss
Average	0%	0%	+ 14%	- 65%	- 58%

Overall, RUSLE estimates were significantly less (α=.05) than USLE estimates. The decrease in soil loss estimates is primarily attributable to a statistically significant decrease (α=.05) in cover management factor (C) values. The RUSLE model accounts for the effective root mass in the top 4" of soil, which is the most significant contributor to the difference in C. LS values were significantly higher (α=.05) using RUSLE, but did not offset the influence of the decreased C values. R and K values were unchanged. Erosion estimates varied widely from one research plot to the next. Erosion estimates for some plots were not significantly different when using RUSLE vs. USLE. However, the RUSLE estimates for 70% of LCTA transects were less than 50% of USLE estimates. These results are specific to application of RUSLE at the YTC; results will vary by geographic location and model inputs.

While these results may be surprising to some land managers, the results computed by RUSLE are superior to those computed by USLE[5]. Some increases in RUSLE estimates should be expected if productivity values (with associated root mass estimates) and soil disturbance conditions are tailored more carefully to each field plot. Nevertheless, RUSLE values may still be lower than USLE values due to changes in the overall erosion model.

YTC Application Notes

RUSLE estimates are sensitive to changes in input variables to differing degrees. Additionally, some assumptions were made in the YTC calculations that do not hold true for all locations where estimates were made. For example:

(1) The analysis assumed "average" site productivity when calculating root mass in the top 4 inches of soil.
(2) A roughness value of 0.5 was used for all plots. In practice, this value can vary from site to site.
(3) The C value changes significantly depending on the choice of B-value (surface cover function variable).
(4) Slope lengths for some plots were evaluated on a "micro" scale during field data collection. While LS calculation is less sensitive to slope length than slope steepness, slope length may be underestimated for some sites, resulting in lower soil loss estimates. However, this may be offset by overestimation of slope length on other sites.

Conclusions

The application of the RUSLE model to military lands requires that standardized methods be developed to satisfy new data requirements. The USDA Agricultural Research Service (ARS) is in the process of developing methods for implementing RUSLE and should be a valuable source of information regarding field methodologies. RUSLE data gaps using the current LCTA methodology should not be difficult to remedy. However, accuracy in field data collection is important for status and trends in erosion to be determined. ARS researchers contacted agree that while the Water Erosion Prediction Project (WEPP) model is superior for cropland, rangeland, and forest applications, it requires considerably more data and expertise than RUSLE in its application and interpretation[6]. For these reasons, at the current time ARS recommends RUSLE for land management applications.

The effect of RUSLE on USLE soil erosion estimates will vary by location. It is suggested that similar comparisons of RUSLE and USLE be conducted for other regions across the U.S. Regardless of the soil-loss model employed, surface erosion can vary spatially and temporally within and among rangeland communities due to climatic variability, topographic changes, soil and geologic inconsistencies, and natural and human-induced perturbations (Wood et al. 1994, Blackburn and Pierson 1994).

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[5] November 8, 1995 personal communication with George R. Foster, RUSLE Project Leader, USDA-ARS.

[6] The use of WEPP should be encouraged where technical staff and data collection resources are available. See NSERL (1995) for a description of the WEPP model.

The USLE and RUSLE are reliable tools for land managers because they are relatively easy to use, widely applied, and generally accepted by the natural resources community[7]. A conservative approach is to use RUSLE to look at trends in erosion estimates at particular locations. The user would thus have an indication of relative changes in soil loss at a particular site. The absolute values of the estimates thus become less important as the emphasis shifts to trends of degradation or improvement. However, this type of approach may constrain the spatial extrapolation of site estimates. The number of sample sites used for erosion estimation must be statistically valid in order to minimize variability and allow for spatial extrapolation with a high level of confidence. The implementation of the RUSLE model will require a commitment of time, technical knowledge, and field application to produce defensible results.

[7] January 24, 1996 personal communication with Robert Riggins, USACERL.

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