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Application of RUSLE to Rangelands

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Abstract

The Universal Soil Loss Equation (USLE) has been revised to more accurately estimate soil loss from both crop and rangeland areas. Major revisions affecting rangeland soil loss estimates include new 'R' factors for the Western United States, a subfactor approach to determine the 'C' factor and a 'LS' table for rangeland. Measured soil losses from erosion simulation plot studies on rangelands throughout the Western U.S. were compared to soil losses estimated by the Revised Universal Soil Loss Equation (RUSLE). Correlations between measured and predicted soil loss varied among the 17 sites tested. The RUSLE factor values are examined and related to special conditions found on rangelands.

Introduction

In 1985, at a meeting of USDA and university erosion researchers, it was decided that two concurrent efforts were needed to improve the erosion technology used in USDA conservation planning: (1) that the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) should be revised to incorporate technology developed after 1978; and (2) that technology was needed to replace the USLE which would include advances in hydrologic and erosion science and specifically would address erosion and deposition associated with concentrated flow. Both of these efforts are now nearing fruition. This paper addresses the Revised Universal Soil Loss Equation (RUSLE) using data collected for the USLE replacement project, USDA's Water Erosion Prediction Project (WEPP) (Lane and Nearing 1989).

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RUSLE Description

RUSLE maintains the basic structure of the USLE, namely:

$$A = R\ K\ L\ S\ C\ P \tag{1}$$

where A is the computed soil loss, R is rainfall-runoff erosivity factor, K is soil erodibility factor, L is slope length factor, S is slope steepness factor, C is cover-management factor, and P is 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, and land use and management represented by CP.

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 individual factor determinations.

R-Factor

In the Western U.S., new R values have been calculated using over 1,000 point values. This additional information represents a significant improvement over the information of Agriculture Handbook #537 (Wischmeier and Smith 1978). Whereas the old R isoerodent maps for the West had maximum point values of about 50 units (hundreds of foot*tonforce*inch/acre *hour/year), new values are as large as 350 units along the Pacific Coastal areas. Some changes are also involved in the Eastern States (east of the 105th meridian). Another change in the R-factor is to reduce R values where flat slopes occur in regions of long intense rainstorms. Ponded water on the soil 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 freezing soil and rain on snow or partly frozen soil.

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. 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 states plus numerous stations in Hawaii.

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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 (US customary units), with high-sand and high-clay content soils having the lower values and high-silt content soils having the higher values. Users have little difficulty choosing a K-factor value because the Soil Conservation Service (SCS) has identified K values for all major soil mapping units in the United States. 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 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. K-values for volcanic soils of Hawaii are also estimated with an alternative algorithm to the erodibility nomograph.

RUSLE also varies K seasonally. Experimental data show that K is not constant but varies with season, being highest in early spring and lowest in mid-fall. 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 rangelands. 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

More questions and concerns are 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 any other USLE factor. For typical slope conditions, a 10% error in slope length results in a 5% error in computed soil loss.

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 slope length relationship has been developed specifically for the Palouse region of the Pacific Northwest of the U.S. (McCool et al. 1987, 1990). 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 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 more nearly 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. 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 RUSLE and its computer program, complex slopes can be readily represented to provide a better approximation of the topography 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, 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 that represent the soil loss for a given condition at a given time, to that of the unit 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

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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:

$$C = PLU * CC * SC * SR \tag{2}$$

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

For cropland, CC and SC and the associated below ground biomass are calculated from a crop and tillage file using a residue decomposition calculation (Gregory et al. 1985). On rangeland, the user inputs ground cover, canopy cover, and then below ground biomass is estimated from above ground biomass using ratios that are specific to different ecological zones (Weltz et al. 1987). Surface roughness values are also specified by the user from a list of typical values for different rangeland cover conditions.

Ground (surface) cover is the term of the subfactors having the greatest effect on erosion. The inclusion of erosion pavements results in large changes in the value of the subfactor. Figure 1 illustrates the sensitivity of the elements considered in the subfactors on the final C-factor.

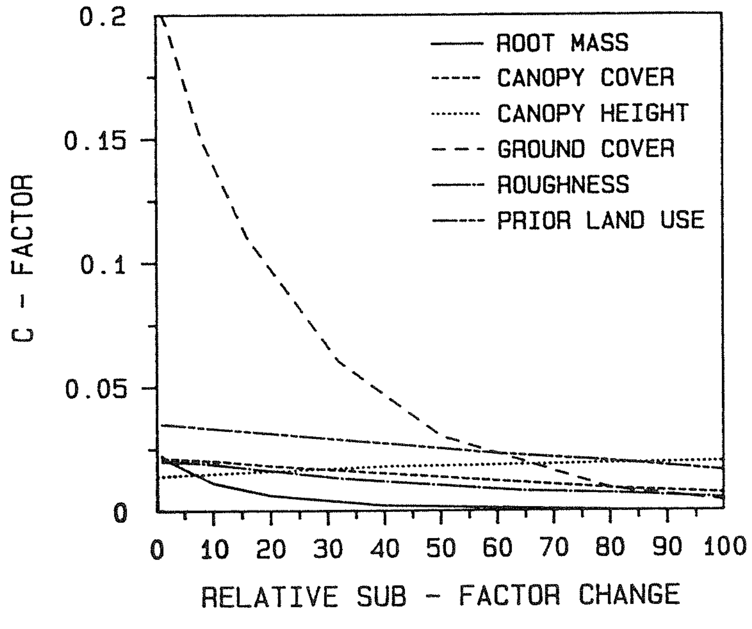

Figure 1. Sensitivity of C-factor to different values.

Grazing effects on rangelands, pasture and meadows are reflected in the grazing induced changes in canopy height, surface cover and root biomass. Finally surface cover, as used in the USLE, reflected vegetation and litter; in RUSLE, surface cover is given as 1.0 minus the amount of bare soil which reflects the addition of litter in the form of rock and stone to the conventional vegetative litter.

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 USLE. 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 stripcropping conditions are considered in RUSLE than in USLE.

Finally, P factors in RUSLE have been developed to reflect conservation practices on rangelands. The practices require estimates of surface roughness and runoff reduction. Some of the practice values are slope dependent. Because no conservation practices are involved in this paper, the technology is not explained further here.

WEPP Rangeland Plots

In the process of collecting field data for parameter identification for WEPP, rainfall simulator experiments were conducted at 17 sites in 7 western states using a rotating boom rainfall simulator (Swanson 1965), Figure 2. The 10 x 35 ft. (3.05 x 10.7 m) long plots, consisted of natural vegetation and treatments of vegetation clipping and bare soil (all litter and erosion pavement removed). A total of 181 simulations are included in this analysis.

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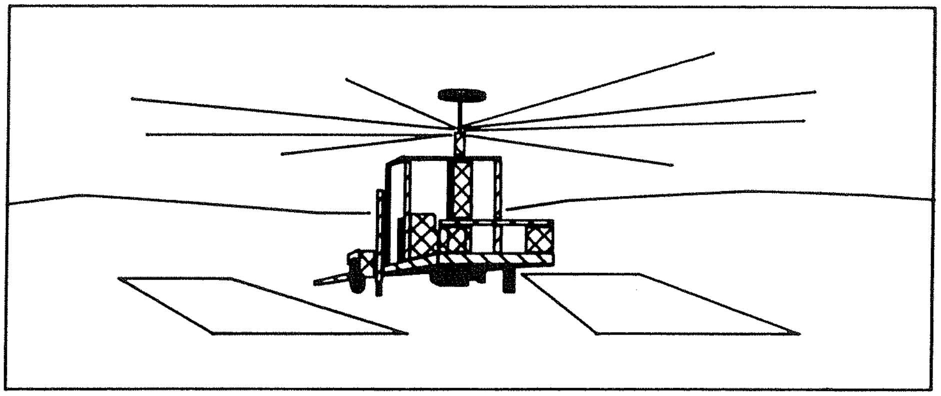

Figure 2. Rotating boom rainfall simulator schematic with parallel plots adjacent to the mechanism.

Table 1 shows the location of the rangeland sites used in this analysis. For each of the plots, simulations were performed for dry (moisture status at beginning of a simulation), wet

Table 1. Descriptions of rangeland sites.

Location (1)	Plant community (2)	Surface soil texture (3)
Tombstone, AZ	Chihuahuan Desert Shrub	Gravelly sandy loam
Tombstone, AZ	Chihuahuan Desert Grass	Sandy clay loam
Sonora, TX	Oak Savanna	Gravelly silty clay loam
Chickasha, OK	Tallgrass Prairie	Loam
Chickasha, OK	Mixedgrass Prairie	Very fine sandy loam
Ft.Supply, OK	Mixedgrass Prairie	Loamy fine sand
Ft.Supply, OK	Mixedgrass Prairie	Fine sand
Woodward, OK	Mixedgrass Prairie	Loam
Freedom, OK	Tallgrass Prairie	Very fine sandy loam
Freedom, OK	Mixedgrass Prairie	Very fine sandy loam
Sidney, MT	Mixedgrass Prairie	Loam
Cottonwood, SD	Mixedgrass Prairie	Clay
Cottonwood, SD	Shortgrass Prairie	Clay
Los Alamos, NM	Pinyon/Juniper	Fine sandy loam
Cuba, NM	Desert Shortgrass	Fine sandy loam
Susanville, CA	Sagebrush	Gravelly sandy loam
Los Banos, CA	Annual Grassland	Loam

conditions (24 hours after the first simulation) and very-wet conditions (a simulation 30 minutes after the wet run). Soil loss predictions were then made using USLE (Wischmeier and Smith 1978) and RUSLE. Note that the differences in the two predictions involve K, LS, and C differences. R was calculated for each simulation and P was assumed to be unity. K was calculated for RUSLE as the instantaneous value at the time of the simulation whereas in the USLE, it was obtained from the nomograph.

Figure 3 illustrates the agreement of the USLE and RUSLE predictions with measured soil loss from the plots. The data were further segregated to illustrate the predictions for all plots and for the clipped and natural plots (i.e., with and without the bare plots). Of particular interest is the correlation of USLE predictions with the bare plot data. Removing the bare plots from the USLE predictions shows very poor correlation ($R^2 = 0.08$) between predicted and measured soil loss, a fact that has concerned range scientists/managers for some time. Also shown are the regression equations and the coefficient of determination. In each instance, the RUSLE predictions were better than those for the USLE.

The large scatter associated with the figures results in part from the inability of the technology to reflect antecedent conditions, i.e., the dry, wet, and very-wet conditions were included as three independent data points whereas RUSLE and USLE predict the same soil loss for each. Note that the very-wet experiments on the bare soil plots also included the introduction of additional water at the upper plot border and were thus not included in the analysis. Thus, some of the scatter might be eliminated by combining the data (at a reduction in the degrees of freedom). Close scrutiny of the individual data revealed that some of the scatter was also associated with the sandy soils where runoff was low.

Discussion and Conclusion

Some of the improvements of the RUSLE technology were not tested with the data included in these experiments. For example, the new isoerodent values were not included because all of the simulations were produced with near constant R-values. Complex and steep slopes were not included (most plots were about 7 to 10% and all were 35-ft long and on uniform slopes). Grazing and its effect on crop canopy (CC) and surface cover (SC) were not addressed specifically although the use of natural plots and the grazing associated with such as well as the role of vegetation clipping might be crude attempts for such.

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Finally, conservation practices such as might be simulated with the P-factor algorithms were not part of the experimental plan (i.e., P was assumed to be unity on all plots).

In general, the agreement of RUSLE with WEPP observed plot data gave better agreement than the USLE between measured and predicted data.

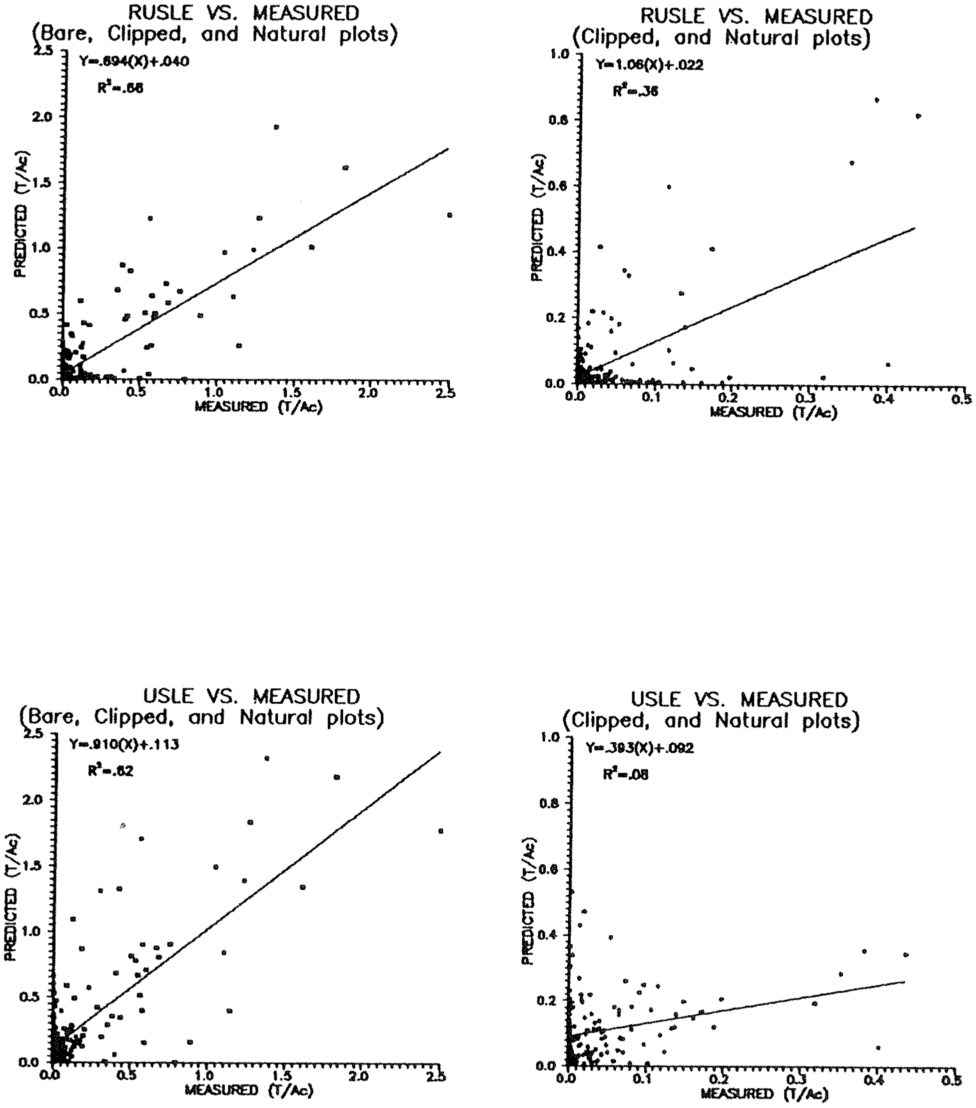

Figure 3. Comparisons of RUSLE and USLE soil loss predictions with WEPP experimental plot data.

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