Comparison of the USLE, RUSLE1.06c, and RUSLE2 for Application to Highly Disturbed Lands

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Abstract

RUSLE1.06c and RUSLE2, recently released erosion prediction models, are described. These land-use independent models are well suited for application to highly disturbed land. Cover-management subfactors make possible the land-use independence. Similarities and differences with the USLE are discussed.

Keywords: soil erosion, erosion prediction, erosion control, conservation planning, rainfall, overland flow

Introduction

The USLE, RUSLE1, and RUSLE2 are widely used to estimate rill and interrill erosion that occurs on overland flow areas. These equations apply where mineral soil is exposed to the erosive forces of raindrops and water drops falling from vegetation and surface runoff occurring as Hortonian overland flow. These equations share features proven in conservation planning over four decades.

Highly disturbed lands include construction sites, highways, reclaimed surface mines, landfills, military training sites, and similar lands where mechanical operations disturb the soil and vegetation to leave the land vulnerable to rill and interrill erosion. The disturbance period is often brief followed by an extended recovery where permanent vegetation develops. Cropland is a special case where a sequence of mechanical operations is periodically repeated.
Rill and interrill erosion also occurs on wildlands, pasturelands, rangelands, and other undisturbed lands. These lands do not experience the mechanical disturbance common to cropland or highly disturbed lands. However, infrequent renovation to encourage forage production often involves mechanical disturbance. Extensive removal of vegetation by livestock and wild animal grazing and fire that removes vegetation and litter subject these lands to rill and interrill erosion.

The USLE (Universal Soil Loss Equation), released in the early 1960s, was developed for cropland (Wischmeier and Smith 1965). Later it was extended to other land uses (Wischmeier and Smith 1978, Dissmeyer and Foster 1980). RUSLE1 (Revised Universal Soil Loss Equation) was released in the early 1990s and evolved to the current RUSLE1.06c released in mid 2003 (Renard et al. 1997, USDA-ARS-NSL 2003). RUSLE1 is land-use independent and applies to any land use having exposed mineral soil and Hortonian overland flow. RUSLE2 was also released in mid 2003, and it too is land-use independent (USDA-ARS-NSL 2003).

The USLE is an index based, empirically derived model. RUSLE1 and RUSLE2 are hybrid models that combine index and process-based equations. RUSLE2 expands on the hybrid model structure and uses a different mathematical integration than does the USLE and RUSLE1.

Purpose of USLE, RUSLE1, and RUSLE2

The purpose of the USLE, RUSLE1, and RUSLE2 is to guide conservation planning. The equations are used to estimate erosion based on site-specific

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conditions for erosion control alternatives. The erosion estimates are judged against a criterion and those practices that meet the criterion provide satisfactory erosion control for the site. All three equations estimate average annual erosion. The usual soil conservation objective is to protect the soil from excessive erosion, even when the main objective is to control sediment leaving the site. Excessive erosion degrades the landscape, reduces soil productivity, increases the difficulty of establishing and maintaining vegetation, inconveniences mowing, and produces sediment that cause downstream damage.

The validity of a model is judged by how well it serves its intended purpose (Toy et al. 2002). Accuracy is important, but most important is the conservation planning decision. Two models that yield the same conservation decision perform equally well. Other considerations are resources required to use a model, availability of input values, ease of use, and robustness. A model may give accurate estimates, but if it is difficult to use, users often sacrifice accuracy for ease of use. Demonstrating that a particular erosion model is more accurate than another is very difficult given the variability in and limited extent of the erosion research data, especially for highly disturbed and wild lands.

Neither the USLE, RUSLE1, or RUSLE2 should be used solely to evaluate overall site environmental or ecological well-being. These equations estimate soil erosion rates, nothing more. The user interprets the erosion estimates according to the user's purpose. Application of these models to wildlands has been criticized. Sometimes the criticism is misdirected to the models rather than to how erosion estimates are used. Erosion rate, even if known with 100% accuracy, is not the sole indicator of ecological well being.

Basic Equations

Sediment production

Detachment and transport are combined in these models as a sediment production term. The equation for sediment production on a uniform slope is:

$$a_i = r_i k_i l_i s_i c_i p_i \qquad (1)$$

where: a_i = erosion rate (spatial average for the slope length λ) for the *ith* storm, r_i = storm rainfall erosivity, k_i = soil erodibility factor, l_i = slope length factor, s_i = slope steepness factor, c_i = cover-management factor, and p_i = support practices factor. Storm erosivity r (EI) is the product of the storm's energy and its maximum 30-minute intensity. Storm energy is closely related to storm amount. The EI variable captures the two most important rainstorm characteristics that determine erosivity, storm amount and a measure of peak intensity. Soil erodibility k is erosion from the unit plot per unit erosivity. A unit plot is 22.1 m long on a 9 percent steepness, periodically tilled up and down slope to break the soil crust and to control the weeds, and maintained in continuous fallow for several years. Time is needed for the effects of previous land use to dissipate and to measure erosion from both moderate and large storms. The unit plot is used to empirically determine soil erodibility as a function of inherent soil properties where the effects of land use have been removed. The product *lscp* adjusts erosion for the unit-plot condition, which is the product *rk*, to erosion for the actual field condition.

Deposition

The USLE does not compute deposition. RUSLE1 and RUSLE2 compute deposition on concave slopes, at dense vegetative strips, in terrace channels, and in sediment basins using process-based equations for transport capacity and deposition. The equation for transport capacity is:

$$T_c = k_t q_p \sin(\theta) \qquad (2)$$

where: T_c = transport capacity, k_t = a transport coefficient that decreases as hydraulic resistance increases from ground cover, vegetative retardance, and surface roughness, q_p = characteristic runoff rate, and θ = slope angle. The product $q_p\sin(\theta)$ is directly proportional to runoff's total shear stress raised to the 1.5 power. Shear stress is divided into two parts, the part dissipated on ground cover, vegetation, and surface roughness and the part that erodes and transports sediment. The term k_t reduces total shear stress to the shear stress active in sediment transport.

The equation used to compute deposition is:

$$D = (V_f / q_p)(T_c - g) \qquad (3)$$

where: D = deposition rate, V_f = fall velocity of the sediment, and g = sediment load. A single deposition coefficient is used in RUSLE1 to represent the sediment. This coefficient varies with soil texture so that RUSLE1 computes deposition as a function of soil texture. The coefficient is not varied along the slope as deposition enriches the sediment load in fines. RUSLE2 divides the sediment into five particle classes based on soil texture. RUSLE2 treats each particle class individually with interaction among the classes. RUSLE2 computes deposition as a function of soil texture and how deposition changes sediment characteristics along the slope, which is turn affects computed deposition. RUSLE2 computes an enrichment ratio for the sediment leaving the end of the slope. Enrichment ratio is the ratio of specific surface area of the sediment to specific surface area of the soil subject to erosion.

Integration of equation 1

USLE

The discovery that erosion is linearly proportional to storm erosivity facilitated the development of the well known USLE:

$$A = RKLSCP \tag{4}$$

where: A = average annual erosion, R = erosivity factor, K = soil erodibility factor, LS = topographic factor, C = cover-management factor, and P = support practices factor. Average annual values are used for each factor to compute erosion.

Only the C-factor value results from a temporal integration as:

$$C = \sum \left(f_j c_i \right) \tag{5}$$

where: f_j = the temporal distribution of erosivity during the year and j = an index for a "crop stage" time step. Experimental erosion data were used to determine cover-management factor (c_j) values by crop stage period (soil loss ratios, Table 5, AH537, Wischmeier et al. 1978). Crop stage periods mark crop development and events like primary tillage, seedbed preparation, and harvest that change cover-management conditions. Values for C are increased when the most erosive period coincides with the period when cover-management conditions are most vulnerable to erosion. Once computed, C factor values for an erosivity distribution zone are placed in tables for use in equation 4.

Erosivity values for the USLE and RUSLE1 were determined from 22-years of weather data from about 1935 to 1957 for the eastern U.S. Erosivity values were computed for storms equal to and greater than 12.5 mm and were summed for each year. The average annual value for erosivity is the R-value used in equation 4. Mapped R-values provide an erosivity index by location. Erosivity varies during the year. The temporal erosivity distribution, f, was empirically determined for half-month periods and mapped by zones in the U.S.

Experimental data were also used to determine LS-factor values for slope length and steepness and P-factor values for support practices. Soil erodibility K-factor values were obtained by plotting erosion from a particular soil in the unit-plot condition versus storm erosivity. The slope of this line through the origin is the soil erodibility K-factor value for that soil. The USDA-Natural Resources Conservation Service (NRCS) assigned and cataloged K-factor values for many soils across the U.S. With the exception of the interaction between erosivity and cover-management, all USLE factors are independent of each other.

RUSLE1

RUSLE1 uses equations to compute half-month values for the cover-management factor. All RUSLE1 versions until the recently released RUSLE1.06c computed half-month values for soil erodibility for the eastern U.S. These RUSLE1 versions compute erosivity-weighted values for K and C using equation 5. RUSLE1.06c assumes a constant K-factor value. RUSLE1 considers a limited interaction among the factors in equation 1. The relationships for LS and ground cover effect vary with the ratio of rill to interrill erosion, which in turn varies with soil texture, slope steepness, and cover-management variables.

RUSLE2

RUSLE2 computes average annual erosion using:

$$A = S \sum \left(r_k k_k l_k c_k p_k \right) \tag{6}$$

where: k = index for day of the year. The mathematical integration in RUSLE2 differs fundamentally from that in the USLE and RUSLE1. Average annual factor values are multiplied in the USLE and RUSLE1. Instead, RUSLE2 multiplies the factor values for each day to estimate daily erosion values, which are summed for average annual erosion. This difference results in as much as a 20% difference in average annual erosion values between RUSLE2 and the USLE and RUSLE1. RUSLE2 uses basic variables rather than the *RKLSCP* factors to compute erosion. Although RUSLE2 does not use these factors to compute erosion, it computes values for them and demonstrates their interaction. Which formulation is best?

RUSLE2 is mathematically superior to the USLE and RUSLE1. Also, RUSLE2 is much more powerful than either the USLE or RUSLE1 and uses better relationships to compute factor values. Use RUSLE1.06 for applications where the USLE equation structure, equation 4, is desired. Do not use the USLE because the RUSLE1.06c equations are superior to the USLE equations. Do not use RUSLE1.06b or older versions of RUSLE1 because RUSLE1.06c was modified to give values comparable to RUSLE2 values (USDA-ARS-NSL 2003).

Recent Developments

Erosivity, precipitation, and temperature

Input climate values for monthly erosivity, precipitation, and temperature were developed from modern climate data from 1960-1999. Fifteen-minute precipitation data were analyzed to determine erosivity density values. Erosivity density is the ratio of monthly erosivity to monthly precipitation. Erosivity density varies spatially and temporally. Erosivity density is higher in the southern U.S. than in the northern U.S. Summer erosivity density is greater than winter erosivity density in the eastern U.S. The converse is true along the most western part of the U.S. Erosivity density does not vary with elevation up to about 3,000 m, the extent of the data. Erosivity density was mapped throughout the continental U.S. Monthly erosivity density is multiplied by monthly precipitation to obtain monthly erosivity at a location. Monthly precipitation and temperature values for any U.S. location are available in the NRCS PRISM database. The PRISM precipitation and temperature values vary spatially in mountainous areas. The new erosivity values are much better than previous values.

RUSLE2 uses 10 yr-24 hr precipitation amounts to compute runoff. A new map of 10 yr EI values for the eastern U.S. was developed for use in RUSLE1.06c.

Soil erodibility

The NRCS assigned K-factor values cannot be used for mixed soils typical of highly disturbed lands. The RUSLE2 modified soil erodibility nomograph is used to estimate K-factor values for mixed soils and subsoils where the surface layer has been stripped away without mixing the soils. The effect of the soil structure in the standard nomograph (Wischmeier et al. 1978) is inconsistent with accepted science regarding the relationship between erosion, texture, and structure.

Topography

The S factor in RUSLE1 and RUSLE2 is based on a much larger data set than the S factor in the USLE. The RUSLE relationship better fits data from highly disturbed lands than does the USLE relationship.

The exponent n in the slope length L factor $(\lambda/22.1)^n$ in RUSLE1.06c varies with land use and soil texture. This exponent in RUSLE2 is computed with equations that are functions of slope steepness, soil biomass, soil consolidation, ground cover, and soil texture.

Cover-management

Cover-management represents how cultural management practices that involve mulch, vegetation, and soil condition affect erosion.

Subfactor method

Both RUSLE1.06c and RUSLE2 use subfactors to compute temporal cover-management factor values. Erosion occurs when erosive agents exert physical forces on the soil that exceed internal resisting forces that hold the soil particles in place (Toy et al. 2002). Vegetative cover above the soil surface; litter, stones, and other material on the soil surface; and surface roughness reduce erosive forces. Physical, chemical, and biological properties modified by land use and land use condition affect soil resistance to erosion. The subfactors capture how major variables affect these external and internal forces.

A strength of RUSLE1 and RUSLE2 is that they are land-use independent, made possible by the subfactor method. Both models treat land use and land use condition as a continuum. A freshly graded and seeded surface mine reclamation site is like a recently tilled and seeded cropped field. Over time, the site evolves to a pasture, range, or wild land like condition. Land use in western South Dakota alternates between crop-land and rangeland as farming economics shift. Previous land use affects erosion with the current land use. A part of a military training ground is undisturbed like rangeland at Fort Hood, Texas or forestland at Fort Benning, Georgia. Another part of the grounds is highly disturbed like a construction site with a very rough soil. All sorts of conditions exist between these extremes. An erosion prediction model derived from cropland data and another derived from rangeland data are unlikely to give common estimates at the boundary between land use conditions. Land users may not know the correct erosion estimate, but they recognize and question inconsistent erosion estimates. Both RUSLE1.06c and RUSLE2 provide the expected consistency.

The subfactor method was originally developed to extend the USLE to undisturbed land (Wischmeier 1975). The USLE subfactor method considered how cover-management conditions above the soil surface, on the soil surface, and within the soil surface affected erosion. Values for this procedure are given in Table 10, AH537 (Wischmeier and Smith 1978). These values give poor results and should not be used. Table 10, AH537 does not consider surface roughness, does not represent properly soil biomass as a function of vegetation type or production level, and does not represent properly the combination of rock, litter, and other ground cover. Also, Table 10 cannot be used for mechanically disturbed land.

The subfactor variables used in both RUSLE1.06c and RUSLE2 include percent canopy cover and fall height; surface roughness; ground cover provided by stones, litter, basal area, live vegetation touching the ground, and other material on the soil surface; plant community type; average annual plant production; and time since the soil has been mechanically disturbed. Plant community type determines the ratio of **effective** root biomass to average annual above ground plant production. The overlap of canopy over ground cover and the overlap of litter over stones are taken into account. The subfactor equations in RUSLE2 are more detailed than those in RUSLE1.06c. For example, the relationships in RUSLE2 consider the distribution of roots with depth and where soil-disturbing operations distribute material within the disturbance depth.

The time invariant C factor method in RUSLE1 uses effective average annual input values to compute a C-factor value. RUSLE2 and the time variant C-factor method in RUSLE1 computes the accumulation of a litter layer on the soil surface and the accumulation of soil biomass. Sources of soil biomass include live and sloughed dead roots, plant material moved into the soil by insects, and material mechanically incorporated into the soil. These biomass pools are a function of precipitation and temperature at a location, plant production level, litter fall, root sloughing, decomposition characteristics of the biomass, and burial characteristics of mechanical operations.

Soil loss ratio values in Table 5, AH 537 (Wischmeier and Smith 1978) and literature values for conservation tillage were used to partially calibrate the subfactor equations. Literature values for the effect of rangeland conditions on erosion, including data collected by the USDA-Agricultural Research Service (ARS) in the Walnut Gulch watershed, Nevada Test Site, and other locations were also used. The WEPP rangeland data were used to develop values for the ratio of effective root biomass to annual plant production. Experiments were conducted at more than 10 locations across the western U.S. Analysis of the ARS-NRCS Range Study Team data was attempted with limited success.

The procedure was to back calculate the effective below ground biomass values using measured erosion and measured values for other variables in the subfactor equations. Measured root biomass values do not work well for estimating effective below ground biomass. Collecting and accurately measuring root biomass is very difficult, not all roots are equally effectiveness in reducing erosion, and research has not determined the relation of erosion to root characteristics. Also, the presence of organic compounds from decomposition of sloughed (dead) roots and litter brought into the soil by insects is not represented by measured root biomass.

C factor values for construction sites

Values for the C and P factors are available in various technical publications for applying the USLE to construction sites. These values are quite inconsistent, which means that some of them are erroneous and should not be used. RUSLE1.06c represents the current state of scientific knowledge and research data (Toy and Foster 1998). Comparable relationships are used in RUSLE2. A project is underway with the Wisconsin Department of Natural Resources to further refine RUSLE2 for application to construction sites.

Support Practices

Support practices include contouring (ridging), barriers (vegetative strips, silt fences), flow interceptors (diversions), sediment basins, and subsurface drainage. These practices affect erosion by affecting runoff. The 10 yr EI in RUSLE1 and 10 yr-24 hr precipitation in RUSLE2 are used to compute runoff using the NRCS curve number method. The curve number is related to a cover-management condition index in RUSLE1 and is computed in RUSLE2 with equations that are functions of ground cover, soil biomass, surface roughness, and soil consolidation. The effectiveness of contouring is computed as a function of runoff and slope steepness. Critical slope length, the location where contouring fails, is computed as a function of the shear stress applied to the soil. Both RUSLE1.06c and RUSLE2 use runoff in process-based equations to compute deposition caused by concave slopes, barriers, and low-grade channels using equations 2 and 3.

Deposition depends on the characteristics of the sediment reaching the support practice. Less deposition occurs if the sediment is fine. For example, less deposition occurs in a terrace channel or a sediment basin if a dense grass strip immediately upslope of the channel or basin deposits sediment that enriches the sediment load in fines. RUSLE2 computes this effect of upslope deposition, but RUSLE1.06c does not.

Computer Programs

The RUSLE2 computer program includes an exceptional graphical user interface. The user can customize the interface to their preferences by choosing screen arrangement, units, significant digits, and the complexity of the inputs and outputs. The program's computational engine maximizes the power of the RUSLE2 hybrid model structure.

The RUSLE1.06c program maintains the simple USLE index structure. However, accommodating interactions among the factors is inconvenient in this structure. The same information must be entered at multiple places in the RUSLE1 program. RUSLE2 represents detailed interactions with simple data entry. RUSLE1 is limited in the complexity of field situations that it can represent. RUSLE2 can analyze very complex hillslope shapes and spatial arrangements of soil, cover-management, and support practices on the slope.

Neither RUSLE1.06c nor RUSLE2 is a simulation model. The user describes the field condition using RUSLE program features. The models use this description to compute erosion. Both models must be told almost everything, including when frost kills vegetation. This approach, while seemingly crude and awkward, improves accuracy, power, and flexibility.

Conclusion

RUSLE2 is modern powerful, easy-to-use erosion prediction technology. USLE and RUSLE1 users, and perhaps users of other models, should shift to RUSLE2 for estimating rill and interrill erosion rates needed for conservation planning on all land uses. Readily available databases facilitate the adoption of RUSLE2. RUSLE1.06c is recommended for those users who wish to continue to use the USLE structure. The equations in RUSLE1.06c are much better than those in the USLE and previous RUSLE1 versions.

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