Managing Rangeland Soil Resources: The Universal Soil Loss Equation

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Some of the earliest soil erosion measurements in the U.S. were made by A.W. Sampson and associates in 1912 on overgrazed rangelands in central Utah. These studies and research by Chapline (1929) illustrated how overgrazing allowed erosion to reduce soil fertility and water-holding capacity. Unfortunately, erosion measurement/research on rangeland languished since these early efforts until the 1970's. Concern for the ecological health of rangeland grew with the general concern for the environment that developed during the late 60's and 70's, and excessive erosion was again recognized as being detrimental to rangelands. As a consequence, management plans for rangelands frequently contained analyses on how management alternatives would affect erosion. Since research has provided little information on erosion associated with rangeland, technology from other geographic areas was adapted to estimate erosion on rangeland. In particular, the Universal Soil Loss Equation (USLE), which has been used successfully on cropland since the early 60's was adapted to estimate erosion on rangeland.

The objective of this paper is to (1) familiarize range scientists with the research which led to the USLE, (2) familiarize range scientists/managers with the factors considered by the USLE, and (3) discuss some of the problems with extrapolating the USLE research from cropland to rangeland areas.

History of Erosion Prediction

Early erosion research, started in 1917 at the Missouri Agricultural Experiment Station, is the predecessor to modern (current) erosion research (Meyer 1984). Miller's 1/80-acre plots (90.75 ft long by 6.0 ft wide) at Missouri greatly influenced research initiated at the 10 experiment stations established by Congress in 1929, during the crusades of Hugh H. Bennett, the "father" of the soil conservation movement. These stations were located at Guthrie, Okla.; Temple, Texas; Tyler, Texas; Hays, Kans.; Bethan, Mo; Statesville, N.C.; Pullman, Wash.; Clarinda, Ia; LaCrosse, Wis.; and Zanesville, Ohio, and provided an extensive data base for the decade or more that these stations operated.

The pre-World War II years were important for erosion research because the importance of soil conservation was recognized; key research procedures were established that are still used; fundamental research was encouraged and produced theory that is just beginning to be used in the more scientifically based erosion prediction methods; researchers were enthusiastic about their endeavors and many outstanding scientists were involved; and adequate funds were available for staffing and facilities. The common experimental design among the stations produced a wealth of data which subsequently was the basis for mathematical erosion prediction relationships like the USLE. Cook (1936), in the earliest effort to mathematically describe soil erosion in the U.S., identified three major factors affecting erosion: (1) susceptibility of the soil to erosion, (2) the potential of rainfall and runoff for causing erosion (erosivity), including the influence of slope steepness and length, and (3) the protection afforded by vegetal cover. He described in detail how other subfactors affect each of these major factors. His concepts have been embodied in the string of erosion prediction methods that led to the USLE.

By 1940, sufficient data had been collected for Zingg (1940) to develop the first erosion equation which calculated erosion as a function of slope length and degree of slope (LS). In the following year, Smith (1941) added a crop factor (C) and supporting practice factor (P) to the equation, which was already beginning to resemble the USLE. This equation, in contrast to the USLE, was limited to a very specific region and soil and specific crops in the vicinity of Missouri. Subsequent research in the 1940's concerned refinement of prediction equation parameters based on data from specific locations; presented new data for crops, rotations, soils encountered in specific regions; and how the erosion hazard of rainfall varies through the year at different locations in the U.S.

By 1949, the concept of using erosion equations to help design agronomic practices to meet specific erosion hazards was recognized (Musgrave 1949). Concurrent with these developments was Ellison's (1947) classic research on fundamental erosion processes. His research provided the foundations for the new process-oriented erosion prediction methods that are just now beginning to be applied by user agencies. Had computers been available in the 40's, current erosion prediction methods might look a lot more like Ellison's theory than like the empirical form of the USLE. The USLE, and its predecessors, were very much structured to be "user" friendly, because by the early 50's, erosion equations were accepted by the USDA-Soil Conservation Service as a powerful tool for tailoring erosion control practices to the needs of specific fields and farms. Unfortunately, during this period, a comparable erosion research program on rangelands in the western U.S. was not underway, and thus, recent efforts to develop erosion methods for rangelands have not had an extensive data base.

Development of the USLE

Prior to the development of the USLE, erosion equations had been developed from site specific data on soil losses, and were therefore limited to specific regions and soils. The need for a single, widely applicable erosion equation was recognized in the early 50's, but development of such an equation would require the collection and combination of

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many data bases into a single data base. Thus, the National Runoff and Soil Loss Data Center was established by USDA-Agricultural Research Service (ARS) at Purdue University in 1954, under the direction of W.H. Wischmeier, for the purpose of developing an erosion prediction equation based on all the data available throughout the U.S. Between 1956 and 1970, additional plot-years and watershed-years of data from continuing studies, and from about 20 new locations, were added to the data bank. Over 10,000 plot-years of data were analyzed to develop the original USLE (Wischmeier and Smith 1965).

Because the costs of collecting data from plots under natural rainfall was rapidly increasing, ARS developed a rainfall simulator, known as the rainulator (Meyer and McCune 1958), to conduct erosion research on plots with artificial rainfall. By the 1970's, many of the natural runoff plot studies were discontinued and replaced with studies using simulated rainfall. When Wischmeier and Smith (1978) revised the USLE, they used rainfall simulator data to describe soil erodibility and to provide values for the effectiveness of conservation tillage and construction practices for controlling soil erosion.

The USLE (Wischmeier and Smith, 1965, 1978) is:

$$A = R \times K \times L \times S \times C \times P$$ where:

A is the estimated average annual erosion rate per unit of area computed by multiplying values for the other six factors. It is an estimate of the average annual sheet and rill erosion from rainstorms on upland areas, and it does not include erosion from gullies or streambanks, snowmelt erosion, or wind erosion. It does include eroded sediment that may subsequently be deposited on the toe of slopes and at other places before runoff reaches streams or reservoirs.

R is the rainfall and runoff factor for a specific location, usually expressed as average annual erosion index units.

K is the soil erodibility factor for a specific soil horizon, expressed as soil loss per unit of area per unit of R for a unit plot (a unit plot is 72.6 feet long, with a uniform 9% slope maintained in continuous fallow with tillage when necessary to break surface crusts and to control weeds). These dimensions were selected because the 1/100 ac erosion research plots used in early erosion work in the U.S. were 72.6 feet long and had slopes near 9%. Continuous fallow was selected as a base, because no cropping system is common to all agricultural areas, and soil loss from any other plot condition would be influenced by residual and current crop and management effects that vary from one location to another.

L is the dimensionless slope-length factor (*not* the actual slope length) expressed as the ratio of soil loss from a given slope length to that from a 72.6-ft length under the same conditions.

S is the dimensionless slope-steepnes factor (*not* the actual slope steepness) expressed as the ratio of soil loss from a given slope steepness to that from a 9% slope under the same conditions.

C is the dimensionless cover and management, or cropping-management, factor expressed as a ratio of soil loss from the condition of interest to that from tilled continuous fallow.

P is the dimensionless supporting erosion-control practice factor expressed as a ratio of the soil loss with practices such as contouring, strip cropping, or terracing to that with farming up and down the slope.

The term 'universal' in the USLE was given to the equation to assist users who were accustomed to previous equations that applied to very specific regions in contrast to the USLE, which applied, initially in 1965, to all of the U.S. east of the Rocky Mountains, and to the 1978 revision, which applies to all of the U.S.

Wischmeier (1972) explained:

> The name 'universal' soil-loss equation originated as a means of distinguishing this prediction from the highly regionalized models that preceded it. None of its factors utilizes a reference point that has direct geographic orientation. In the sense of the intended functions of the equation's six factors, the model should have universal validity. However, its application is limited to states and countries where information is available for local evaluations of the equation's individual factors.

The USLE is sometimes referred to as being a "midwestern" equation, but the equation is much more broadly based. Data used to develop the USLE came from 48 locations listed in Agriculture Handbook 537 (Wischmeier and Smith 1978). Out of the 48 locations, more than half, 27, are outside of the Midwest by the most liberal definition of the Midwest. If locations like Zanesville and Coshocton, Ohio (representative of eastern hill country), and Hastings, Neb., and Hayes, Kans. (representative of the Great Plains) are taken out of the Midwest count, the number on non-Midwest locations is 31 out of 48 locations. If these locations are plotted on a U.S. map, they are reasonably well distributed across the U.S. east of the Rocky Mountains. Data from the 48 locations were principally used to determine the effects of soil, topography, cover, and management on erosion. Data used to calculate the erosivity factor for the USLE came from 181 locations, with several, like Albuquerque, N. Mex.; Red Bluff, Calif.; Billings, Mont.; and Casper, Wyo.; being from the West (Wischmeier and Smith, 1978). Therefore, a more correct representation of the USLE is that it was primarily developed from cropland data east of the Rocky Mountains.

In the early 70's, the USLE was beginning to be applied to noncropland applications like construction sites and undisturbed land, including rangelands. Since an extensive data base was not available for these applications, Wischmeier (1975) developed the subfactor method to estimate values for the C factor. The subfactor method uses relationships for canopy, ground cover, and "within" soil effects to estimate a composite value for C, the USLE cover-management factor. This development allowed the use of data collected from more basic studies to be used in the USLE. Recognizing the need for data, scientists began erosion experiments on rangeland to develop USLE parameter values, and to evaluate the performance of the USLE on rangelands. Table 1 lists some of this research, including some references showing problems with the use of the USLE on rangeland.

Parameter Values

Determination of values of the individual USLE parameters for use on western rangelands pose some unique problems and conditions not encountered on cultivated cropland. These conditions prevent the direct extrapolation of some

Table 1. Examples of research evaluating USLE or USLE parameter performance on rangelands.

Authors & Dates	Area where work was done	Comments
Dissmeyer, 1982	N. Mex.	Used subfactor approach in evaluating C on rangeland.
Foster, et al. 1981	General	Discussed applicability of USLE to rangelands.
Hart, 1982	Utah	Measured erosion on sagebrush plots with a rainfall simulator.
Hart, 1984	Utah	Fair agreement of USLE with simulated rainfall data. Slope factor needs adjustment.
Johnson et al. 1980	Ida.	Used canopy and ground cover to compute potential erosion for sagebrush control.
Johnson et al. 1985	Ida., Nev.	Used rainfall simulator and found interpretation of C on ungrazed areas needed refinement.
McCool, 1982	Wash.	Analysis of LS factor.
Osborn, Simanton, Renard, 1976	Ariz., N. Mex.	Showed importance of stone surface cover.
Renard, Simanton, Osborn, 1974	Ariz.	Used small watersheds; significant channel erosion.
Renard, Simanton, 1975	Ariz., N. Mex.	Explored estimation of erosion factor.
Renard, 1980	Ariz.	Compared numerous sediment yield formulae.
Renard, Stone, 1982	Ariz.	Correlation of USLE estimates with stock pond yields.
Simanton, Osborn, Renard, 1977	Ariz.	Showed effect of root plowing and reseeding on erosion control.
Simanton, Osborn, Renard, 1980	Ariz.	Applied to small watersheds on storm basis.
Simanton, Renard (a & b), 1982	Ariz., N. Mex.	Evaluated erosivity of air-mass thunderstorms.
Simanton et al. 1984	Ariz.	Measured erosion reduction caused by stone surface cover.
Smith et al. 1984	Texas, Okla.	Sediment yield estimates with modified USLE, watersheds <122 ha and on watersheds with mixed land uses.
Tracy et al. 1984	Ariz.	Measured drop-size distribution of air-mass thunderstorms for use in evaluating erosivity.
Trieste, Gifford, 1980	Utah	Used small plots with rainfall simulator. Suggested USLE did not apply well to rangelands.
Trott, Singer, 1983	Calif.	USLE soil erodibility factor should consider soil mineralogy.
Verma, Thames, Mills, 1977	Ariz.	Measured erosion from disturbed and natural plots with artificial or simulated rainfall.
Williams, 1982	Texas, Okla., Iowa, N. Mex.	Estimated sediment yield from mixed cover watersheds with modified USLE.

values from cropland, and require caution in the extension of other values.

The rainfall/runoff erosivity factor (R) is computed as the product of the kinetic energy of an individual storm times the maximum 30-minute intensity for the storm (EI). The annual value then is the summation of all such storms in the course of a year. The equation used to compute kinetic energy for each intensity period of the storm (time-intensity record) was developed from data collected at the Bureau of Standards in the late 1930's (Laws and Parsons 1943). Other investigators have developed specific equations for algorithms in other parts of the country, but the Bureau of Standards equation is generally used throughout the country (Tracy et al. 1984).

The individual storm EI is nearly proportional to the total precipitation times the maximum 30-minute intensity, rainfall parameters observed to be most important for estimating runoff. Studies (e.g., at the Southwest Rangeland Watershed Research Center) have shown that individual storm runoff has a high correlation with EI. Thus, although runoff might intuitively have been a parameter to be included directly in the USLE, the use of EI serves as a surrogate for runoff and precipitation-induced erosion.

The erosivity factor R (remember, R = summation of EI for storms in a year) needs adjustment to account for erosion from runoff associated with thawing soils and snowmelt. This adjustment was developed as 1.5 times the winter precipitation (measured as inches of water) which is added to EI erosivity for nonwinter storms. This adjustment is very general, and data to support it are scarce. Since this type of erosion can be appreciable on many rangelands, additional research is needed on this problem.

The cover-management factor (C) of the USLE represents the ratio of soil loss for land under specified conditions to the corresponding loss from clean-tilled, continuous fallow. Obviously, the standard fallow plot used for cropland soils is inappropriate for rangelands. An untilled bare plot, cleared of all surface vegetation and stones and maintained through chemical control of range vegetation, seems more appropriate than the tilled fallow for the USLE unit plot on rangeland.

The C-factor, like many other USLE terms, represents the integrated effects of several conditions that affect erosion. In the evaluation of the C-factor, one must have information regarding the plant canopy (height and density) and basal area. The term thus reflects the interception of raindrops in the canopy and, in turn, how drops reformed on the canopy affect splash erosion. The term also reflects the binding effect of plant roots and how the soil changes as it lies idle. Important, but ill defined, is how the grazing animal changes the value of the C-factor. Not only does the grazing animal remove some of the plant canopy which otherwise would become cover (litter) in direct contact with the ground, but the hooves may roughen the surface, or even compact the soil, and thereby alter infiltration, and thus, runoff (reflected in the K-term). Research to better define these cause-effect relationships is needed to fill this major void in the technology.

Rock fragments, litter, and leaves in direct contact with the soil surface are very effective ground cover affecting infiltration and erosion. Erosion rates, from simulator plots with rock fragment cover, were found to decrease exponentially with increasing percent ground cover (Simanton et al., 1984). This relationship is considered in the C-factor.

The topographic factors L and S describe the effect of slope length and steepness on erosion. Since the USLE is a sheet and rill erosion prediction equation, slope length refers to overland flow from where it originates to where runoff reaches a defined channel, or to where deposition begins. Thus, the USLE does not consider deposition like that on the toe of concave slopes; nor does it describe gully erosion. Although slopes are usually treated as uniform landscape profiles, techniques are available for treating nonuniform profiles (Wischmeier and Smith 1978). Maximum slope lengths are seldom longer than 600 ft. and the USLE does not apply to slope lengths shorter than 15 to 20 ft. Selection of a slope length requires judgment, and the interpretation of any topographic map complicates selection of the slope length value. Accurate selection of a slope length often requires an on-site inspection.

The maximum steepness of plots used on cropland plots to derive the USLE S factor was about 25 percent, flatter than any rangeland slopes. Data from rangelands (Hart 1984) suggest that the USLE may be overestimating the slope effect on rangeland, and the S factor will likely be adjusted downward in the current USDA-BLM (Bureau of Land Management) revisions of the USLE based on analysis of new data. Use of plots with simulated rainfall is providing a partial data base for rangeland erosion (Simanton and Renard 1982a).

By definition, the support practice factor (P) in the USLE is the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down slope culture. Unfortunately, experimental data to quantify this term for practices on rangeland are not available, and thus, values for P are selected based on judgment and experience obtained on cropland. Practices generally reflected by P (e.g., terraces and strip cropping) are not typical on rangelands.

The soil erodibility term (K) of the USLE is intended to reflect the susceptibility of soil to erosion. Basically, K is the slope of a regression line through the origin for data on soil loss (A) and EI after adjusting the ratios for C, LS, and P to those of unit conditions. Thus, when the K value was determined with natural storm data, it represented a range of storm sizes and antecedent soil conditions. Later, similar experiments were performed using rainfall simulators, and produced a soil erodibility nomograph (Wischmeier and Smith 1978) that gives K as a function of a soil's percent silt and very fine sand, percent sand (0.10 to 2.0 mm), percent organic matter, an index of soil structure, and a relative index of infiltration. Values estimated with this nomograph for bare, untilled fallow plots at the Southwest Rangeland Watershed Research Center were comparable with experimental data.

Discussion

The USLE is a useful tool for estimating erosion, for assessment of the impact of erosion on productivity, and for use as a guide in selecting erosion control practices on a variety of land uses, including rangelands. Its utility as a planning tool has been proven by over two decades of use by the USDA-Soil Conservation Service (SCS) on cropland. Furthermore, the USLE was developed by researchers in ARS and the State Agricultural Experiment Stations, along with users in action agencies like the SCS. Thus, it represents the collective input of a wide variety of researchers and users.

The USLE is a package of erosion information and knowledge. To a major degree, the extent that the USLE inadequately describes erosion represents significant gaps in the general knowledge about erosion. Fundamentally, the USLE is scientifically sound, although clearly, its factor values can be improved for western rangelands. Research is underway to make these improvements, although, at current funding levels, the answers will not likely come very rapidly.

The USLE provides a methodology and consistent means for estimating erosion, something that is very important to federal agencies like SCS and BLM, dealing with large regions. With the USLE as a convenient package of technology, technicians without a complete knowledge of erosion literature can effectively estimate erosion.

The validity of an analytical method like the USLE must be judged. Such methods are judged to be valid if they serve their intended purpose. Obviously, this criterion involves more than just the accuracy of the method's estimates. For example, resources required to use this method must be reasonable for the user, and experience with the USLE shows that it can be used by the field technican for in situ planning of erosion control alternatives.

The accuracy issue can be addressed by considering whether the method leads to the desired management decision which, in this case, relates to erosion control. The issue here is not one of whether or not estimating erosion is a good method to estimate rangeland condition. Given that erosion is a concern on rangeland because of the need to provide long-term protection to the soil resource, does the USLE provide useful estimates of erosion on rangelands? We contend that it does, but we recognize that many professionals do not agree with us.

In the end, each user of the USLE is obligated to decide if the USLE is valid for his application, and to inspect the results he obtains with it. The user makes the decision—not the USLE, because it is a tool that provides one input of information to go along with other inputs that the user may have available, such as specific data. Used appropriately, the USLE is a useful tool in the toolbox of analytical methods for guiding rangeland management.

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