

Literature Review of Wischmeier Universal Soil

Loss Equation

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I. Origins and Data Base for Wischmeier USLE

Soil conservation specialists have for many years attempted to estimate soil loss from individual fields or slopes to determine land use practices which will ensure long-term productivity of the soil. Soil loss prediction techniques have developed over many years as understanding of the erosion process expanded and increasingly more erosion research was conducted. Early estimates were primarily qualitative in nature and illustrated that some cultural practices differed in their ability to control soil erosion. Initially, equations were developed to describe soil loss using a single independent variable. These single factor equations were for local situations where other contributing factors were nearly constant. Multiple factor equations were developed as more data became available and researchers were better able to describe contributing factors. Zingg(1940) expressed soil loss as a function of length and per cent of slope.

$$A=CS^mL^{n-1}$$

where:

A=average soil loss per unit area from a land slope of unit width,

C=a constant of variation,

S=degree of land slope,

L=horizontal length of land slope,

m,n=exponents of degree and horizontal length of land slope, respectively.

Values of 1.4 and 1.6 were proposed by Zingg for m and n, respectively.

Smith(1941) added crop and conservation practice factors to the equation and introduced the limiting annual soil loss concept. Browning et al. (1947) added soil erodibility and management factors. The relationship of rainfall characteristics to the amount of soil eroded was introduced by Musgrave(1947). The equation proposed by Musgrave was:

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$$E = (0.00527) I R S^{1.85} L^{0.85} P_{30}^{1.75}$$

where:

E=the soil loss,mm per year

I=the inherent erodibility of a soil at 10% slope and 22m slope length, mm per year.

R=a vegetal cover factor,

S=degree of slope, %

L=length of slope, meters, and

P=the maximum rainfall,mm.

Smith and Whitt(1947,1948) proposed an equation of the form

$$A = a + bs^m$$

and

$$A = CSLKP$$

where:

A=the average annual soil loss,

C=the average annual rotation soil loss from plots, and

S,L,K and P=are multipliers to adjust the plot soil loss C for slope steepness, length, soil group, and supporting conservation practice, respectively.

Van Doren and Bartelli(1956) evaluated the factors affecting soil loss for Illinois soil and conditions.

In 1954, a National Runoff and Soil-Loss Data Laboratory was established by the U.S. Department of Agriculture at Purdue University. More than 8,000 plot-years of basic erosio-plot data were assembled from 37 locations in 21 states and transferred to punched cards to facilitate classification and machine computations. A re-evaluation of the various factors affecting soil loss (Smith and Wischmeier,1957; Wischmeier and Smith, 1958; and Wischmeier et al., 1958) was made which led to the Universal Soil Loss Equation(USLE).

The universal soil loss equation was designed to meet the need for a convenient working tool for conservationists, technicians and planners. Their primary need was a relatively simple technique for predicting the most likely soil-loss rates for specific situations. Concepts developed by many researchers since 1930. and analyses of the assembled data, led to the conclusion that all important parameters for soil-loss prediction could be grouped under six major factors. Predetermined criteria required that each of the factors:(1) could be represented by a single

number, (2) could be predicted from meteorological soils, or erosion-research data on a locational basis, and (3) must be free from any geographically oriented base.

The most accurate type of mathematical expression for the relationship of each of the six major factors to soil loss was determined from exploratory statistical analyses of the assembled data. The effects of slope length and steepness, crop sequence, and soil-and crop-management practices were most accurately described in the form of % increases or decreases in soil loss. Therefore, a multiplicative model was selected for the equation which utilizes four dimensionless factors to modify a basic soil loss that is described by dimensional rainfall and soil factors.

The factors of the USLE were developed using an evaluation unit called "unit plot". A unit plot is 72.6 feet (22.13meters) long on a uniform lengthwise slope of 9%. The plot was tilled up and down slope and was in continuous bare fallow for at least two years. These dimensions were selected because most of the plot in U.S. erosion studies from 1930 to about 1960 were 72.6 feet long and on slopes near 9%. Continuous fallow was selected as a common base for two reasons: (1) No cropping system is common to all agricultural areas, and (2) 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. The unit plot was used as the basis for defining the variation in L,S,C, and P.

The universal soil loss equation is

$$A=RKLSCP$$

where A is the computed soil loss in the dimensions selected for K and for the time period selected for R.

R is the rainfall factor, usually expressed in units of the rainfall-erosivity index, EI, and evaluated from the iso-erodent map.

K is the soil erodibility factor. Commonly expressed in tons per acre per EI unit and evaluated from the erodibility nomograph.

L is a dimensionless slop-length factor, evaluated from the slope-effect chart.

S is the slope-steepness factor, evaluated in combination with L.

C is the cropping and management factor, evaluated by a technique utilizing EI distribution curves and a soil loss ratio table.

P is the factor for supplemental practices such as contouring, terraces, and stripcropping.

In general terms, the first four factors have fixed values at a given site at

least in the short run, and together they determine the basic soil loss potential for that site. The last two factors are readily changed by land use and management decisions and very substantially affect the relation of actual soil loss to the basic potential computed by R,K,L and S. (The values of L, S and K can also be changed, but less readily; L, by terraces or diversions; S, by topographic modification; K by long-term management or use of chemical soil stabilizers.)

Aside from the general considerations of the USLE, specific uses and limitations will discuss in the second section.

II. Limitations of USLE

The USLE was developed as a method to predict average annual soil loss from inter-rill and rill erosion. With the parameter values available, cropping and management alternatives can be determined to reduce the estimated soil loss to suggested tolerance values for the soil type. Each of these factors is itself a function of several to many secondary variables or subfactors, the most important of which are used to obtain local values of the major factor as defined for the equation. As detailed by Wischmeier (1976) the USLE may properly be used to:

- (1) predict average annual soil loss from a field slope with specific land use conditions.
- (2) guide the selection of cropping and management systems, and conservation practices for specific soil and slopes.
- (3) predict the change in soil loss that would result from a change in cropping or conservation practices on a specific field.
- (4) determine how conservation practices may be applied or altered to allow more intensive cultivation,
- (5) estimate soil losses from land use areas other than agricultural, and
- (6) provide soil loss estimates for conservationists to use for determining conservation needs.

For a better understanding of how the equation functions and likely variability in confidence limits on its quantitative predictions, each of the factors will be considered in more detail.

1. Rainfall Factor, R.

The function of R is to quantify the interrelated erosive forces of rainfall and runoff. The parameter use to evaluate R must be predictable on a probability

basis from meteorological data. It must be definable for specific storms, seasons and specific periods of time as well as on an annual basis and seasonal or annual evaluation must be influenced by all significant rains rather than only by annual maxima.

The parameter EI meets all the requirements, and for nonorographic rainfall it is the best rainfall erosivity index (Wischmeier, 1959). For a given storm, EI is defined as the product:

$$EI = KE \times I_{30} \times 10^{-2}$$

where

KE = Kinetic energy of the storm in foot-tons per acre-inch.

I = maximum 30 minute intensity.

Individual storm values of this interaction term are nearly always less than 100 and are highly correlated with soil loss. Since the relationship is linear, individual storm values of EI can be summed to obtain seasonal or annual values of the parameter.

To obtain rainfall energy data for testing its correlation with runoff and soil loss, Wischmeier and Smith (1958) derived the rainfall energy intensity relationship: $KE = 916 + 331 \log_{10} I$, where KE is kinetic energy in foot-tons per acre-inch and I is intensity in inches per hour. Drop size measurements of nonorographic rain made in the United States and several other countries have all shown fair to good agreement with respect to the relation of median drop diameter to intensity (Smith and Wischmeier, 1962). The terminal velocities of drops falling freely through the atmosphere are proportional to drop size, and for equal mass the Kinetic energy is proportional to velocity squared. Therefore, the kinetic energy per unit of rainfall increases as intensity increases. Computed kinetic energies for derivation of the relationship were based on detailed drop size distribution data by Laws and Parsons (1943) and on terminal velocities for various sized drops as measured by Laws (1941) and Gunn and Kinzer (1949). The relation of median drop diameter to intensity has, however, been shown to be different for low intensity rain in which drops are formed at low altitude and warm cloud conditions.

Two exceptions to use of the EI parameter for R need to be noted. One applies to rainfall in which the drops are formed at low altitude and in warm clouds, as on the leeward side of mountain. This type of rain is characterized by small drops and very low intensities. Therefore, the kinetic energy per inch of rain is

extremely low and annual EI values may be less than 10. The second exception is the hurricane associated storms on the flate coastal plains of the Gulf of Mexico. Because of the flat slopes, runoff velocities are too slow to be highly erosive, and the prolonged high intensities quickly cover the soil surface with a film of water sufficiently deep to shield it from the raindrop impact. The extremely high 30 minute intensities compute EI values that substantially overpredict observed soil losses for these conditions. Derivation of "effective" EI values that reflect the effects of the deep, low velocity surface water cushions may offer a solution to this localized problem.

2. Soil Erodibility Factor, K.

The soil erodibility factor, K, in the USLE is a quantitative description of the inherent erodibility of a particular soil. K is defined as the average increase in soil loss for each additional unit of EI when L, S, C and P equal 1. This is the term b in the linear model $y=bx+a$ for data obtained under the conditions previously outlined as criteria for a "unit plot". This definition also facilitates computation of confidence limits on K values computed from short term data. K is usually expressed in tons per acre per EI unit, and observed values have ranged from 0.02 to 0.69 (Olson and Wischmeier, 1963).

Using the average soil loss per EI unit for a particular soil is adequate for predicting long term average soil loss but inadequate for estimating soil losses during specific storms or in specific year.

Soil properties that affect infiltration rate, permeability, total water capacity, dispersion, splash, abrasion, and transporting forces also affect erodibility. The soil erodibility nomograph can be used to obtain the soil erodibility factor, K. Five soil parameters are needed to use the nomograph: per cent silt (0.002-0.05 mm) plus very fine sand (0.05-0.01 mm), per cent sand (0.10-2.0 mm), organic matter content, structure, and permeability.

3. Slope-Length Factor, L.

This factor adjusts the plot data to field slope lengths. It is defined as the ratio of soil loss from a particular slope length to that from a 72.6 feet length when all other conditions are the same. For slopes of from 1 to 10 percent, the ratio $(\lambda/72.6)^{0.5}$, where λ =slope length in feet, is commonly used for L. An exponent of 0.6 is recommended for steeper slopes, and 0.3 for long slopes with less than 0.5% gradient (Wischmeier and Smith, 1965).

For field application, slope length has been defined as the distance from the point of origin of overland flow to the point where either the slope decreases to the extent that deposition begins, or the runoff water enters a well-defined channel (Smith and Wischmeier, 1957).

The length-exponent is believed to be related to the importance of runoff-induced erosion relative to rainfall induced erosion. The exponent is related to slope steepness, particle size, storm characteristics and residue management. Evaluation of these interactions is the length exponent and improve confidence limits.

4. Slope Steepness Factor, S.

The factor S accounts for the increase in erosive potential of rainfall and runoff as slope steepens. It is defined as the ratio of soil loss from a given slope to that from a 9% slope when all other factors are the same.

In practice, appropriate LS values can be conveniently obtain from the slope effect chart derived by the formula:

$$LS = \lambda^{0.5} (0.00076S^2 + 0.0053S + 0.0076)$$

The slope formula and slope effect chart assume uniform gradients. Concave or convex slopes must be subdivided for prediction of sediment loads. For the upper segment, dimensions for entering the LS chart are obtained from that segment alone. For the lower segment, however, the steepness of the segment is used with the overall slope length. A change in land use along a slope does not terminate the effective slope length unless the runoff from the upper field is diverted.

The parabolic equation for effect of slope steepness is applicable to tilled land with slopes in the 2 to 20 percent range. But cannot be extrapolated indefinitely beyond the range of the data.

5. Crop Management Factor, C.

The factor C is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from tilled, continuous fallow. For cropland, values of C range from near 0 to 1.0. The specific value depends on the particular combination of cover, crop sequence and management techniques, and it also depends on the particular stage of development of the vegetal cover at the time of the rain. The correspondence of expected periods of highly erosive rainfall with periods of good or poor soil cover differs appreciably between climatic areas. Therefore, the value of C for a particular cropping and management system will not be the same for all parts of the country.

The soil loss ratios tabulated in Agriculture Handbook No. 282 are averages for cropstage periods that cover time intervals of one to three months. the ratio will change according to the growth stage.

6. Practic Factor, P.

This factor is similar to C except that P accounts for additional effects of practices that are superimposed upon C, such as contour farming, terrace systems, diversions, or contour stripcropping. These practices reduce the erosive potential of runoff by their influence on drainage pattern, runoff concentration and runoff velocity.

III. Sources of Error in Factor Values :

- (1) Evaluating the factors on too broad a base.
- (2) Applying C and P values from the handbook in discriminately without considering length limits beyond which the practices become ineffective.
- (3) Extrapolating factor relationships far beyond the range of the data from which they were derived.
- (4) Defining slope length incorrectly.
- (5) Evaluating irregular slopes.
- (6) EI does not reflect the erosive potential of runoff that is not directly associated with rainfall or overestimate soil loss.

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