CHAPTER 1. INTRODUCTION AND HISTORY

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PURPOSE OF HANDBOOK

Scientific planning for soil conservation and water management requires knowledge of the relations among those factors that cause loss of soil and water and those that help to reduce such losses. Controlled studies on field plots and small watersheds have supplied much valuable information on these complex interrelations of factors. But the maximum benefits from such research can be realized only when the findings are applied as sound practices on the farms, ranches, and other erosion-prone areas throughout the United States. Specific guidelines are needed for the selection of the control practices best suited to the particular needs of each site.

Such guidelines are provided by the procedure for soil-loss prediction presented in this handbook. The procedure methodically combines research information from many sources to develop design data for each conservation plan. Widespread field experience for more than four decades has proved that this technology is valuable as a conservation-planning guide.

The procedure is founded on the empirical Universal Soil Loss Equation (USLE) (described in handbooks by Wischmeier and Smith 1965, 1978) that is believed to be applicable wherever numerical values of its factors are available. Research has supplied information from which at least approximate values of the equation's factors can be obtained for specific farm or ranch fields or other small land areas throughout most of the United States. Tables and charts or the personal-computer program presented in this handbook makes information readily available for field use.

The Revised Universal Soil Loss Equation (RUSLE) includes analyses of data not available when the previous handbooks were prepared. The analyses are documented so that users can review, evaluate, and repeat them in the process of making local analyses. Debate on this revision of USLE is important. Any such debate should be focused on the data, theory, and concepts described in the chapters. Many reviewers have helped with the debate. Their reviews were essential, and they should help to establish the credibility of this revision.

Judgments were necessary during the revision because some data were limited and inconclusive, and a few were conflicting. The decisions were made by the use of the collective knowledge of a number of erosion scientists. Furthermore, the technology was revised to permit the addressing of problems not included or inadequately addressed in earlier versions of USLE. The current revision is intended to provide the most accurate estimates of soil loss without regard to how the new values compare with the old values.

This revision updates the content of the earlier handbooks (Wischmeier and Smith 1965, 1978) and incorporates new material that has been available informally or in scattered research reports and professional journals. Some of the original charts and tables have been revised to conform with additional research findings, and new charts and tables have been developed to extend the usefulness of RUSLE. In some instances, expanding a table, chart, or computer program sufficiently to meet the needs for widespread field application required the projection of empirical factor relationships appreciably beyond the physical limits of the data from which the relationships were derived. Estimates obtained in this manner are the best information available for the conditions they represent. These instances are identified in the chapter discussions of the specific erosion factors, tables, charts, and computer program.

The background material for each RUSLE factor value is presented in the text that helps the user select correct values of individual factor parameters. This revision, with its background chapters, user's guide, and associated computer program, will provide erosion technology for use in addressing problems being proposed in the last decade of the 20th century or until new technology becomes available, such as that from USDA's Water Erosion Prediction Project (WEPP) (Foster and Lane 1987, Lane and Nearing 1989).

HISTORY OF EROSION-PREDICTION EQUATIONS

Efforts to mathematically predict soil erosion by water started only about a half century ago. The development of erosion-prediction technology began with analyses such as those by Cook (1936) to identify the major variables that affect soil erosion by water. Cook listed three major factors: susceptibility of soil to erosion, potential erosivity of rainfall and runoff, and soil protection afforded by plant cover. A few years later, Zingg (1940) published the first equation for calculating field soil loss. That equation described mathematically the effects of slope steepness and slope length on erosion. Smith (1941) added factors for a cropping system and support practices to the equation. He also added the concept of a specific annual soil-loss limit, and he used the resulting equation to develop a graphic method for selecting conservation practices for certain soil conditions in the midwestern United States.

Progress continued on methods to predict erosion during World War II, but publication of the research was delayed until after the war. Browning and associates (1947) added soil erodibility and management factors to the Smith (1941) equation and prepared more extensive tables of relative factor values for different soils, crop rotations, and slope lengths. This approach emphasized the evaluation of slope-length limits for different cropping systems on specific soils and slope steepness with and without contouring, terracing, or stripcropping. Smith and Whitt (1947) presented a method for estimating soil losses from fields of claypan soils. Soil-loss ratios at different slopes were given for contour farming, stripcropping, and terracing. Recommended limits for slope length were presented for contour farming. Relative erosion rates for a wide range of crop rotations were also given. Then Smith and Whitt (1948) presented a "rational" erosion-estimating equation, $A = C \cdot S \cdot L \cdot K \cdot P$, which broadened the application to principal soils of Missouri. The C factor was the average annual soil loss from claypan soils for a specific rotation, slope length, slope steepness, and row direction. The other factors for slope steepness (S), slope length (L), soil erodibility (K), and support practice (P) were dimensionless multipliers used to adjust the value of C to other conditions. P-factor values were discussed in detail. Smith and Whitt acknowledged the need for a rainfall factor to make this equation applicable over several states.

The Milwaukee, Wisconsin, regional office of USDA's Soil Conservation Service (SCS) recognized the value of a soil-loss equation for farm planning and teamed with researchers in that region to develop a system for regional application. The result was the slope-practice method of estimating soil loss for use in the Corn Belt. To adapt the Corn Belt equation for use in other regions, a workshop for erosion specialists from throughout the United States was held in Ohio in 1946. Workshop participants reviewed soil-loss data from all over the United States, reappraised the factors previously used, and added a rainfall factor. The resulting so-called Musgrave equation included factors for rainfall, flow characteristics of surface runoff as affected by slope steepness and slope length, soil characteristics, and vegetal cover effects (Musgrave 1947).

Graphs to solve the Musgrave equation were prepared by Lloyd and Eley (1952). They tabulated values for many major conditions in the northeastern states. Van Doren and Bartelli (1956) proposed an erosion equation for Illinois soils and cropping conditions that estimated annual soil loss as a function of nine factors. One of the factors was soil loss as measured on research plots; soil loss was adjusted to site conditions by several factors used by previous researchers and also factors for prior erosion and management levels.

The state and regional erosion-prediction equations were so useful that soil conservation leaders recommended that an effort be initiated to develop a national equation. As a result, the Agricultural Research Service (ARS) established the National Runoff and Soil Loss Data Center at Purdue University (West Lafayette, Indiana) in 1954. The Data Center was given the responsibility of locating, assembling, and consolidating all available data from runoff and erosion studies throughout the United States for further analyses (Wischmeier 1955). During subsequent years, Federal-state cooperative research projects at 49 U.S. locations contributed more than 10,000 plot-years of basic runoff and soil-loss data to this Center for summarizing and overall statistical analyses.

To hasten the development of a national equation, joint conferences of key researchers and users were held at Purdue University in February and July of 1956. The participants concentrated their efforts on reconciling the differences among existing soil-loss equations and on extending the technology to regions where no measurements of erosion by rainstorms had been made. The equation that resulted had seven factors; they were for crop rotation, management, slope steepness, slope length, conservation practice, soil erodibility, and previous erosion. The group established the maximum permissible loss for any soil as 5 $\text{ton} \cdot \text{acre}^{-1} \cdot \text{yr}^{-1}$ but set lower limits for many soils. Workshop participants concluded that insufficient data were available to justify adding a rainfall factor; subsequent analyses at the Data Center led to a rainfall factor for the states east of the Rocky Mountains. Subsequent study also showed that the equation's crop rotation and management factors could be combined into one factor (Wischmeier et al. 1958).

Using the data assembled at the Data Center along with conclusions from deliberations at the 1956 conferences and subsequent analyses, Wischmeier, Smith, and others developed USLE as described in earlier handbooks (Wischmeier and Smith 1965, 1978). USLE quantifies soil erosion as the product of six factors representing rainfall and runoff erosiveness, soil erodibility, slope length, slope steepness, cover-management practices, and support conservation practices.

USLE was designed to provide a convenient working tool for conservationists. A relatively simple technique was needed for predicting the most likely average annual soil loss in specific situations. A goal for the equation was that each factor (1) could be represented by a single number; (2) could be predicted from meteorological, soil, or erosion research data for each location; and (3) must be free from any geographically oriented base. The term "Universal" in USLE distinguishes this prediction model from the regionally based models that preceded it. However, the use of USLE should be limited to situations in which its factors can be accurately evaluated and to conditions for which it can be reliably applied (Wischmeier 1976).

USLE overcame many of the deficiencies of its predecessors. The form of USLE is similar to that of previous equations, but the concepts, relationships, and procedures underlying the definitions and evaluations of the erosion factors are distinctly different. Major changes include (1) more complete separation of factor effects so that results of a change in the level of one or several factors can be more accurately predicted; (2) an erosion index that provides a more accurate, localized estimate of the erosive potential of rainfall and associated runoff; (3) a quantitative soil-erodibility factor that is evaluated directly from research data without reference to any common benchmark; (4) an equation and nomograph that are capable of computing the erodibility factor for numerous soils from soil survey data; (5) a method of including the effects of interactions between cropping and management parameters; and (6) a method of incorporating the effects of local rainfall patterns throughout the year and specific cropping conditions in the cover and management factor (Wischmeier 1972).

Regression analysis of the assembled data determined the mathematical relationship between each USLE factor and soil loss. Effects of slope length and steepness, crop sequence, and soil- and crop-management practices were most accurately described as percentage increases or decreases in soil loss. A multiplicative model was selected for the equation. It uses four dimensionless factors to modify soil loss as described by dimensioned rainfall and soil factors.

USLE was introduced at a series of regional workshops on soil-loss prediction in 1959-62 and by a U.S. Department of Agriculture special report (USDA 1961). Several years of trial use by SCS and others plus extensive interaction between the developers and users resulted in improved factor values and the evaluation of additional conditions. Finally, USLE was presented in Agriculture Handbook No. 282 (Wischmeier and Smith 1965).

Widespread acceptance of USLE took time but came progressively as more regions and groups began to use this equation. During the same period, important improvements in USLE expanded its usefulness by providing techniques for estimating site values of its factors for additional land uses, climatic conditions, and management practices. These include a soil-erodibility nomograph for farmland and construction areas, topographic factors for irregular slopes, cover factors for range and woodland, effects of tillage practices on cover and management, prediction of erosion in construction areas, estimated erosion index values for the western states and Hawaii, soil erodibility factors for benchmark Hawaiian soils, and improved design and evaluation of erosion-control-support practices. These improvements were incorporated in an updated version of USLE, published as Agriculture Handbook No. 537 (Wischmeier and Smith 1978).

The erosion-research history that led to the development of USLE (Smith and Wischmeier 1962, Meyer 1984, Meyer and Moldenhauer 1985) shows that USLE was the logical culmination of several decades of innovative effort by scientists having unusual expertise and dedication. Since its introduction, USLE has had a tremendous impact and has become the major soil conservation planning tool in the United States and abroad.

Since the publication of Agriculture Handbook No. 537, additional research and experience have resulted in improvements in USLE. These include new and (in some instances) revised isoerodent maps; a time-varying approach to reflect freeze-thaw conditions and consolidation caused by extraction of moisture by a growing crop for the soil erodibility factor (K); a subfactor approach for evaluating the cover-management factor (C) for cropland, rangeland, and disturbed areas; a new equation to reflect slope length and steepness (LS) (the new terms also reflect the ratio of rill to interrill erosion); and new conservation-practice values (P) for both cropland and rangeland practices. Finally, the computations are now implemented using a personal computer. These changes are detailed in this revision in the chapters for each RUSLE factor.

The revision of USLE described in this handbook incorporates the latest information available for using this erosion-prediction approach. Research on the principles and processes of erosion and sedimentation by water is continuing in order to improve the methods of predicting and controlling erosion. Knowledge from such research has been used in developing physically based models such as the erosion and sedimentation components of CREAMS (Knisel 1980, Foster et al. 1981a). Development of a new generation of technology for predicting water erosion is under way by a USDA team in WEPP working with other agencies and academic institutions (Foster and Lane 1987). The goal of this WEPP effort is a process-oriented model or family of models that are conceptually superior to the lumped-model RUSLE and are more versatile as to the conditions that can be evaluated. The WEPP technology is expected to replace RUSLE sometime in the future.

SOIL-LOSS TOLERANCE

A major purpose of the soil-loss equation is to guide the making of methodical decisions in conservation planning. The equation enables the planner to predict the average rate of soil erosion for each of various alternative combinations of cropping systems, management techniques, and erosion-control practices on any particular site. The term "soil-loss tolerance" (T) denotes the maximum rate of soil erosion that can occur and still permit crop productivity to be sustained economically. The term considers the loss of productivity due to erosion but also considers rate of soil formation from parent material, role of topsoil formation, loss of nutrients and the cost to replace them, erosion rate at which gully erosion might be expected to begin, and erosion-control practices that farmers might reasonably be able to implement. When predicted soil losses are compared with the value for soil-loss tolerance at that site, RUSLE provides specific guidelines for bringing about erosion control within the specified limits. Any combination of cropping, ranching, and management for which the predicted erosion rate is less than the rate for soil-loss tolerance may be expected to provide satisfactory control of erosion. Of the satisfactory alternatives offered by this procedure, the alternative(s) best suited to a particular farm or other enterprise may then be selected.

Values of soil-loss tolerance ranging from 1 to 5 $\text{ton} \cdot \text{acre}^{-1} \cdot \text{yr}^{-1}$ for the soils of the United States were derived by soil scientists/conservationists, agronomists, engineers, geologists, and Federal and state researchers at six regional workshops between 1959 and 1962. Factors considered in defining these limits include soil depth, physical properties and other characteristics affecting root development, gully prevention, on-field sediment problems, seeding losses, reduction of soil organic matter, and loss of plant nutrients. Since the early discussions, several reports have been produced in which soil-loss tolerance is discussed (Schmidt et al. 1982, Johnson 1987). The passage of Public Law 95-192 and the 1977 Soil and Water Resources Conservation Act (RCA) prompted considerable interest in the effect of soil erosion on crop productivity. New experimental research and computer simulation models have furthered the interest in soil-loss tolerances. Two symposia proceedings of note that resulted from this activity are "Erosion and Soil Productivity" (ASAE 1985) and "Soil Erosion and Crop Productivity" (Follett and Stewart 1985). Needless to say, many issues about soil-loss tolerance remain unresolved.

A deep, medium-textured, moderately permeable soil that has subsoil characteristics favorable for plant growth has a greater tolerable soil-loss rate than do soils with shallow root zones or high percentages of shale at the surface. Widespread experience has shown that the concept of soil-loss tolerance may be feasible and generally adequate for indefinitely sustaining productivity levels.

Soil-loss limits are sometimes established to prevent or reduce damage to offsite water quality. The criteria for defining the tolerance limits of field soil-loss tolerance limits for this purpose are ***not*** the same as those for tolerances designed to preserve cropland productivity. Soil depth is not relevant for offsite sediment control, and uniform limits on erosion rates still allow a range in the amount of sediment per unit area that is delivered to a stream. Soil material eroded from a field slope may be deposited along field boundaries, in terrace channels, in depressional areas, or on flat or vegetated areas traversed by overland flow before it reaches a watercourse. Erosion damages the cropland on which it occurs, but sediment deposited near its place of origin does not directly affect water quality.

If the soil-loss tolerance established for sustained cropland productivity fails to attain the desired water-quality standard, other limits that consider other factors should be established rather than altering the value for soil-loss tolerance. Other factors may include distance of the field from a major waterway, sediment-transport characteristics of the intervening area, sediment composition, needs of the particular body of water being protected, and the probable magnitude of fluctuations in sediment loads (Stewart et al. 1975). Placing limits on sediment yield might provide more uniform water-quality control than would lowering the limits on soil movement from field slopes. The sediment-yield criteria would also require fewer restrictions on the selection of crop system for fields in which only small percentages of eroded soil become off-farm sediment.

As currently used in conservation-planning activities, T values are often an issue of policy. We recommend that T values remain as originally defined and intended: namely, the erosion rate that can occur and yet permit crop productivity to be sustained economically. If issues of water quality, economics, and policy are to be addressed for erosion control, we recommend that they be designated T_{WQ} (soil loss for water-quality concerns), T_{EP} (soil loss for economic planning), and T_{POL} (soil loss for policy concerns).

SOIL-LOSS EQUATION

The erosion rate for a given site results from the combination of many physical and management variables. Actual measurements of soil loss would not be feasible for each level of these factors that occurs under field conditions. Soil-loss equations were developed to enable conservation planners, environmental scientists, and others concerned with soil erosion to extrapolate limited erosion data to the many localities and conditions that have not been directly represented in the research.

Erosion and sedimentation by water involve the processes of detachment, transport, and deposition of soil particles (Foster 1982). The major forces are from the impact of raindrops and from water flowing over the land surface. Erosion may be unnoticed on exposed soil surfaces even though raindrops are eroding large quantities of sediment, but erosion can be dramatic where concentrated flow creates extensive rill and gully systems. Factors affecting erosion can be expressed in an equation of the form (Renard and Foster 1983)

$$E = f\,(C, S, T, SS, M) \qquad [1\text{-}1]$$

where

E = erosion,
f = function of ( ),
C = climate,
S = soil properties,
T = topography,
SS = soil surface conditions, and
M = human activities.

Sediment yield should not be confused with erosion; the terms are not interchangeable. Sediment yield is the amount of eroded soil that is delivered to a point in the watershed that is remote from the origin of the detached soil particles. In a watershed, sediment yield includes the erosion from slopes, channels, and mass wasting, minus the sediment that is deposited after it is eroded but before it reaches the point of interest (fig. 1-1). USLE and RUSLE do not estimate sediment yield.

USLE is essentially an expression of the functional relationship shown in equation [1-1] (Wischmeier and Smith 1965, 1978). Both USLE and RUSLE compute the average annual erosion expected on field slopes as

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad [1\text{-}2]$$

where

- A = computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R. In practice, these are usually selected so that A is expressed in $ton \cdot acre^{-1} \cdot yr^{-1}$, but other units can be selected (that is, $t \cdot ha^{-1} \cdot yr^{-1}$).
- R = rainfall-runoff erosivity factor—the rainfall erosion index plus a factor for any significant runoff from snowmelt.
- K = soil erodibility factor—the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 72.6-ft (22.1-m) length of uniform 9% slope in continuous clean-tilled fallow.
- L = slope length factor—the ratio of soil loss from the field slope length to soil loss from a 72.6-ft length under identical conditions.
- S = slope steepness factor—the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions.
- C = cover-management factor—the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.
- P = support practice factor—the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to soil loss with straight-row farming up and down the slope.

RUSLE is an erosion model designed to predict the longtime average annual soil loss (A) carried by runoff from specific field slopes in specified cropping and management systems as well as from rangeland. Widespread use has substantiated the usefulness and validity of RUSLE for this purpose. It is also applicable to nonagricultural conditions such as construction sites.

RUSLE users need to be aware that A (in addition to being a longtime average annual soil loss) is the average loss over a field slope and that the losses at various points on the slope may differ greatly from one another. On a long uniform slope, the loss from the top part of the slope is much lower than the slope average, and the loss near the bottom of the slope is considerably higher. For instance, a 360-ft uniform slope that averages 20

$ton \cdot acre^{-1}$ will have an average of less than 7 $ton \cdot acre^{-1}$ loss on the first 40 ft but over 29 $ton \cdot acre^{-1}$ loss on the last 40 ft. If the slope steepness changes within that length, the variation can be even greater. This suggests that even if a field soil loss is held to "T," soil loss on some portion of the slope may reach or exceed 2T, even when the ephemeral gully and other types of erosion that are not estimated by RUSLE are ignored. These higher-than-average rates generally occur at the same locations year after year, so excessive erosion on any part of the field may be damaging the soil resource.

With appropriate selection of its factor values, RUSLE will compute the average soil loss for a multicrop system, for a particular crop year in a rotation, or for a particular crop stage period within a crop year. Erosion variables change considerably from storm to storm about their means. But the effects of the random fluctuations such as those associated with annual or storm variability in R and the seasonal variability of the C tend to average out over extended periods. Because of the unpredictable short-time fluctuations in the levels of influential variables, however, present soil-loss equations are substantially less accurate for the prediction of specific events than for the prediction of longtime averages.

USLE has also been used for estimating soil loss from disturbed forested conditions. RUSLE does not address this particular application. Users of such technology are referred to Dissmeyer and Foster (1980, 1981).

Some recent research addresses the application of USLE technology to mine spoils and reconstructed topsoil (Barfield et al. 1988). The effects of compaction on erosion are significant in such instances and are treated as an integral part of the subfactor for calculating C (see ch. 5). Furthermore, slope steepness effects on soil loss from disturbed lands (McIsaac et al. 1987a) are treated specifically in chapter 4 with the application of an LS table (see table 4-3). Other RUSLE terms remain unchanged by massive land disturbance such as that associated with construction. It is important to realize that the amount of research on effects of land disturbance on RUSLE technology is not as extensive as that associated with most other applications.

The soil-loss equation was initially developed in U.S. customary units. The factor definitions are interdependent, and the direct conversion of acres, tons, inches, and feet to metric units produces integers that are best suited for expressing equations in that system. Only U.S. customary units are used in the equation and factor-evaluation materials, but the metric equivalents are given in appendix A.

Numerical values for each of the six factors were derived from analyses of research data and from National Weather Service precipitation records. For most conditions in the United States, the approximate values of the factors for any particular site may be obtained from charts and tables in this handbook or by use of the computer program developed to assist with the RUSLE evaluation. Users in localities or countries where the rainfall characteristics, soil types, topographic features, or farm practices are substantially beyond the range of present U.S. data will find these charts, tables, and computer program incomplete and perhaps inaccurate for their conditions. However, RUSLE provides guidelines that can reduce the amount of local research needed to develop appropriate technology for their conditions.

The RUSLE User Guide (ch. 7) illustrates how to select factor values either with the computer program or by use of data from the tables and charts. Users who have no experience with the soil-loss equation may wish to read chapter 7 next. After users have referred to the computer program and have located the values used therein, they may readily move to the intervening chapters (ch. 2-6), which define the technical details associated with the factors. The soil-loss-prediction procedure is more valuable as a guide for the selection of practices if the user has general knowledge of the principles on which the equation is based. Therefore, the significance of each factor is discussed before the introduction of the computer program and before the reference table or chart from which local values may be obtained. Limitations of the data available for evaluation of some of the factors are also discussed.

Chapters 2-6 are written as background for the development of the technology to permit evaluation of the individual RUSLE factors. Although liberal use is made of material from previous versions of USLE (Agriculture Handbooks No. 282 in 1965 and No. 537 in 1978), direct quotes from that material are not always noted. The computer program, intended to assist the user of this technology, is a new development that was not a part of earlier versions.

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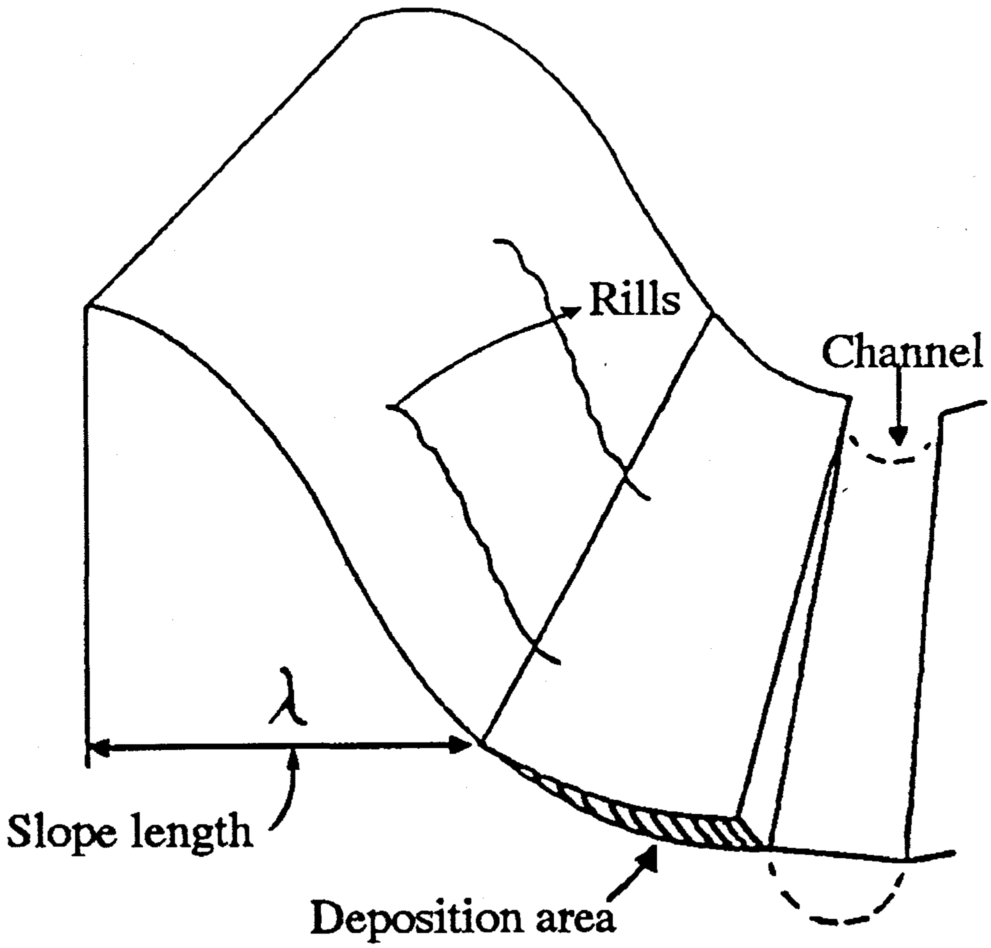

Figure 1-1. Schematic slope profile for RUSLE applications for interrill and rill erosion. λ is the RUSLE slope length (to the point where deposition occurs). Sediment yield is the sediment transported out of the channel section summed for time periods such as a storm event, month, crop stage, or year.