DRAFT

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User's Guide

Revised Universal Soil Loss Equation

Version 2

RUSLE2

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Washington, D.C.

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Acknowledgements

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This version of the User's Guide is a draft, and users will note that some figures and appendices are missing. Also, portions of the text for Cover and Management are incomplete, and text for the Support Practices section is missing.

NRCS users, technical service providers and other clients using the official NRCS version of the RUSLE2 program and database should be aware of differences between statements in this User Guide and the RUSLE2 program. Notably, these users have limited access to certain parts of the database. Read Only or Read, Edit restrictions on parts of the database are intended to help maintain the integrity of the official NRCS RUSLE2 database.

NRCS users with questions should contact the state specialist with RUSLE2 responsibilities. Non-NRCS users with questions about the official NRCS RUSLE2 program and the official NRCS RUSLE2 database can contact:

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Table of Contents

Glossary of Terms

(Not available in this draft.)

1. Welcome to RUSLE2

Version 2 of the Revised Universal Soil Loss Equation (RUSLE2) estimates soil loss, sediment yield, and sediment characteristics from rill and interrill (sheet and rill) erosion caused by rainfall and its associated overland flow. RUSLE2 uses factors that represent the effects of climatic erosivity, soil erodibility, topography, cover-management and support practices to compute erosion. RUSLE2, like other mathematical models, uses a system of equations to compute erosion. The RUSLE2 database and its rules and procedures are all used to describe a site-specific condition and, given a description to estimate erosion. Keep in mind, RUSLE2 is not a simulation model that attempts to mathematically replicate field processes.

RUSLE2 is used to guide conservation planning, inventory erosion rates over large areas, and estimate sediment production on upland areas that might become sediment yield in watersheds. It can be used on cropland, pastureland, rangeland, disturbed forestland, construction sites, mined land, reclaimed land, landfills, military lands, and other areas where mineral soil is exposed to raindrop impact and surface overland flow produced by rainfall intensity exceeding infiltration rate.

The RUSLE2 computer program, a sample database, a tutorial that describes program mechanics, a slide set that provides an overview of RUSLE2, and other supporting information are available for download from Official RUSLE2 Internet Sites supported by the University of Tennessee at http://bioengr.ag.utk.edu/RUSLE2/, the USDA-Agricultural Research Service (ARS) at http://www.sedlab.olemiss.edu/RUSLE/ and the USDA-Natural Resources Conservation Service (NRCS) at ftp://fargo.nserl.purdue.edu/pub/RUSLE2/.

2. Why Upgrade from RUSLE1 to RUSLE2?

Although RUSLE2 is a second generation of RUSLE1, it is not simply an enhancement of RUSLE1. Instead, RUSLE2 is a new model with new features and capabilities. If you are using RUSLE versions 1.05 and 1.06, or even perhaps an older version of RUSLE1, we strongly recommend that you upgrade to RUSLE2, which uses a modern graphical user interface instead of the text-based interface of RUSLE1. RUSLE2 can operate in either U.S. customary units or SI units. RUSLE2 can globally switch between the two systems of units or the units on individual variables can be changed to one of several units. Those who work with metric units will find RUSLE2 much easier to use than RUSLE1. RUSLE2 can also manipulate attributes of variables, which includes graphing, changing units and setting number of significant digits. RUSLE2 is much more powerful than RUSLE1, has improved computational procedures, and provides much more output useful for conservation planning than does RUSLE1.

Even though RUSLE2 appears quite different on the computer screen than does RUSLE1, it also has many similarities with RUSLE1. The general approach is the same and many of the values in the database are the same for both RUSLE2 and RUSLE1. Thus, the conversion from RUSLE1 to RUSLE2 should be relatively easy.

3. About RUSLE2 User's Guides and Databases

3.1. RUSLE2 Tutorial

RUSLE2 is a straight forward computer program that is best learned by using it. A **self-guided tutorial** is available on the RUSLE2 Internet site that can be downloaded and used to help learn the mechanics and operation of the RUSLE2 computer program. This tutorial can be used to learn the basic mechanics and operations of the RUSLE2 computer program. As you become familiar with the operation of the RUSLE2 program, we encourage you to thoroughly read this User's Guide on RUSLE2 and the RUSLE2 Slide Set, especially the speaker notes that accompany most slides that can be downloaded from the RUSLE2 Internet site. Information on RUSLE2 computer mechanics is also included in **Appendix A** (Not available in this draft).

3.2. RUSLE2 Database

Although many values in the RUSLE1 database can be directly transferred to the **RUSLE2 database** using procedures included in RUSLE2, we recommend that you develop or obtain a new database for RUSLE2. Several of the inputs in RUSLE2 are different from those in RUSLE1, and new input variables have been added. Also, core values in the RUSLE2 database have been updated based on new analysis. The RUSLE2 download includes a sample database. But rather than use this sample database as an operational database, we recommend that you obtain the RUSLE2 database available from the USDA-Natural Resources Conservation Service (NRCS) by contacting the state agronomist at your NRCS State Office. This database can also be downloaded from website address:
http://bioengr.ag.utk.edu/RUSLE2/tutorial.htm.

Values in the RUSLE2 operational database must be based on the **RUSLE2 Core Database** given in **Appendix C** (Not available in this draft). Values in the operational database must be consistent with those in the core database, which ensure consistency in RUSLE2 applications among clients, locations and other situations where similar erosion values are expected. This consistency is very important when RUSLE2 is used by a national agency where adequacy of the erosion prediction technology is partly judged on consistency of estimates. The NRCS database has been extensively reviewed to ensure consistency, minimum error and expected erosion values.

3.3. RUSLE2 Help

The RUSLE2 computer program contains an extensive set of **Help** information. Most of the Help information is arranged by variable within RUSLE2. Information on a particular variable can also be obtained at the location within RUSLE2 where the variable occurs.

3.4. RUSLE2 Slide Set

A **slide set** is available with the RUSLE2 download. This slide set, which includes more than 140 slides, provides an extensive overview of RUSLE2. The speaker notes that accompany many of the slides provide additional background. Also, slides can be selected from this set and used for RUSLE2 training and for making presentations on RUSLE2.

3.5. RUSLE2 User's Guide

The **User's Guide** describes RUSLE2, its factors, selection of input values, and application of RUSLE2. The **Table of Contents** lists the topics covered by the User's Guide. Rather than reading the entire User's Guide, specific topics can be selected from the Table of Contents and individually reviewed. Also, the **Glossary of Terms** can be useful for information on specific topics.

3.6 Getting Started

Like all other hydrologic models, RUSLE2 requires a proper approach for selecting input values, running the model, and interpreting its output values. Also, RUSLE2 has particular limitations that must be considered. Before you begin to apply RUSLE2 to your own applications, become well acquainted with RUSLE2 and its factors by reviewing the RUSLE2 Slide Set. After you have installed RUSLE2, run the sample database that can be downloaded with RUSLE2 that includes several example profiles. Change selected variables like location, soil, slope length and steepness, and management and support practices in these examples to help learn the mechanics of the RUSLE2 computer program, as well as how main inputs affect soil loss and other variables. Start out with the **field office simple slope template** rather than one of the more complex templates.

3.7. Scientific and Technical Documentation

Scientific and technical documentation for RUSLE2 is currently being prepared. Until this documentation is complete, refer to the Agriculture Handbook No. 703 (AH703), entitled "Predicting Soil Erosion by Water - A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE)," reference manual for RUSLE1.[1] The mathematical equations used in RUSLE2 and general procedures are similar to those in RUSLE1. Therefore, at most, AH703 provides only general background on RUSLE2.

4. Customer Support

If needed information is not available in RUSLE2 documentation, contact one of the RUSLE2 experts listed below. The USDA-Agricultural Research Service (ARS) and the University of Tennessee are the lead research agencies that developed RUSLE2. The USDA-Natural Resources Conservation Service (NRCS), the major user of RUSLE2, has much expertise and has developed extensive database information for many different types of applications of RUSLE2 across the U.S. and in the tropics. Contact your NRCS state agronomist to obtain additional databases, information and direct assistance on RUSLE2 applications. Other agencies, such as the USDI-Office of Surface Mining, also provide support for RUSLE2 for specific applications like reclaimed surface mines.

RUSLE2 Contacts:

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5. About RUSLE2

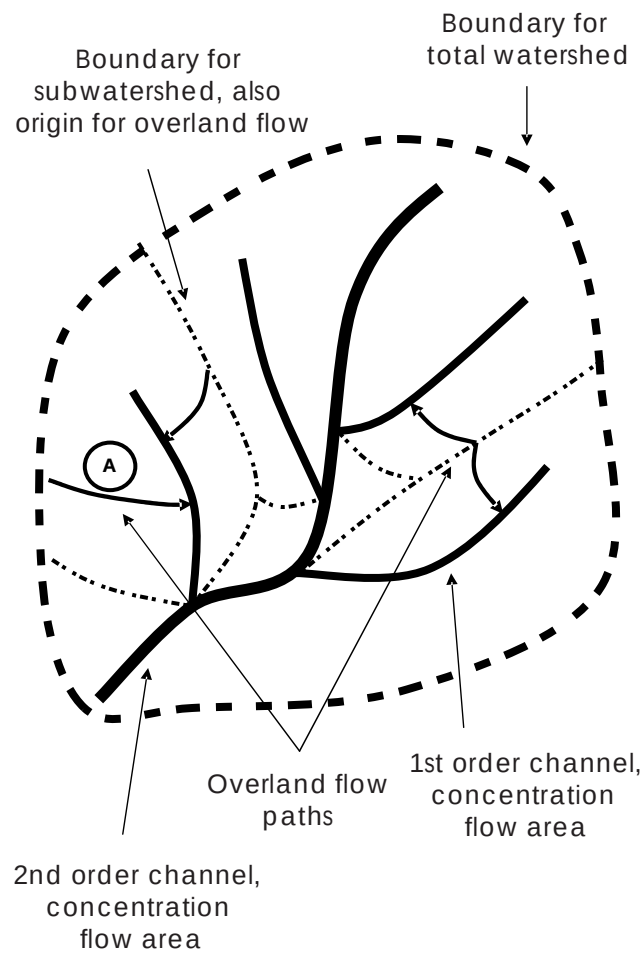
5.1. Fundamental Definitions

RUSLE2 uses several important terms to describe erosion (see **Glossary of Terms**). In the mid-1940's, W. D. Ellison defined erosion as, "...a process of detachment and transport of soil particles."[2] **Detachment** is the separation of soil particles from the soil mass and is expressed in units of mass/area. Soil particles separated from the soil mass are referred to as **sediment**. Sediment movement downslope is sediment transport, described as **sediment load** expressed in units of mass/width of slope. The sediment load at the end of the RUSLE2 hillslope profile is defined as sediment yield. **Deposition**, expressed as mass/acre, is the accumulation of sediment on the soil surface.

Detachment transfers sediment from the soil mass to the sediment load so that sediment load increases along the hillslope where detachment occurs. Conversely, deposition transfers sediment from the sediment load to the soil mass with a corresponding accumulation of sediment on the soil surface. Deposition is a selective process that **sorts** sediment. This process **enriches** the sediment load in fines in comparison to the soil where detachment originally produced the sediment.

RUSLE2 considers two types of deposition, local and remote. **Local deposition** is sediment deposited very near, within a few inches (several millimeters) of where it was detached. Deposition in micro-depressions (**surface roughness**) and in low gradient furrows is an example of local deposition. The difference between local detachment and local deposition is called **net detachment** (or **net deposition**). **Remote deposition** is sediment deposited some distance, 10's of feet (several meters) from the origin of the sediment. Deposition on the toe of a concave slope, at the upper side of vegetative strips, and in terrace channels is an example of remote deposition. **Full credit for soil saved** is taken in RUSLE2 for local deposition, but only **partial credit** is given to remote deposition for soil saved, depending on the location of the deposition. Sediment deposited at the end of a hillslope profile is given very little credit as soil saved.

Figure 5.1. **Overland flow paths in a typical application of RUSLE2.**



5.2. Hillslope Overland Flow Path (Hill-slope Profile) as the Base Computational Unit in RUSLE2

The base RUSLE2 computation unit is a single overland flow path along a hillslope profile, as illustrated in Figure 5.1. An **overland flow path** is defined as the path where runoff flows from the origin of overland flow to where it enters a major flow concentration. **Major flow concentrations** are locations on the landscape where sides of a hillslope intersect to collect overland flow in defined channels. **Ephemeral** or **classical gully erosion** occurs in these channels. These defined channels are distinguished from **rills** in two

Figure 5.2. **Complex hillslope, convex-concave profile.**

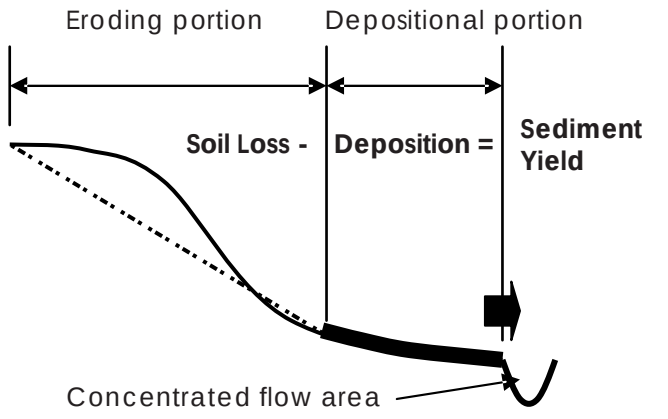
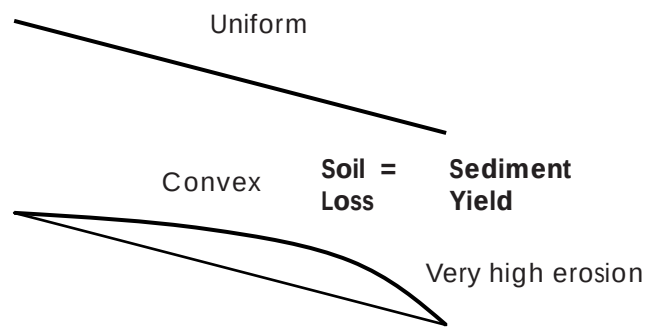


Figure 5.3. **Sediment yield equals soil loss on uniform and convex slopes.**



ways. Rills tend to be parallel and are sufficiently shallow enough that they can be obliterated by normal farming and grading operations as a part of construction activities. When the rills are reformed, they occur in new locations determined by **microtopograpy** left by soil disturbing operations like tillage. In contrast, concentrated flow areas occur in the same locations even after these channels are filled by tillage. Location of these channels is determined by **macrotopography** of the landscape.

An infinite number of overland flow paths exist on any landscape. A particular overland flow path (**hillslope profile**), such as the one demonstrated by label "A" in Figure 5.1, is chosen for the one on which the conservation plan is to be based. The profile that represents the one-fourth to one-third most erodible part of the area is the selected profile. RUSLE2 is used to estimate erosion for this profile, which is used in **conservation planning** to choose a management practice that adequately controls erosion.

The first step in describing the selected profile is to identify a base point on the hillslope through which the overland flow path is to pass. The overland flow path through that point, such as profile "A" in Figure 5.1, is described by dividing the slope into segments and specifying distance and steepness for each segment. The overland path is traced from the origin of overland flow through the base point to where it is terminated by a concentrated flow channel as illustrated in Figure 5.1.

Figure 5.2 shows the shape of a typical overland flow path on a common natural landscape. This **complex** hillslope profile has an upper **convex** section and a **concave** lower section. This profile has two important parts. The upper part is the **eroding portion**, where *net erosion* occurs, and the lower part is the **depositional portion**, where **net deposition** occurs. The net erosion rate on the eroding portion of the hillslope is defined as **soil loss** (mass/area). Soil loss on the eroding portion of the landscape degrades the soil and that portion of the landscape. A typical conservation planning objective is to reduce soil loss to a rate less than **soil loss tolerance (T)**, or another quantitative planning criterion. Keeping soil loss to less than T protects the soil and maintains its productive capacity.

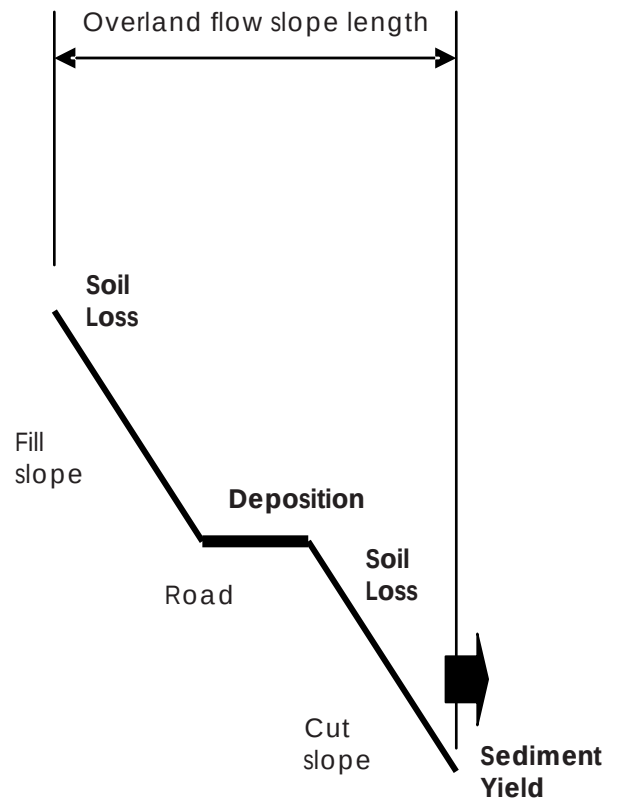
Sediment yield from the hillslope profile and the site is also an important conservation planning consideration. Excessive sediment leaving a site can cause downstream sedimentation and water quality problems. Sediment yield is less than soil loss by the amount of deposition. The sediment yield computed by RUSLE2 is the sediment leaving the hillslope profile represented in RUSLE2. This sediment yield will be the sediment yield for the site only if the RUSLE2 hillslope profile ends at the boundary of the site.

Many conservation planning applications only involve the eroding portion of the hillslope, which can be approximated by a **uniform slope** as illustrated in Figure 5.3. The **slope length** is the distance from the origin of overland flow to where deposition begins, which is the traditional definition of slope length in the USLE and RUSLE1. However, soil loss estimated using a uniform slope of the same average steepness and slope length as a nonuniform shaped profile will differ between the profiles, sometimes by as much as 15 percent. The difference is especially important on convex shaped hillslopes where erosion near the end

of the hillslope can be much larger than the erosion rate at the end of a uniform profile. Deposition like that in Figure 5.2 for concave hillslope sections does not occur on the uniform and convex shaped hillslopes illustrated in Figure 5.3. Sediment yield equals soil loss on those profiles.

Another important complex hillslope shape is shown in Figure 5.4 where a concave section occurs in the middle of the hillslope. A field example is a cut slope-road-fill slope that is common in hilly terrain being logged. Deposition can occur on the mid-section of

Figure 5.4. **Soil loss, deposition, and sediment yield from a complex slope, concave-convex shape.**



the hillslope where the road is located. Soil loss occurs on the cut slope and on the fill slope where overland flow continues across the road onto the cut slope. Although the steepness and length of the fill slope is the same as that for the upper cut slope, **soil loss** is likely to be much greater on the cut slope than on the fill slope because of the increased overland flow. Although the USLE and RUSLE1 cannot easily describe this hillslope, RUSLE2 easily describes it, determines appropriate overland flow slope lengths, and computes soil loss on the two **eroding portions** of the hillslope, deposition on the **depositional portion** of the hillslope, and **sediment yield** from the hillslope. Note that the slope length used in RUSLE2 does not end where deposition begins for this hillslope profile.

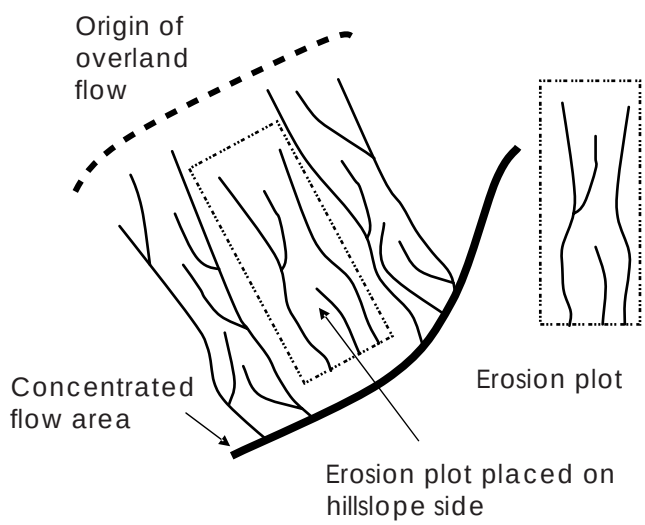
In addition to computing how slope shape affects erosion, RUSLE2 can also compute how variations in soil and management along a hillslope profile affect erosion.

5.3. Does RUSLE2 Apply to Certain Conditions?

5.3.1. Rill Erosion or Concentrated Flow Erosion?

RUSLE2 does not apply to concentrated flow areas where ephemeral gully erosion occurs. Whether or not RUSLE2 applies to particular eroded channels is not determined by size or depth of the channels. The determination depends on whether the channels in the field situation would be included if RUSLE2 plots were to be placed on that landscape. The core part of RUSLE2 that computes net detachment (**sediment production**) is its empirically derived data collected from plots like those illustrated in Figures 5.5 and 5.6.

Figure 5.5. **Relation of erosion plots to landscape.**



The length of these plots were typically about 75 feet (25 meters), and widths ranged from 6 feet (2 meters) to about 40 feet (13 meters) wide, with plots as wide as 150 feet (50 meters) at one location. These plots were always placed on the sides of the hillslope where overland flow occurred, not in the swales where concentrated flow occurs. Thus, RUSLE2 can estimate soil loss for rills 15 inches (375 mm) deep

Figure 5.6. Erosion plots 12 ft (3.65 m) wide, 72.6 ft (22.1 m) long, near Columbia, Missouri.

on sides of hillslopes because these rills would be in plots placed on this part of the landscape, but it cannot estimate erosion from a 4 inch (100 mm) deep ephemeral gully or 10 feet (3 meter) deep classical gully in a concentrated flow area because plots would not be placed in these locations.

5.3.2. Can RUSLE2 Be Used to Estimate Sediment Yield from Large Watersheds?

Sediment yield from most large watersheds is often less than sediment production within the watershed. Thus, much sediment is deposited within a typical watershed. RUSLE2, in contrast to the USLE and RUSLE1, can estimate the deposition that occurs on the overland flow portion of the landscape. This deposition can be substantial on many hillslopes, up to 75 percent of the sediment produced on the eroding portion of the hillslope. If RUSLE2 is being used to estimate sediment yield in watersheds, it should be applied only to the eroding portion of the landscape to compute a soil loss comparable to that computed by the USLE. Otherwise, a different set of sediment delivery ratio values from those used by the USLE would have to be used with RUSLE2 to take into account deposition on overland flow areas.

In addition to the sediment produced, which is estimated by RUSLE2, by interrill and rill erosion on upland areas, erosion in concentrated flow areas (ephemeral gullies), classical gullies, stream channels, and mass movement of material into channels are other major sources of sediment that contribute to sediment yield, which are not estimated by RUSLE2.

5.3.3. Estimating Soil Loss With RUSLE2 for Large Areas

RUSLE2 can be used to estimate soil loss for large areas. The approach is to select sample points over the inventory area where RUSLE2 will be applied to compute soil loss. These sample points should be selected according to the requirements of the inventory, giving special attention to the required accuracy and how soil loss estimates will be aggregated according to soil, topography, land use and conservation practice. RUSLE2 can be applied in several ways. One way is to estimate a "point" soil loss at the sample point. A slope length to the point and values for steepness, soil, and cover and management at each sample point are determined. A slope segment of 1 foot (0.3 meters) at the end of the slope length, along with values, is used in RUSLE2 to compute soil loss at the point. Another approach is to determine a slope length through the point that extends to the location that deposition begins or to a concentrated flow area if deposition does not occur. Values for conditions along the slope length are used in RUSLE2 to compute a soil loss for the slope length. A limitation of this approach is that soil loss values cannot be aggregated based on conditions that vary along a slope length, such as multiple soil types. A third approach, which was used by NRCS for the National Resources Inventory (NRI), uses the slope length through the point to either deposition or a concentrated flow area and conditions at the point to compute soil loss. This approach does not provide an estimate of soil loss at the point. Soil loss values cannot be aggregated for variables that are related to position on the slope. For example, the same soil loss is computed at the top of slope as at the bottom of slopes when slope steepness is the same for both locations.[3] Although computing soil loss for the entire slope length has limitations, a major advantage is that the number of sample points is significantly reduced that are needed to obtain an accurate estimate of average soil loss for the area or for the main variables that are not landscape position dependent.

An approach that absolutely should not be used is to determine spatially averaged values for slope length and steepness, soil, and cover-management conditions for the inventory area and use these values in RUSLE2 to compute a single soil loss value for the area. Soil loss estimates by this method are inaccurate because of nonlinearities in the RUSLE2 equations. No simple, universally applicable method can be developed to select the proper values. The issue is directly related to the proper mathematical procedures for spatial integration, which is exactly the reason why

RUSLE2 is much superior mathematically to the USLE or RUSLE1 as discussed below.

5.4. Equation Structure of RUSLE2

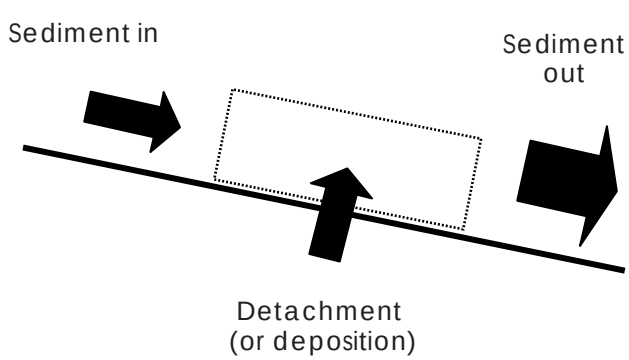
RUSLE2 uses an equation structure similar to the Universal Soil Loss Equation (USLE) and RUSLE1. RUSLE2 computes average annual soil loss on each *ith* day as:

$$a_i = r_i\, k_i\, l_i\, S\, c_i\, p_i \qquad \textbf{[5.1]}$$

where: $\mathbf{a_i}$ = average annual soil loss, $\mathbf{r_i}$ = erosivity factor, $\mathbf{k_i}$ = soil erodibility factor, $\mathbf{l_i}$ = soil length factor, **S** = slope steepness factor, $\mathbf{c_i}$ = cover-management factor, $\mathbf{p_i}$ = supporting practices factor, all on the *ith* day. The slope steepness factor S is the same for every day and thus does not have a subscript. To emphasize, values for these factors are average annual for a particular day—not for the year, which is the reason that lower case symbols are used rather than upper case as in RUSLE1 and USLE.

RUSLE2 computes deposition when sediment load exceeds transport capacity using:

Figure 5.7. **Schematic of conservation of mass equation for computing sediment load along the slope.**



$$D_p = (V_f/q)(T_c - g) \qquad \textbf{[5.2]}$$

where: $\mathbf{D_p}$ = deposition, $\mathbf{V_f}$ = fall velocity of the sediment in still water, **q** = overland flow (runoff) rate per unit width of flow, $\mathbf{T_c}$ = transport capacity, and **g** = sediment load. RUSLE2 computes runoff rate using the 10-year-storm erosivity, the NRCS curve number method, and a runoff index computed using cover-management variables.

RUSLE2 computes transport capacity using:

$$T_c = K_T\, q\, s \qquad \textbf{[5.3]}$$

where: **s** = sine of the slope angle, and $\mathbf{K_T}$ = a transport coefficient computed as a function of cover-management variables. Sediment load is computed from the steady state conservation of mass equation of:

$$g_{out} = g_{in} + \Delta x\, D \qquad \textbf{[5.4]}$$

where: $\mathbf{g_{out}}$ = sediment load leaving the lower end of a segment on the slope, $\mathbf{g_{in}}$ = sediment load entering the upper end of the segment, Δx = length of sediment, and **D** = net detachment or deposition within the segment. The sign convention is "+" for detachment because detachment adds to the sediment load, and "-" for deposition because it reduces the sediment load. Equation 5.4 is graphically illustrated in Figure 5.7.

Equations 5.2 through 5.4 are solved for each of the five particle classes: primary clay, primary silt, small aggregate, large aggregate and primary sand. The distribution among these classes at the point of detachment is computed by RUSLE2 as a function of soil texture. The wide range in fall velocity for sediment particle classes allows Equation 5.2 to compute the sorting of sediment where coarse and dense sediment are deposited first, which enriches the sediment load in fines and less dense particles.

Average annual soil loss is computed as:

$$A = \left(\sum_{i=1}^{365m} a_i\right)/m \qquad \textbf{[5.5]}$$

where: **A** = average annual soil loss, **m** = number of years in the analysis, and **365m** = the number of days in the analysis period. The value for m = 1 for continuous vegetation on range, pasture and similar lands; length (duration in years) of cropping-management rotations on cropland, and the number of years following a disturbance, like construction, logging, grading of a reclaimed surface mine, or closing of a land fill.

For comparison, RUSLE1 is:

$$A = RLSP\left\{\left(\sum_{k=1}^{24m}(f_k k_k)\right)/m\right\}\left(\sum_{k=1}^{24m}(f_k c_k)\right)/m \qquad \textbf{[5.6]}$$

where: **R** = average annual erosivity, $\mathbf{f_k}$ = distribution of erosivity by half month period, **L** = slope length factor, **P** = supporting practices factor, and **k** = index for the

half month period. The **24** in Equation 5.6 is the number of half month periods in a year. Values for the terms **K** and **C** are computed from:

$$K = (\sum_{k=1}^{24m} (f_k k_k))/m \qquad \textbf{[5.7]}$$

and:

$$C = \sum_{k=1}^{24m} (f_k c_k))/m \qquad \textbf{[5.8]}$$

Values for **K** and **C** were computed and placed in tables so that RUSLE1 could be used in a "paper version" using **A** = RKLSCP as an alternative to using the RUSLE1 computer program.

The USLE is:

$$A = RKLSP(\sum_{j=1}^{N} f_j c_j)/m \qquad \textbf{[5.9]}$$

where: **j** = the index for crop stage periods and **N** = the number of crop stages over the analysis period. A crop stage period is one where the cover-management factor **c** can be assumed to be constant. Values for **C** were computed from:

$$C = (\sum_{j=1}^{N} f_j c_j)/m \qquad \textbf{[5.10]}$$

and were also computed and placed in tables so the USLE could easily be used in a paper version as A = RKLSCP.

The numerical integration used in RUSLE2 to solve Equations 5.1 and 5.5 is much superior to the approximations used in RUSLE1 and the USLE. The difference in soil loss estimates between RUSLE2 and the other equations can be as much as 15 percent because of the mathematical integration procedures. Modern computers are readily available to solve complex equations that can be used to eliminate the need for paper versions of RUSLE2, which is generally too complex for a paper version.

The USLE, introduced in the early 1960's and revised in 1978,[4] was totally empirical, having been derived from more than 10,000 plot years of data from natural runoff plots and an estimated equivalent of 2,000 plot-years of data from rainfall simulator plots. The strength of the USLE is its empiricism, which is also its weakness. The USLE cannot be applied to situations where empirical data are not available for a specific field condition to derive appropriate factor values.

Federal legislation in the 1980's required erosion prediction technology applicable to almost every cropland use, a requirement that the USLE could not meet. A "subfactor" method that estimates values for the cover-management factor C allows RUSLE1 to be applied to any land use. Process-based equations were also added to estimate the values for the support practice factor P so that soil loss could be estimated for modern strip cropping systems, something not possible with the USLE. Data were not available for these systems needed to derive USLE P factor values. This hybrid approach of starting with an empirical structure then adding process-based equations where empirical data were not adequate—greatly increased the power of RUSLE1 over the USLE.

RUSLE2 significantly expands on this hybrid approach by combining the best of empirical-based and process-based erosion prediction technologies. Modern theory on erosion processes of detachment, transport, and deposition of soil particles by raindrop impact and surface runoff was used to derive RUSLE2 relationships where the required equations could not be derived from empirical data. RUSLE2 is a well-validated erosion prediction technology that builds on the success of the USLE and RUSLE1. Procedures used to validate RUSLE2 are described in **Appendix B** (Not available in this draft).

5.5. Major Factors Affecting Erosion

The four major factors affecting interrill and rill erosion are: (1) climate, (2) soil, (3) topography, and (4) land use.

5.5.1. Climate

Rainfall drives interrill and rill erosion. The most important characteristics of rainfall are rainfall intensity (how hard it rains) and rainfall amount (how much it rains). Soil loss is high in Mississippi where much intense rainfall occurs, whereas soil loss is low in the deserts of Nevada where very little rainfall occurs. Thus, rainfall erosivity varies by location. Specifying the location of a site identifies the erosivity at the site.

Table 5.1. RUSLE2 database components.

COMPONENT	COMMENTS
Worksheet	Computes soil loss for alternative management practices, alternative profiles, and average soil loss for an area.
Profile	Computes soil loss for a single hillslope profile, the basic computational unit in RUSLE2.
Climate	Contains data on average annual erosivity, EI_{30}, rainfall amount and temperature.
Storm erosivity	Contains data on the distribution of erosivity during the year.
Soil	Contains soil data, including erodibility, texture, hydrologic soil group, time to consolidation, sediment characteristics and soil erodibility nomographs.
Management	Contains descriptions of cover-management systems. Includes dates, operations, vegetation, type and amount of applied materials.
Operation	Contains data on operations, which are events that affect soil, vegetation and residue. Includes the sequence of processes used to describe each operation, such as: an operation places residue in the soil; values for flattening, burial and resurfacing ratios; ridge heights; and initial soil roughness.
Vegetation	Contains data on vegetation, like values for residue type, yield, above ground biomass at maximum canopy, senescence, flow retardance, root biomass, canopy cover, fall height and live ground cover.
Residue	Contains data that describes the residue assigned to each vegetation. Includes values for decomposition, mass-cover relationship and how residue responds to tillage.
Contouring	Contains values for row grade used to describe degree of contouring.
Strips/barriers	Contains data that describes filter strips, buffer strips and rotational strip cropping. Includes cover-management in strips, width of strips, number of strips across slope length, whether or not a strip is at the end of the slope, and offset of rotation by strip.
Hydraulic system	Identifies the hydraulic elements and their sequence to describe hydraulic systems of diversions, terraces and impoundments. Includes numbers across slope length, and whether or not a system is at the end of the slope or specific locations on the slope length.
Hydraulic element	Contains data on the grade of the named channel for terraces and diversions.
Subsurface drainage system	Contains data on the percent of the area covered by optimum drainage.

5.5.2. Soil

Some soils are naturally more erodible than are other soils. Erosion by raindrop impact is not easily seen, but varying degrees of rilling indicate differing erodibility among soils. Knowledge of basic soil properties, such as texture, provides an indication of erodibility. For example, soils high in clay and sand have low erodibilities, while soils high in silt have high erodibilities. Soils are mapped and named as map units and components that make up map units. Soil properties, including erodibility, are assigned by soil component and map unit. These properties are, in effect, specified when the name of a soil mapping unit is selected.

5.5.3. Topography

Topography, especially steepness, affects soil loss. Intense rilling is evidence that steep slopes, like road cuts and fills, experience intense erosion when bare. Runoff that accumulates on long slopes is also highly erodible, especially when it flows onto steep slopes. Thus, slope steepness and, to a lesser extent, slope

length are major indicators of how topography affects erosion. Slope shape also affects erosion by evidence of deposition that occurs on concave slopes.

5.5.4. Land Use

Erosion occurs when soil is left bare and exposed to raindrop impact and surface runoff. However, vegetative cover greatly reduces soil loss. Given this, two types of practices are used to control soil loss. One type is cultural practices, like planting, vegetative cover, crop rotations, conservation tillage and applying mulch. The other type is utilizing supporting practices, like contouring, strip cropping and terraces that "support" cultural management practices. Among the factors of climate, land use, soil and topography, land use is the most important because it has the greatest range of effect, and it is the one factor that can most easily be changed to control soil loss and sediment yield.

A powerful feature of RUSLE2 is that it is land use independent. By using fundamental variables to represent cover-management effects, RUSLE2 can be applied to any land use. These variables include: percent canopy cover; fall height; ground cover provided by live vegetation, plant litter, crop residue and applied materials; surface roughness; soil biomass; degree of soil consolidation, and ridge height. RUSLE2 applies to cropland, rangeland, disturbed forestland, construction sites, reclaimed mined land, landfills, military training sites, and other areas where "mineral" soil is exposed to the forces of raindrop impact and overland flow produced by rainfall in excess of infiltration.

5.5.5. Computing Soil Loss With RUSLE2

RUSLE2 computes erosion by using inputs for climate, soil, topography and land use. Information on these factors is stored in the RUSLE2 database using names for locations, which identifies climate, soil, cover-management and supporting practice. When RUSLE2 is run, the user selects a name from the list for each of these factors, and RUSLE2 "pulls" the data associated with these names from its database. The user then enters additional site-specific information on topography, yield (production level), rock cover, and type and amount of applied materials, like manure and mulch. This information describes a hillslope profile. Once the information has been entered in RUSLE2, the profile can be named and saved in the RUSLE2 database. The RUSLE2 **profile** component computes erosion on a single hillslope profile.

The RUSLE2 **worksheet** component is used in most conservation planning applications to compute erosion for a set of alternate conservation practices for a single hillslope profile for a particular location, soil and topography. The worksheet is a convenient way to compare alternatives. The "field office expanded" template provides additional worksheets. One of these worksheets can be used to compare hillslope profiles where all attributes, including location, soil, topography, cover-management and supporting practices, can vary among the profiles. Another worksheet can be used to compute average soil loss for a spatial area, like a field or watershed, where profiles vary over the area. Like profiles, individual worksheets can also be named and saved.

The components of the RUSLE2 database are listed in Table 5.1. With the exception of a few site specific inputs, RUSLE2 uses values stored in its database to make its computations. Input values in the database can be modified during a RUSLE2 analysis. However, you may be locked out of certain database elements because of settings in the RUSLE2 access control. Contact your RUSLE2 administrator for information on changing your access control.

The mechanics of the RUSLE2 interface are described in a tutorial available from the RUSLE2 download site. Similar information is summarized in **Appendix C** (Not available in this draft). When the RUSLE2 program is first opened, the opening screen provides two choices. The first choice is to select either a profile or worksheet to perform erosion computations, or select one of the database components to work on the database. The second choice is to select a template. Templates control the appearance of the RUSLE2 interface and determine the complexity of the field problems that can be analyzed. RUSLE2 is easiest to use when using a simple uniform slope, which is the "field office simple slope" template. As you become familiar with RUSLE2, move to other templates to analyze complex slopes.

6. RUSLE2 Database Components

This section describes each of the RUSLE2 database components, the variables in each component, the role of each variable, and how to determine a value for each variable.

6.1. Climate

Table 6.1 lists the variables in the climate database component.

6.1.1. Average Annual Erosivity-R

6.1.1.1. Selecting R-Values in the U.S.

The average annual erosivity factor R is an index of rainfall erosivity at a location. For example, if all things are equal, R-values (erosion) in central Mississippi are about 10 times greater than those in western North Dakota. The R factor reflects the effect of both rainfall amount and rainfall intensity. Thus, R-values can vary

Table 6.1. Variables in climate database component.

VARIABLE	SYMBOL	COMMENT
Average annual erosivity	R	An index of the erosivity at a location, closely related to rainfall amount and intensity.
10 yr EI_{30}	$(EI_{30})10$	Erosivity of an infrequent moderately erosive rain, used to compute the following: transport capacity and deposition for concave slopes, vegetative strips and channels; reduction of erosion by ponding; effectiveness of contouring; and critical slope length for contouring.
Erosivity distribution	Identifier name	Describes how erosivity varies during the year, and how it interacts with variations of soil erodibility and cover-management variables during the year to significantly affect erosion.
In R_{eq} Area?	Yes or no	The R_{eq} area is a region in the northwestern part of the U.S. where the erodibility of cropland and other highly disturbed soils is greatly increased during winter months. Answer "Yes" to use R_{eq} relationships for these land uses.
Use R_{eq} distribution?	Yes or no	The wintertime adjustment for increased erodibility does not apply to land uses, like pasture and rangeland. If answered "No," R_{eq} relationships will not be used.
R equivalent	R_{eq}	The effect of the greatly increased erodibility is accounted for in the R_{eq} region by using an equivalent erosivity value based on annual precipitation.
EI distribution for R_{eq}	—	An erosivity distribution that describes the greatly increased erodibility during the winter.
Adjust for soil moisture	Yes or no	An adjustment is made for soil moisture when the R_{eq} relationship is selected for cropland and other situations of highly disturbed soil, which only applies to R_{eq} zone.
Annual precipitation	V_{rf}	RUSLE2 computes annual precipitation from the monthly precipitation values used to compute time to soil consolidation.
Vary soil erodibility with climate	Yes or no	With the exception of when the R_{eq} relationships are used, select "Yes" to vary soil erodibility values through time as a function of monthly precipitation and temperature.
Monthly temperature		Average annual monthly temperature, which is used to compute the temporal variation of soil erodibility and decomposition of dead plant materials (litter, residue and roots).
Monthly rainfall		Average annual monthly precipitation (rainfall, snow and applied irrigation water), which is used to compute the temporal variation of soil erodibility and decomposition of dead plant materials (litter, residue and roots).

significantly among locations having nearly equal rainfall amounts.

Values for R are available from the USDA-NRCS for any location in the U.S. Values for selected locations are included in the sample database that is downloaded with RUSLE2. If none of these sources are available, R-values can be selected from Figures 6.1 – 6.4.

Figure 6.1. **R-values for the eastern United States.**

"Data being updated. Map not yet available."

Figure 6.2. **R-values for the Rocky Mountain region of the United States.**

"Data being updated. Map not yet available."

Figure 6.3. **R-values for California.**

"Data being updated. Map not yet available."

Figure 6.4. **R-values for Washington and Oregon.**

"Data being updated. Map not yet available."

6.1.1.2. Estimating Erosivity for High Elevations

Erosivity varies greatly with location in mountainous areas. Erosivity maps, like those in Figure 6.2, do not provide accurate values because of insufficient map scale and limited rainfall data. Rain data are often not available at high elevations because rain gages are usually located at lower elevations in valleys where economic activities, like aviation and farming, occur.

Values for R can be estimated where data on rainfall amount, but not intensity, are available. The R-value for each month is computed by multiplying the R-value at the nearest location where R is known by the fraction of erosivity in the month. The monthly R-value at the second location is computed as the product of the known monthly R-value and the ratio of non-snow monthly precipitation at the locations raised to the power of 1.5, which takes into account both rainfall amount and intensity. The R-value is then obtained by summing the monthly values. When data on rainfall amount are not available, you can estimate annual precipitation in remote mountainous areas based on the type and production level of vegetation. Estimate R by multipling the known R-value by the ratio of precipitation values for the two locations raised to the 1.5 power.

6.1.1.3. Snowmelt Erosivity

RUSLE2 does not estimate erosion caused by snowmelt. However, RUSLE2 does estimate erosion by rainfall for the period when snow cover is not present. Precipitation data used to estimate R-values should be based only on rainfall and should not include snow values. The R_{eq} relationships discussed below in section 6.1.8. do not apply to conditions where a snow pack covers the soil for the winter months, nor does it estimate the erosion that occurs when the snow pack melts.

6.1.1.4. Estimating Erosivity for Regions with Limited Rainfall Data

RUSLE2 is frequently applied in regions outside the U.S., where detailed rainfall data are not available. **Appendix D** (Not available in this draft) describes approaches that can be used to estimate erosivity values when rainfall data are limited. These procedures can also be used in the U.S. to expand the rainfall database to determine R-values.

6.1.1.5. Computing Erosivity from Rainfall Data

Average annual erosivity is computed as the sum of the erosivity ($\mathbf{EI}_{30}$), which is the product of the total energy and the maximum 30-minute intensity of individual storms. Total storm energy is closely related to storm rainfall amount, and maximum 30-minute intensity is a measure of peak rainfall intensity. Total energy for a storm is computed by using the following:

$$E = \sum_{k=1}^{M} e_k \Delta V_k \qquad \textbf{[6.1]}$$

where: **e** = unit energy (energy per unit of rainfall), Δ**V** = rainfall amount for the *kth* period, **k** = an index for periods during a rain storm where intensity can be considered to be constant, and **M** = number of periods.

Unit energy is computed from:

$$e = 0.29[1 - 0.72 \exp(-0.082i)] \quad \textbf{[6.2]}$$

where: unit energy **e** has units of MJ/ha*mm and **i** = rainfall intensity (mm/h).[5] Table 6.2 illustrates computation of total energy for a storm. The total energy for the storm is 8.90MJ/ha. The maximum 30-minute intensity must be determined to multiply by the storm energy to determine storm erosivity. Maximum 30-minute intensity is the average intensity for the continuous 30 minutes with the maximum rainfall. (Also, I_{30} = 2*amt of rain in 30 minutes with maximum rainfall amount). Plotting cumulative rainfall for the storm as illustrated in Figure 6.5 is helpful for determining maximum 30-minute rainfall. This storm is unimodal (single peak) at the time of the 30 minutes having the most rainfall. The amount of rainfall is 28.7 mm for the 30 minutes with the most rainfall, which gives an intensity of 57.4 millimeters per hour for I_{30}. The erosivity for the storm is 8.90 MJ/ha % 57.4 mm/h = 511.9 MJ*mm/(ha*h). The computation of storm erosivity in U.S. customary units is similar, except that the erosivity values are divided by 100 to provide working numbers of increased convenience. Rains of less than 0.5 inch (12 mm) and separated from other rains by more than 6 hours are not included in the computations unless the maximum 15-minute intensity exceeds 0.5 inch per hour (12 mm/hour). These storms add little erosivity and significantly reduce the amount of rainfall data that must be processed.

Total erosivity for a year is the sum of the storm erosivities in the year as:

$$R_j = \sum_{j=1}^{J} (EI_{30})_j \quad \textbf{[6.3]}$$

where: $\mathbf{R_j}$ = the erosivity for the year, $\mathbf{EI_{30}}$ = the erosivity of individual storms, **j** = an index for each storm, and **J** = number of storms in the year.

The average annual erosivity is computed from:

$$R = (\sum_{m=1}^{M} R_m)/M \quad \textbf{[6.4]}$$

where: **R** = average annual erosivity, $\mathbf{R_m}$ = erosivity for individual years, **m** = index for year, and **M** = total number of years.

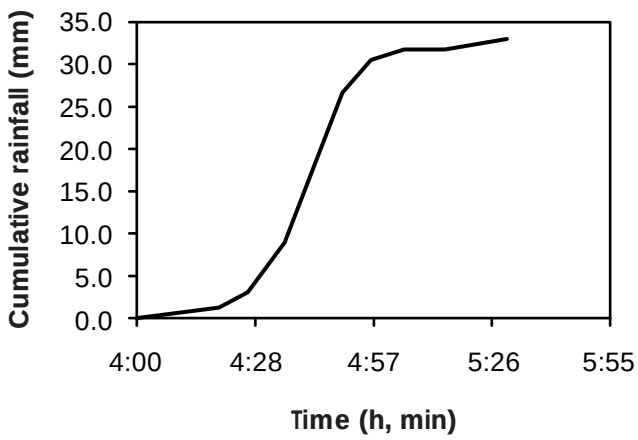
Annual erosivity varies greatly year to year. At least 15 years of data are needed to obtain a reasonable estimate of average annual erosivity. Twenty and even 30 years of data are preferred. Extreme storms with a greater than 50-year return period are not included. These extreme storms can significantly distort the average annual erosivity. Values for R used in RUSLE2 should be obtained from the USDA-NRCS that has prepared a database of R-values across the U.S. on a 1-km by 1-km grid.[6] Values from this database can be extracted and used in RUSLE2. Values from the NRCS database have been adjusted for elevation and other spatial factors that affect erosivity.

Values of average annual erosivity can be computed for individual locations and mapped as illustrated in

Table 6.2. Sample computation of erosivity EI_{30} for an individual storm.

TIME (hrs:min)	DURATION OF INTERVAL (minutes)	CUMULATIVE RAIN DEPTH (mm)	RAINFALL IN INTERVAL (mm)	INTENSITY (mm/h)	UNIT ENERGY (MJ/ha*mm)	ENERGY IN INTERVAL (MJ/ha)
4:00		0.0				
4:20	20	1.3	1.3	3.8	0.137	0.17
4:27	7	3.0	1.8	15.2	0.230	0.41
4:36	9	8.9	5.8	38.9	0.281	1.64
4:50	13	26.7	17.8	82.1	0.290	5.15
4:57	3	30.5	3.8	76.2	0.290	1.10
5:05	8	31.8	1.3	9.5	0.194	0.25
5:15	10	31.8	0.0	0.0	0.081	0.00
5:30	20	33.0	1.3	3.8	0.137	0.17
Total	**90**		**33**			**8.90**

Figure 6.5. Cumulative rainfall for a storm.



Figures 6.1 – 6.4. Values can be used from these figures if the NRCS database is not available.

6.1.1.6. Erosivity for the *ith* Day

RUSLE2 uses a value for erosivity for the ***ith*** day to compute soil loss on the *ith* day in equation 5.1. This erosivity is computed by multiplying the average annual R-value by the fraction f_i of erosivity that occurs on the *ith* day. The erosivity (r_i) on any day is determined from the distribution for erosivity during the year, which is discussed in section 6.1.3.

$$r_i = f_i R \qquad [6.5]$$

6.1.2. 10 yr EI_{30}

The 10-year EI_{30} (**10 yr EI_{30}**) is used to compute runoff using the NRCS curve number method and the reduction of erosivity by ponding. Runoff is used to compute factor values for contouring, the critical slope length for contouring, and sediment transport capacity. Sediment transport capacity is used to compute deposition by runoff entering concave slope sections, dense vegetation, high ground cover, and rough soil surfaces. The 10 yr EI_{30} value is the maximum storm erosivity that occurs in any year that has the probability of occurring once every 10 years (a 10 year return period).

Figure 6.6. 10 yr EI_{30} values for the eastern United States.

"Data being updated. Map not yet available."

Figure 6.7. 10 yr EI_{30} values for the Rocky Mountain region of the United States.

"Data being updated. Map not yet available."

The USDA-NRCS has determined values for 10 yr EI_{30} from observed weather data. Values for 10 yr EI_{30} are available for any location in the U.S. in a database that can be obtained by contacting the NRCS state agronomist in your state. If these data are unavailable, a 10 yr EI_{30} value can be selected from Figures 6.6 - 6.9.

6.1.3. Distribution of Erosivity During the Year

Erosivity varies temporally in patterns that vary by location as illustrated in Figure 6.10. For example, erosivity is nearly uniform at Memphis, Tennessee, while 80 percent of the erosivity occurs in the months of May, June and July in North Dakota, a period when clean tilled row crops are especially susceptible to erosion because little cover is present. Therefore, on a relative basis, greater erosion occurs with clean tilled crops, like corn per unit R in North Dakota, than in Tennessee because time of peak erosivity overlaps with the time when the cropping system leaves the soil most vulnerable to erosion in North Dakota. Growing a crop like wheat, which provides the greatest protection during peak erosivity, can significantly reduce erosion. Another example is to ensure that the exposed portion of a construction site is minimal during peak erosivity. Soil erodibility also varies during the year. Erosion is greatest when peak erodibility, erosivity, and vulnerability of cover-management all correspond.

Figure 6.8. 10 yr EI_{30} values for California.

"Data being updated. Map not yet available."

Figure 6.9. 10 yr EI_{30} values for Washington and Oregon.

"Data being updated. Map not yet available."

Figure 6.10. Erosivity distribution for locations in California, North Dakota, Tennessee, and Massachusetts.

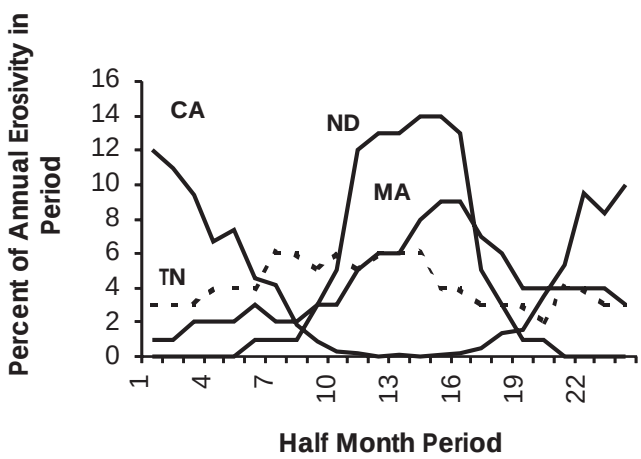


Figure 6.11. Erosivity (EI) distribution zones for the United States.

"Data being updated. Map not yet available."

The distribution of erosivity is entered into RUSLE2 by half-month period, which RUSLE2 expands into daily values. The procedure used to expand the half-month values into daily values is described in section 6.1.7.

Values for the erosivity distributions at any U.S. location are available from the USDA-NRCS state agronomist in your state. If these data are not available, use the values that are available in the sample database downloaded with RUSLE2. These values are associated with the EI distribution zones shown in Figure 6.11.

6.1.4. Annual Monthly Precipitation and Temperature

RUSLE2 uses data for average annual monthly precipitation and temperature to compute decomposition of plant litter, crop residue, dead roots, and applied materials like manure and mulch. The best source of these weather data is the database available from the USDA-NRCS state agronomist in your state. Values for your location can be extracted from this database, which provides information on a 1-km by 1-km grid basis across the U.S.

If values are not available from NRCS, the values can be obtained from local weather records. The most recent 30 years of data should be used. Do not use less than 20 years of data. Using data from a nearby location with essentially the same weather is better than using data from a record taken less than 20 years ago.

Use care in developing these data. Measurements at certain locations are not representative of the area where RUSLE2 will be applied. For example, rainfall and temperature data from an urban airport may not represent a neighboring rural area. Sometimes data from a single station is used to apply RUSLE2 to a county. Data from surrounding stations should be reviewed for consistency. A better data set is one where data from neighboring stations are averaged, rather than using data from individual stations. Unexplained variability in the weather data introduces variability in soil loss estimates from RUSLE2 that does not represent "real" variations and that should be considered in conservation planning.

Both temperature and rainfall vary spatially in mountainous areas. The best approach is to contact the USDA-NRCS state agronomist in your state for rainfall and temperature values at your location. However, if these values are not available, use professional judgment to develop temperature and precipitation values.

6.1.5. Varying Soil Erodibility with Climate

RUSLE2 varies soil erodibility as a function of monthly precipitation and temperature. This capability should be used for all locations and conditions where the standard erosivity relationships are used, including all areas in the western U.S. However, the soil erodibility should not be varied with climate for the R_{eq} zone described in section 6.1.8.

6.1.6. RUSLE2 Reduces Erosivity for Ponding

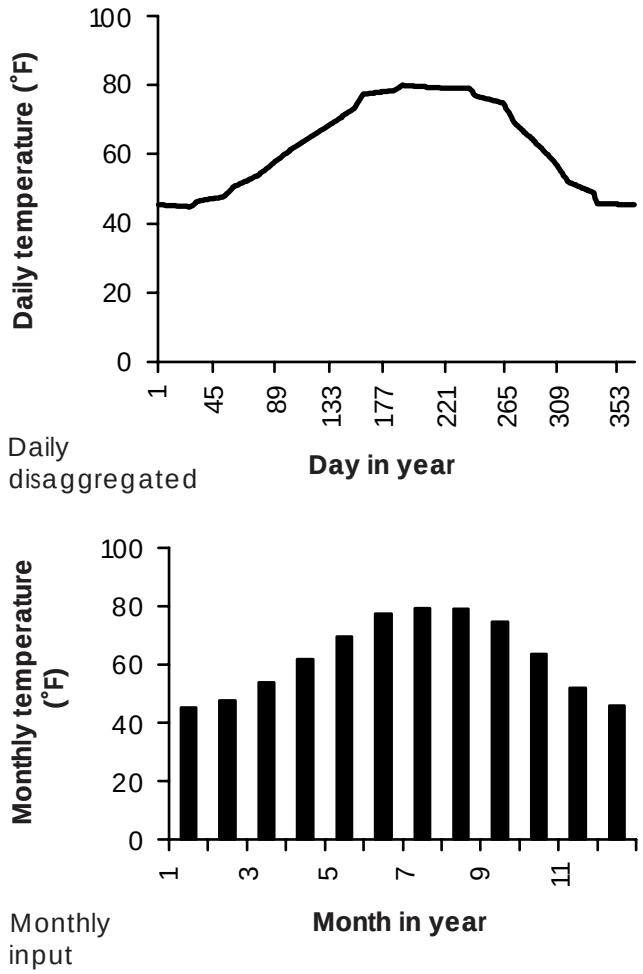
Intense rainfall on slopes less than about one (1) causes ponded water that reduces the erosivity of raindrop impact, an effect very important in the Mississippi Delta region. RUSLE2 automatically computes the effect of ponding on erosivity by internally reducing R values. The reduction is computed as a function of slope steepness and the 10 yr EI_{30}. The 10 yr EI_{30} storm captures the effect of a large, intense, relatively infrequent storm where ponding is most likely to have its greatest effect. In contrast to RUSLE1, RUSLE2 assumes that ponding reduces erosivity on

both flat and ridged surfaces, and the adjustment for ponding in RUSLE2 cannot be "turned off."

6.1.7. Disaggregating Half Month and Monthly Values into Daily Values

Although RUSLE2 uses average annual daily weather values in its computations, input values for weather values are on a half-month and monthly basis. RUSLE2 "disaggregates" half-month and monthly values into daily values. This procedure uses linear equations that preserve the half-month and monthly averages in the input data. The resulting daily values are sometimes not smooth, especially for rainfall values that vary up and down from month to month in comparison to the smooth trends in temperature. Preserving average values was considered to be more important than having a smooth curve. Examples of RUSLE2 disaggregated monthly values are shown in Figures 6.12 and 6.13.

Figure 6.12. RUSLE2 disaggregated temperature values for Birmingham, Alabama.

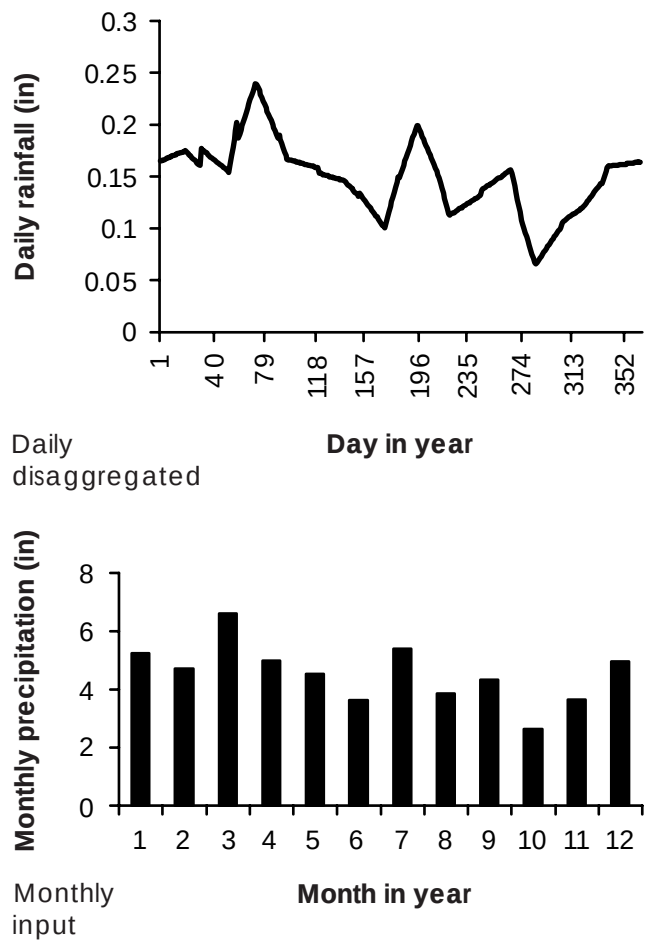


6.1.8. Erosivity Relationships in the R_{eq} Region

6.1.8.1. R_{eq} Values

The erosion processes in the Northwestern Wheat and Range Region (NWRR),[7] adjacent areas with similar climate, and certain other areas of the western U.S. are different from those in other regions. Erosion from rainfall and/or snowmelt on thawing cropland, construction sites, and other sites of highly disturbed soils in this region is much greater than expected based on standard R-values. Therefore, equivalent R-values, or R_{eq} values, are used to apply RUSLE2 to these special conditions. In addition, a modified erosivity distribution and special equations for the topographic and cover-managements factors are also used. The R_{eq} erosivity distribution is described below, and the topographic and cover-management relationships are described in sections 6.3.1.1. and 6.4.

Figure 6.13. RUSLE2 disaggregated precipitation values, Birmingham, Alabama.



The conditions where these relationships apply is known as the R_{eq} zone. This zone is illustrated in Figure 6.14. Northwestern Colorado, southeastern Utah and southwestern Colorado are special transitional areas that use different relationships from those in the R_{eq} zone.

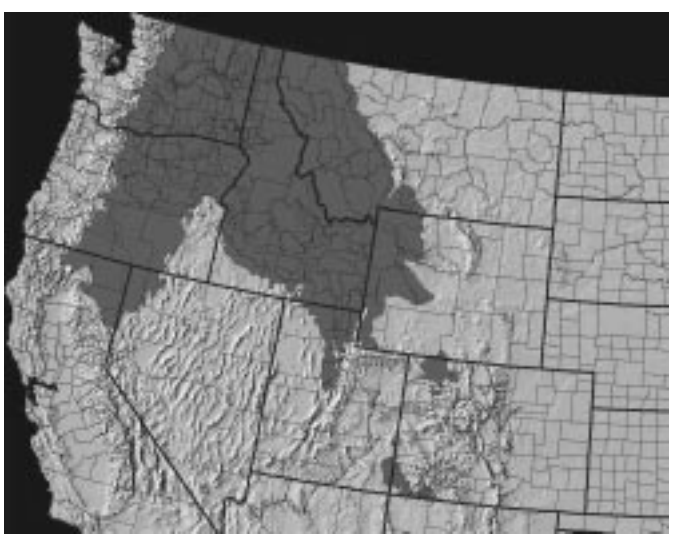
Values for R_{eq} are used instead of standard R-values in the R_{eq} zone. Values for R_{eq} are computed from annual precipitation as:

$$R_{eq} = 7.86 V_{rf} - 50.5 \qquad \textbf{[6.6]}$$

where: R_{eq} = the equivalent erosivity (U.S. erosivity units) and V_{rf} = average annual precipitation (in). Equation 6.6 is an empirical equation developed primarily for conditions across eastern Washington into Idaho. Equation 6.6 should not be applied to situations that give an R_{eq} value greater than 200 U.S. erosivity units. Similarly, an R_{eq} value greater than 200 U.S. erosivity units should not be used in RUSLE2.

The best approach is to obtain R_{eq} values from the NRCS. A value for R_{eq} can be entered directly into the RUSLE2 database for a particular location, or RUSLE2 can compute it from average precipitation using equation 6.6. If R_{eq} values cannot be obtained from NRCS, values can be taken from Figures 6.15 - 6.16.

Figure 6.14. **R_{eq} zone.**



At first, the **R_{eq}** may appear to apply to areas beyond the NWRR where frozen soils and runoff from snowmelt occur, such as the northern tier of states in the U.S. However, that region does not experience the repeated freezing and thawing that is characteristic of the R_{eq} zone. Instead, the freezing, thawing, and runoff on thawing soils in those areas is limited to about one month instead of occurring repeatedly throughout the winter months in the R_{eq} zone. Research at Morris, MN, showed that only about 7 percent of the annual erosion at that location is associated with erosion during the spring thaw. The soil is much more susceptible to erosion during the thawing period, but that effect is considered in the temporally varying soil erodibility factor K for all areas of the U.S. except for the R_{eq} region where the R_{eq} erosivity distribution accounts for the variation of soil erodibility.

Figure 6.15. **R_{eq} values for cropland areas in Washington, Oregon, and northern Idaho.**

"Data being updated. Map not yet available."

Figure 6.16. **R_{eq} values for cropland areas in southern Idaho and northern Utah.**

"Data being updated. Map not yet available."

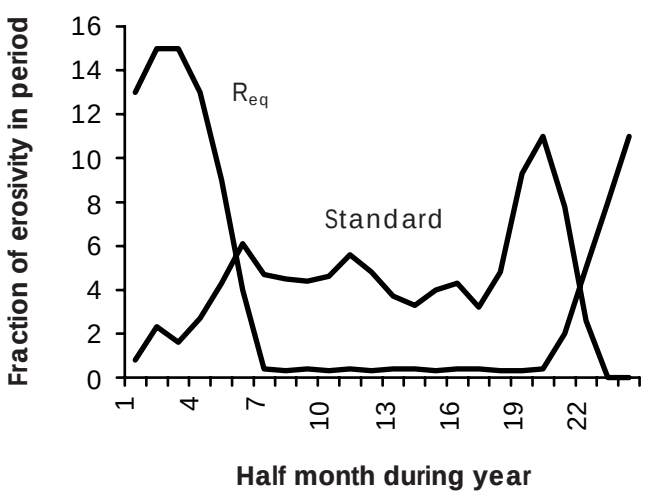
NOTE: ***The R_{eq} effect and relationships do not apply to conditions where a snow pack accumulates and remains through the winter. The R_{eq} relationships in RUSLE2 cannot be used to compute soil loss when the snow pack melts.***

Rainfall and runoff on thawing soil is common to regions like the upper Mid-South and lower Midwest regions of the U.S. that experience repeated freezing and thawing events and where much rainfall routinely occurs during the winter. Even though repeated freezing and thawing is experienced, the soil is not super-saturated by a restricting frost layer a few inches below the soil surface like that in the R_{eq} zone. The temporally varying soil erodibility factor K partially takes into account the increased erosivity during freezing and thawing.

6.1.8.2. R_{eq} Distribution

A special erosivity distribution is needed for the R_{eq} zone to account for the greatly increased erosion that occurs during the winter months. The R_{eq} erosivity distribution is shown in Figure 6.17 with the erosivity distribution based on standard erosivity computations.

Figure 6.17. **R_{eq} erosivity distribution and standard erosivity distribution for Pullman, Washington.**



6.1.8.3. Selection of RUSLE2 Climate Values for the R_{eq} Zone

Several considerations are necessary in applying RUSLE2 in the R_{eq} zone. The first consideration is whether or not to use the R_{eq} relationships. Definitely the R_{eq} relationships are used for cropland where tillage occurs annually and on disturbed areas like construction sites, reclaimed land sites, and disturbed forest lands within one year after the disturbance. The R_{eq} relationships do not apply to undisturbed lands like pasture and rangelands. Hay and similar lands where mechanical soil disturbance (cultivation) occur regularly but infrequent and as time elapses after landfill closure or reclaimed mine site grading require special consideration. The recommended approach is to assume that the transition time between the R_{eq} effect and standard erosivity effect equals the time to soil "consolidation." Erosion is computed assuming both the R_{eq} relationships and the standard erosivity relationships. A soil loss is interpolated between these two values depending on how frequently a mechanical soil disturbance occurs or how time has elapsed since a disturbance.

NOTE: ***The soil moisture relationships are unique to the R_{eq} zone and should not be used outside of the R_{eq}.***

If the R_{eq} relationships are to be used, answer **Yes** to the question **In R_{eq} area?** and **Yes** to the question **Use R_{eq} EI distribution**. The standard R_{eq} erosivity distribution that is in the RUSLE2 sample database should be used throughout the R_{eq} zone. Select the appropriate special erosivity distribution for either northwestern Colorado, southeastern Utah or southwestern Colorado. Answer **Yes** to the question **adjust for soil moisture** when the R_{eq} relationships are used in RUSLE2. The amount of moisture in the soil profile during the winter months greatly affects erosion in the R_{eq} zone. Certain management practices and crops grown ahead of the winter greatly decreases soil moisture and soil loss. Answering **Yes** instructs RUSLE to take into account these effects. Answer **No** to the question **Vary soil erodibility with climate** when the R_{eq} relationships are used. Answer **Yes** for **varying soil erodibility with climate** when the standard erosivity is used, including all areas of the U.S. - like the western U.S.

6.2. Soil

The values included in the soil component of the RUSLE2 database are listed in Table 6.3.

6.2.1. Basic Principles

Soils vary in their susceptibility to erosion. The soil erodibility factor **K** is a measure of erodibility for a standard condition. This standard condition is the unit plot, which is an erosion plot 72.6 feet (22.1 meters) long on a 9 percent slope, maintained in continuous fallow, tilled up and down hill periodically to control weeds and break crusts that form on the soil surface. The plots are plowed, disked, and cultivated, much like for a clean tilled row crop of corn or soybeans except that no crop is grown. After a unit plot is established, the first two to three years of soil loss data are not used to determine a K value to allow time for residual effects from previous cover-management to disappear, especially following high production sod, forest conditions with lots of roots and litter, or any condition with much soil biomass. About 10 years of soil loss data are required to obtain an accurate estimate of K, which is determined by fitting a straight line to soil loss values for individual storms to erosivity of the storms as illustrated in Figure 6.18.

Values of **K** are determined by fitting the equation:

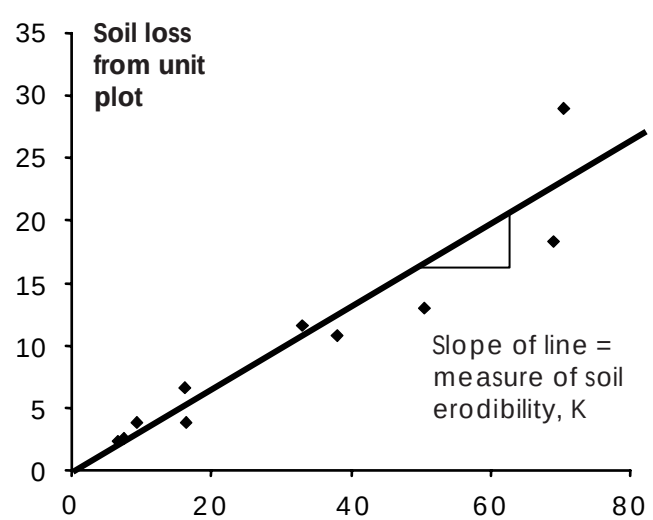
$$A_u = EI_{30}\,K \qquad \textbf{[6.7]}$$

where: $\mathbf{A_u}$ = the soil loss from the unit plot measured for an individual storm and $\mathbf{EI_{30}}$ = the erosivity of the storm that produced the soil loss. The fitting is done so that the equation passes through the origin.

Table 6.3. Variables in soil component of **RUSLE2** database.

VARIABLE	COMMENTS
Soil erodibility factor (K)	Soil erodibility factor value, preferably from NRCS soil survey. **(Note: does not include effect of rock surface cover, but does include effect of rock in soil profile.)**
Soil texture	USDA soil texture name, if sand, silt and clay content entered, RUSLE2 assigns appropriate textural class.
Sand, silt, clay content (%)	Based on USDA classification; if texture entered, RUSLE2 selects values for mid-point of textural classification for sand, silt and clay percentage.
Hydrologic soil group (undrained)	Index for potential of soil to produce runoff under unit plot conditions for undrained conditions: A (lowest runoff potential), B, C, D (highest runoff potential.)
Hydrologic soil group (drained)	Index for potential of soil to produce runoff under unit plot conditions with a high performing subsurface drainage system installed to NRCS specifications. A (low runoff potential), B, C and/or D (high runoff potential) is selected based on drainage system and soil properties **(Note: hydrologic soil group not automatically an A for drained conditions because soil properties may limit drainage.)**
Rock cover (%)	Percent of soil surface covered by rock fragments sufficiently large not to be moved by runoff; rock diameter is generally larger than 10 mm.
Calculate time to consolidation	Answer **Yes** for RUSLE2 to compute time to soil consolidation.
Time to soil consolidation	Time for erodibility of soil to decrease and level out after a mechanical soil disturbance. Enter a value or have RUSLE2 compute a time based on average annual precipitation.
Soil tolerance (T)	Soil loss tolerance value assigned by NRCS; standard for protecting soil as natural resource, not for sediment yield; another value beside T for specific conservation planning criteria.

Figure 6.18. **Measured soil loss from unit plot used to determine soil erodibility K factor.**



The unit plot provides a way to empirically determine K values for particular soils using a standard procedure, much like engineering materials are tested. Not all soils occur on a hillslope with a 9 percent steepness, which requires that Equations 6.11 - 6.13 be used to adjust measured soil loss values to the unit plot condition. Also, data from non-unit plots conditions have been used to estimate K values. Soil loss values measured from these conditions are adjusted to unit plot conditions using the equations in section 6.4 for the cover-management effect.

The soil erodibility factor K represents the combined effect of susceptibility of soil to detachment, transportability of the sediment, and the amount and rate of runoff given a particular rainfall erosivity, as measured under the standard unit plot condition. Fine textured soils high in clay have low K values, about 0.05 to 0.15 tons per acre per U.S. erosivity unit, because they are resistant to detachment.[8] Coarse

textured soils, such as sandy soils, have low K values, about 0.05 to 0.2 tons per acre per U.S. erosivity unit, because of low runoff even though these soils are easily detached. Medium textured soils, such as the silt loam soils, have moderate K values, about 0.25 to 0.45 tons per acre per U.S. erosivity unit, because they are moderately susceptible to detachment and they produce moderate runoff. Soils having a high silt content are especially susceptible to erosion and have high K values. They are easily detached, and they tend to crust, produce large amounts and rates of runoff, and produce fine sediment that is easily transported. Values of K for these soils typically exceed 0.45 tons per acre per U.S. erosivity unit and can be as large as 0.65 tons per acre per U.S. erosivity unit.

The RUSLE2 soil erodibility factor is entirely an empirical measure of erodibility and is not based on erosion processes. It is not a soil property like texture. The soil erodibility factor K is defined by the variables used to express erosivity, which is the product of storm energy and maximum 30-minute intensity. RUSLE2 K values are unique to this definition, and values based on other measures of erosivity, such as runoff, must not be assumed for K. Values for K are not proportional to erodibility factor values for other erosivity measures and may not increase or decrease in the same sequence relative to each other. For example, the RUSLE2 K value for a sandy soil is low whereas the value for an erodibility factor based on runoff is high.

Soil organic matter reduces the K factor because it produces compounds that bind soil particles and reduce their susceptibility to detachment by raindrop impact and surface runoff. Also, organic matter increases soil aggregation to increase infiltration and reduce runoff and erosion. Permeability of the soil profile affects K because it affects runoff. Soil structure affects K because it affects detachment and infiltration. Soil structure refers to the arrangement of soil particles, including primary particles and aggregates, in the soil. Soil mineralogy has a significant effect on K for some soils, including subsoils, soils located in the upper Midwest of the U.S., and volcanic soils in the tropics.

Values for K have been determined for several "benchmark" soils from experimental erosion data. Values for K can be estimated for other soils by comparing their properties with those of the benchmark soils and assigning K values based on similarities and differences in properties that affect K values. Values for K are available from the USDA-NRCS soil survey database.[9] Also, RUSLE2 includes a soil erodibility nomograph, discussed in section 6.2.2.2. that can be used to estimate K. See AH703 for additional information on the soil erodibility factor K.[10]

6.2.2 Selection of K Values

6.2.2.1 From NRCS Soil Survey

Values for K should be selected from those given in the USDA-Natural Resources Conservation Service (NRCS) soil survey. Values for K, for both topsoil and subsoil layers, are available for almost all cropland soils in the U.S. and for a limited number of soils for other land uses such as rangelands and forestlands. Values for K will not be available for soils on construction sites, landfills, or reclaimed surface mines because of the mixing of soil materials and soil-like materials associated with surface mining. The RUSLE2 soil erodibility nomograph can be used to estimate K values for these soils. RUSLE2 also includes a soil erodibility nomograph to estimate K values for volcanic-derived tropic soils.

NOTE: ***Use the K value in the NRCS soil survey where no adjustment has been made for rock cover on the soil surface but where adjustments have been made for rock in the soil profile.***

6.2.2.2. Estimating K Values with the RUSLE2 Soil Erodibility Nomograph

The RUSLE2 soil erodibility nomograph can be used to estimate K values for most soils, including those on construction sites, landfills, reclaimed surface mine sites and military training sites.[11] Table 6.4 lists the input values used with the nomograph.

The soil erodibility nomograph was derived from empirical erosion data collected from rainfall simulator 35 feet (10.7 meter) erosion plots located primarily in Indiana. The nomograph should not be extrapolated beyond the range of input values shown on the nomograph. For example, a value for organic matter greater than four percent is not recommended or allowed in RUSLE2. The definitions and variable descriptions used in the nomograph must be carefully followed.[12]

The RUSLE2 soil erodibility nomograph is based on soil properties that are location independent. A K value estimated with the RUSLE2 soil erodibility nomograph should be adjusted upward for locations having more frequent and greater rainfall than at Columbia, MO, and downward for locations where the rainfall is less

Table 6.4. Variables used in soil erodibility nomograph.

VARIABLE	COMMENTS
Clay (%)	Based on mass (weight), proportion of the total for the clay, silt and sand; clay dia ≤ 2 μm.
Silt + very fine sand (%)	Based on mass (weight), proportion of the total for the clay, silt, and sand, 2 < silt dia ≤ 50 μm, 50 < very fine sand dia ≤ 100 μm.
Inherent organic matter (%)	Based on mass (weight), proportional to the total clay, silt, sand and organic matter. **(Note: Do not use organic matter content to reflect management different from the unit plot conditions.)**
Structure	Arrangement of primary particles and aggregates in soil.
Permeability	Potential of the soil for producing runoff; reflects the entire soil profile, not just permeability of soil surface layer; and should not be determined from a permeater measurement.
Is permeability with coarse fragment present?	Permeability class selected should be selected based on rocks in soil profile; select **Yes** and RUSLE2 will estimate effect of rocks in soil under certain condition.
Coarse fragment (%)	Mass (weight) of soil made up of rock fragments > 3 in (75 mm) diameter

frequent than at Columbia.[13] For example, K values estimated using the RUSLE2 soil erodibility nomograph should be adjusted upward for Mississippi and downward for Wisconsin. RUSLE2 does not have a procedure to make this adjustment.

Organic matter is one of the major variables used in the soil erodibility nomograph. **The value used in the nomograph is the organic matter content of the soil in the unit plot condition after previous land use effects have disappeared.** Organic matter added to a soil by management practices such as adding animal manure, plowing under "green" manure, and improved residue management reduce soil erosion. This important effect is considered in RUSLE2 in the cover-management factor C, not in the soil erodibility K.[14] Adjusting K to

Table 6.5. Variables in RUSLE2 nomograph for estimating K values for tropic soils of volcanic origin.

VARIABLE	COMMENTS
Unstable aggregates (%)	Percent (%) size fraction of unstable aggregates < 0.25 mm.
Base saturation (%)	Percent (%) base saturation, percentage of cations that are not Al^{+3} or H^{+}, both of which are acidic cations, percent base saturation defines the percentage of the Cation Exchange Capacity (CEC) that is occupied by the basic cations.
Silt (%)	Fraction of silt in the total of sand, silt and clay according to USDA classification, 0.002 < silt dia ≤ 0.05 mm.
Coarse sand (%)	Fraction of coarse sand in the total of sand, silt and clay according to USDA classification, 0.5 < silt dia ≤ 1 mm.
Silt + very fine sand (%)	Fraction of silt + very fine sand in the total of sand, silt and clay according to USDA classification, 0.002 < silt dia ≤ 0.1 mm.

account for organic matter as influenced by land use is double accounting and is a misuse of RUSLE2.

Similarly, cover-management practices affect runoff, but the permeability class chosen to compute K from the soil erodibility nomograph is based on unit plot conditions. The permeability code in the nomograph should be adjusted to a class less permeable for increased runoff for naturally occurring restricting layers such as a rock, fragipan or clay layer near the soil surface. Restricting layers, like a plow pan, created by land use are not considered in selecting a permeability class in the nomograph because those layers would not be present on a unit plot.

The soil erodibility nomograph does not apply to soils of volcanic origin, organic soils such as peat, Oxisols, low activity clay soils, calcareous soils, or soils high in mica. Also, the nomograph is less accurate for subsoils than for topsoils. Professional judgment is used to assign K values for those soils. Contact the NRCS soil scientist in your state for assistance.

6.2.2.3. Estimating K Values with Erodibility Nomograph for Tropic Soils of Volcanic Origin

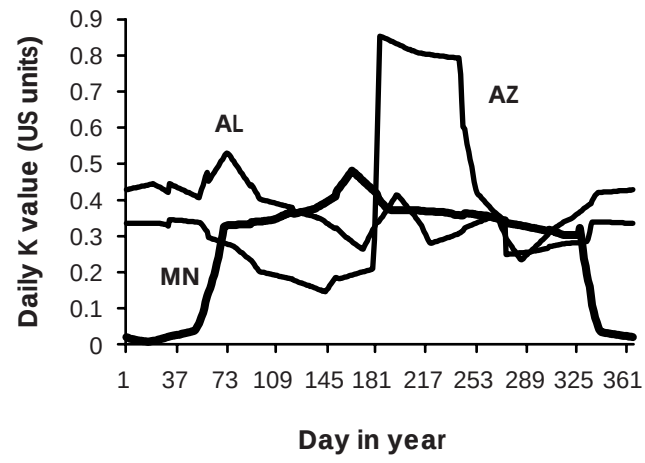
RUSLE2 includes a nomograph that can be used to estimate K values for tropic soils of volcanic origin. The variables used in that nomograph are listed in Table 6.5.

Standard procedures used to determine sand, silt and clay content do not always work well for tropic soils of volcanic origin. Some of these soils are not easily dispersed by standard techniques resulting in the apparent fractions of the silt and sand being too large. Refer to El-Swaify et al. (1982) for additional information on procedures required to disperse these soils and soil erodibility factor values for these soils.[15]

6.2.3 Temporal Variability in K

Soil erodibility K varies by season. It tends to be high early in the spring during and immediately following thawing and other periods when the soil is wet. The value entered for K is a base value. RUSLE2 uses monthly precipitation and temperature to compute monthly K values that vary about the base K value. The monthly values are "disaggregated" into daily values using the procedure described in section 6.1.7. The variation of K computed by RUSLE2 for St. Paul, MN, Birmingham, AL, and Tombstone, AZ, are shown in Figure 6.19.

Figure 6.19. **Temporally variable K factor at St. Paul, Minnesota; Birmingham, Alabama; and Tombstone, Arizona.**



The low values for St. Paul during the winter months represent frozen soil that is nonerodible. RUSLE2 does not fully represent the thawing period in early spring in St. Paul, primarily because observed data are too few to determine a relationship for this period. The peak for Birmingham in March results from rainfall rather than from temperature. The main influence of temperature on temporally varying K values is in late summer when increased temperature increases soil evaporation and reduces runoff and erosion. The peak erodibility during the summer for Tombstone is because most of the annual rainfall at the location occurs during this period.

NOTE: ***In contrast to* RUSLE1 *where the time varying soil erodibility relationships were not used in the western U.S., the temporally varying erodibility relationships should be used in the western U.S. for* RUSLE2.**

A constant erodibility value that does not vary during the year can be used in RUSLE2 by answering **No** to the question **Vary erodibility with climate** in the climate database component.

6.2.4. Soil Texture

Soil texture is the distribution of the primary particles of sand, silt, and clay in the soil based on the USDA classification. RUSLE2 uses values for sand, silt, and clay fractions to compute the distribution of the sediment particle classes at the point of detachment and the diameter of the small and large aggregate particle classes. See section 6.2.5. for a description of the sediment classes used in RUSLE2.

Table 6.6. Diameter of primary particle classes.

PRIMARY PARTICLE CLASS	DIAMETER (mm)
Clay	≤ 0.002
Silt	0.002 < dia ≤ 0.05
Sand	0.05 < dia ≤ 2
Very fine sand	0.05 < dia ≤ 0.1
Coarse sand	0.5 < dia ≤ 1

The fractions for soil texture are based on mass (weight) of the total of these three primary particle classes. The size of these classes is given in Table 6.6. Refer to the USDA-NRCS Soil Survey Manual for procedures that are to be used to determine this particle information.[16] Some soils, including tropic soils of volcanic origin, may be difficult to disperse to make these determinations.

Primary particles are the smallest discrete mineral soil particles. Primary particles are combined into aggregates, which are conglomerates of primary particles. Aggregates are larger than the primary particles that compose them, and the density of aggregates are less than the density of primary particles because of open space within aggregates. This open space can be partially filled with water, and the rate that pore space becomes filled (rate of soil wetting) greatly affects aggregate stability, soil erodibility and sediment size. Rapid wetting significantly reduces aggregate stability and soil erodibility. This effect is one reason why erosion can vary greatly among seemingly similar storms.

Values for sand, silt and clay content are for the upper soil layer susceptible to erosion, usually assumed to be 4 inches (100 mm) thick. Values for soil texture are available in the NRCS Soil Survey for soils that have been mapped and can be used in RUSLE2. Otherwise these values can be determined from mechanical analysis of soil samples according to standard procedures. RUSLE2 assigns the appropriate textural class using the values entered for sand, silt and clay content.

If the sand, silt and clay content is not known, select the soil textural class if it is known or can be determined by professional judgment, such as from feel of the soil. When a textural class is selected in RUSLE2, RUSLE2 assigns central values for sand, silt and clay content for that textural class based on the textural triangle. The values assigned by RUSLE2 are shown in Table 6.7.

6.2.5. Sediment Characteristics at the Point of Detachment

RUSLE2 computes deposition as a function of sediment characteristics, in particular as a function of fall velocity V_f in equation 5.2. Fall velocity is a function of both

Table 6.7. Sand, silt and clay contents assigned for a texural class.

TEXTURAL CLASS	SAND (%)	SILT (%)	CLAY (%)
Clay	20	20	60
Clay loam	33	33	34
Loam	41	41	18
Loamy sand	82	12	6
Sand	90	6	4
Sandy clay	51	5	44
Sandy clay loam	60	13	27
Sandy loam	65	25	10
Silt	8	87	5
Silt loam	20	65	15
Silty clay	6	47	47
Silty clay loam	10	56	34

Table 6.8. Characteristics of default sediment classes assumed by RUSLE2.

SEDIMENT CLASS	DENSITY (SPECIFIC GRAVITY)	DIAMETER (MM)	COMMENTS
Primary clay	2.60	0.002	Fraction = 0.2 (clay in soil)
Primary silt	2.65	0.010	Fraction strongly related to silt in soil
Small aggregate	1.80	0.03 to 0.1	Fraction and diameter increase with clay content in soil
Large aggregate	1.60	0.3 to 2	Fraction and diameter increase with clay content in soil
Primary sand	2.65	0.200	Fraction strongly related to sand content in soil

particle diameter and density. When soil is eroded, the sediment is a mixture of primary particles and aggregates. RUSLE2 uses the five particle classes of primary clay, primary silt, small aggregate, large aggregate and primary sand to describe sediment.

RUSLE2 computes the distribution of these five particle classes and the diameters of the small and large aggregate classes at the point of detachment as a function of soil texture.[17] In general, the fractions and diameters of the aggregate classes increase as the clay fraction in the soil increases. Clay is assumed to be a binding agent that increases aggregation. Values used by RUSLE2 for each sediment particle class are listed in Table 6.8. Fall velocity V_f in still water is computed using Stokes law for the small particle classes and standard drag relationships for the large particle classes assuming that the sediment particles are spheres.

RUSLE2 computes how deposition changes the distribution of the sediment particle classes as illustrated in Table 6.9. RUSLE2 also computes enrichment (an increase in the fraction) of sediment fines (primary clay and primary silt) when deposition occurs. RUSLE2 also computes the sand, silt, and clay content in the sediment leaving the RUSLE2 hillslope profile. For example, RUSLE2 computed that the fraction of primary clay sediment class leaving the grass filter strip after deposition was 25 percent, in comparison to 5 percent at the point of detachment.

RUSLE2 assumes that small aggregates are composed of clay and silt primary particles, and large aggregates are composed of clay, silt, and sand primary particles. RUSLE2 computes the distribution of these particles in each aggregate class as a function of soil texture. RUSLE2 also computes an enrichment ratio as specific surface area of the sediment at the lower end of the last RUSLE2 element divided by the specific surface area of the sediment at the point of detachment. The specific surface areas assumed in RUSLE2 are 20 m^2/g for clay, 4 m^2/g for silt, and 0.05 m^2/g for sand. Specific surface area indicates the relative importance of each particle class as a binding agent and for transporting soil-absorbed chemicals.

The names assigned the five sediment classes are partly arbitrary. Values for fraction, diameter, and density assigned to each class can be manually

Table 6.9. Sediment characteristics for a silt loam soil (20% sand, 65% silt, 20% clay) at detachment and after deposition by a dense grass strip.

SEDIMENT CLASS	DIAMETER (MM)	% AT DETACHMENT	% AFTER DEPOSITION
Primary clay	0.002	5	25
Primary silt	0.010	24	39
Small aggregate	0.030	36	19
Large aggregate	0.400	28	14
Primary sand	0.200	7	3

entered to over-write the values that RUSLE2 computes. Manually entering these values creates a custom sediment description. However, when these values are manually entered, RUSLE2 will not properly compute enrichment if these values are manually overwritten.

6.2.6. Rock Cover

Rock cover on the soil surface acts as ground cover and reduces erosion much like plant litter, crop residue, and applied mulch, except the rock does not decompose and add organic matter to the soil. RUSLE2 combines rock cover with other ground cover into a single value, taking into account the overlap of plant and applied materials on the rock cover. This single ground cover value is used in the equations used to compute the effect of cover-management on erosion. This overlap is the reason that values for rock cover and other ground cover cannot be added to obtain the total cover.

Also, the effects of rock and other ground cover cannot be separately computed and then multiplied to determine the total ground cover effect because of the nonlinerity in the equation used to compute the effect of ground cover on erosion. These equations are discussed in section 6.4.2.2.2.

NOTE: ***The nonlinearity in the equations used to compute the ground cover effect is the reason that a K factor value cannot be used in RUSLE2 where an adjustment has already been made for rock cover.***

Rock cover, which also includes non-decomposing surface material, is a site-specific entry based on field measurements. The same technique used to measure other ground cover like plant litter and crop residue can be used to measure rock cover.[18] To be counted as ground cover, rock must be sufficiently large not be moved by raindrop impact or surface runoff. The minimum rock size that is measured is site specific, but as a guideline, the minimum rock size is 10 mm (3/8 inch) diameter except on coarse texture rangeland soils where the minimum size is 5 mm (3/16 inch).

NOTE: ***Do not use rock cover values or rock content in the soil profile from the NRCS Soil Survey to determine rock cover.***

The appropriate time to measure rock cover is during the 1/4 to 1/3 period of the year, or during crop rotation when the slope is most susceptible to erosion. The best time to measure rock cover on cultivated land is after rainfall has exposed the rock and its influence can be readily seen.

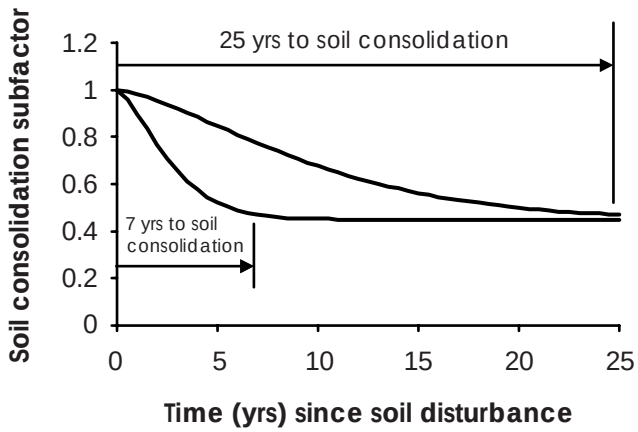
6.2.7. Hydrologic Soil Group

Hydrologic soil group is an index of the runoff potential of the soil under unit plot conditions. These designations are A (lowest potential), B, C and D (highest potential). RUSLE2 uses the hydrologic soil designation in the NRCS curve number method to compute runoff. Hydrologic soil group designations are available by map unit and component in the NRCS Soil Survey. The USDA-NRCS Hydrology Manual provides information on assigning hydrologic soil group designations for those soils not included in the NRCS soil survey.[19] The soils with the lowest runoff potential, such as deep sandy soils, are assigned an A hydrologic soil group. The soils where almost all of the rainfall becomes runoff are assigned a hydrologic soil group of D. Examples of D soils include clay where internal soil properties control infiltration and silt soils that readily crust. Soils with a naturally occurring layer like a fragipan, or rock near the soil surface, also are assigned a D hydrologic soil group.

A hydrologic soil group designation also reflects site drainage conditions. Thus, two hydrologic soil group designations are used, one for undrained conditions and one for drained conditions. Runoff potential can be high on soils because of a perched water table or a low-lying position on the slope even though soil properties would indicate a low runoff potential. Artifically draining these soils with deep parallel ditches or buried tile lines can greatly increase internal drainage and reduce runoff and erosion.

The hydrologic soil group assigned for the drained condition represents runoff potential under drained conditions based on soil properties and a drainage system based on NRCS specifications. For example, a drained sandy soil might be assigned an A hydrologic soil group, whereas a drained clay soil might be assigned a C hydrologic soil group because of properties of the clay limit drainage. RUSLE2 uses the hydrologic soil group for the drained and undrained conditions to compute the soil loss reduction caused by tile drainage. The same equations used in the soil erodibility nomograph for the effect of permeability are used in these computations by scaling the four hydrologic soil groups over the six permeability classes used in the erodibility nomograph.

Figure 6.20. Effect of time on soil consolidation for 7 and 25 years to consolidation.



6.2.8. Time to Soil Consolidation

RUSLE2 assumes that soil erodibility is 2.2 times as erodible immediately after a mechanical disturbance than after the soil has become "fully consolidated." Erosion decreases with time and "levels out" as illustrated in Figure 6.20. The time required for the erosion rate to "level out" after a mechanical disturbance is the time to soil consolidation. The erodibility of a soil fully consolidated is 45 percent of that immediately after disturbance. An exponential decay curve is used to describe this decrease in erodibility. The time to consolidation is the time when 95 percent of the decrease in erodibility has occurred.

This decrease in erodibility occurs because of wetting and drying of the soil. RUSLE2 assumes seven years for the **time to soil consolidation**, which should be used for all cropland soils, but another value can be used. Answering **Yes** to the question **Calculate time to consolidation from precipitation** causes RUSLE2 to compute a **time to soil consolidation** that is a function of average precipitation, which should be used for pasture, range, disturbed forest, construction sites, and reclaimed lands. RUSLE2 assumes seven years for the time to soil consolidation where average precipitation exceeds 20 inches (500 mm) and computes a time to soil consolidation that increases to as long as 25 years in the driest areas of the western U.S. The increased time to soil consolidation reflects how the effects of an infrequent mechanical soil disturbance persists longer in very low rainfall areas.

6.2.9. Soil Loss Tolerance (T)

The objective of conservation planning is to control average annual soil loss to a particular level, which is usually soil loss tolerance (T). Soil loss tolerance values range from 2 tons per acre (4 tons per hectare) per year to 5 tons per acre (11 tons per hectare) per year based primarily on how erosion is judged to harm the soil. Shallow and fragile soils that cannot be easily reclaimed after serious erosion are assigned low T values. Limiting soil loss to T controls erosion so that soil is protected as a natural resource and its productive capacity is maintained for an extended period. Soil loss tolerance considers the damages caused by erosion and the benefits of soil conservation.

Also, soil loss tolerance values include a socio-economic consideration by being assigned at a level that sufficient erosion control can be reasonably and profitably reached with current soil conservation technology.[20] The value entered for soil loss tolerance in RUSLE2 should be a value appropriate for the particular analysis. For example, a multiple of T was used in certain USDA conservation programs. Even if a specific absolute value is not to be used, a nonzero value must be entered so that RUSLE2 can compute the ratio of segment soil loss to T adjusted for slope position, as discussed below.

Although soil loss tolerance values were principally developed for cropland soils, T values are also used for conservation planning for reclaimed surface mines, landfills and military training sites. Controlling erosion greatly facilitates establishing vegetation. For example, applied mulch cover controls erosion and promotes seed germination and early growth of vegetation. Also, erosion control regulations for reclaimed land require that excessive rilling be prevented. A rule of thumb is that rilling begins when soil loss exceeds about 7 tons per acre (15 tons per hectare) per year, which is met by T values less than 5 tons per acre (11 t/ha) per year. A major concern on waste disposal sites is that buried waste not be exposed. Controlling soil loss to less than 5 tons per acre (11 tons per hectare) per year significantly reduces the likelihood that rill erosion will expose waste material. However, a well designed surface runoff system is required to ensure that concentrated flow does not occur and cause incised gully erosion.

Soil tolerance values are primarily for protecting the soil as a natural resource and not for protecting offsite resources from excessive sedimentation or water

Table 6.10. Soil loss along a uniform slope and convex slope of same length and average steepness.

	UNIFORM			CONVEX				
SEGMENT	STEEPNESS (%)	SOIL LOSS	SOIL LOSS/ADJ T	STEEPNESS (%)	SOIL LOSS	SOIL LOSS/ADJ T	SOIL LOSS	SOIL LOSS/ADJ T
1	6	2.50	0.99	2	1.09	0.32	0.88	0.26
2	6	4.22	1.00	4	2.85	0.65	2.29	0.52
3	6	5.29	1.00	6	5.29	1.00	4.26	0.81
4	6	6.12	1.00	8	8.44	1.40	6.81	1.10
5	6	6.84	1.00	10	13.10	1.80	10.50	1.50
	aver A for slope = 5.0			aver A for slope = 6.2			aver A = 5.0	

quality degradation. The criteria for controlling sediment yield from a site should be based on how both amount and sediment characteristics affect the resource.

The usual approach for using soil loss tolerance in conservation planning is to assume a uniform slope having a slope from the origin of overland flow to either where deposition occurs, as illustrated in Figure 5.2, or to a concentrated flow area that ends overland flow, as illustrated in Figure 5.3. These portions of the hillslope are referred to as the eroding portions. The steepness of the uniform slope is the average steepness of the slope length. Soil loss is computed for this uniform profile and compared to the soil loss tolerance (T) value for the soil. A satisfactory erosion control system is one that controls soil loss to equal to or less than the T value.

RUSLE2 can also compute erosion along nonuniform hillslope profiles by dividing their slope lengths into segments, where steepness, soil and management can be entered for each segment. RUSLE2 computes a soil loss for each segment, but these segment soil loss values cannot be directly compared to T values without first adjusting the T value for position on the slope.[21] The conservation planning objective is that each segment soil loss for a profile is equal to or less than the T adjusted for slope position. The ratio of segment soil loss to T adjusted for slope position should be equal to or less than one (1).

Table 6.10 illustrates this ratio for the uniform and convex hillslope profiles illustrated in Figure 5.3, where the average steepness for the convex profile is the same as the steepness of the uniform profile. The average soil loss for the convex profile is about 25 percent greater than the average soil loss for the uniform profile, which illustrates that assuming a uniform profile underestimates soil loss for a convex profile. The difference in the soil loss values between the profiles increases as the degree of curvature of the convex profile increases. In this example, the steepness at the end of the convex slope is about 2.5 times the average steepness of the profile.

Dividing the uniform profile into five segments illustrates how soil loss varies along a uniform profile. In this example, the soil loss on the last segment is 6.84 tons per acre, which is 1.37 times the average soil loss for the profile. Even though soil loss on the last segment is significantly greater than the average soil loss, the conservation practice for the uniform profile is assumed to be acceptable because average soil loss for the profile equals or is less than the T value. Thus, the conservation planning objective is not to reduce soil loss everywhere along the profile to T, but to reduce the average soil loss for the profile to T. Soil loss on the last segment of the convex profile is 2.1 times the average soil loss for the profile. Extra protection is needed on the convex profile to provide the same level of protection as provided on the uniform profile. When average soil loss for the convex profile is reduced to soil loss tolerance, the soil loss on the last segment is 2.1 times the soil loss tolerance while it is 1.37 times on the uniform profile.

The ratio of segment soil loss to T adjusted for slope position provides a way to compare soil loss among segments on various profile shapes so that the same level of erosion control is achieved on each profile. This ratio is constant everywhere along a uniform pro-

file, which shows that adjusting the T value for slope position treats each segment consistently. The same level of erosion protection is achieved on the convex profile as on the uniform profile when the ratio of segment soil loss to T adjusted for slope position is one or less everywhere along the profile. In the example in Table 6.10, the convex profile requires a more intense conservation practice on the last two segments than is required on the remainder of the profile because the convex profile shape accelerates erosion near its end. In this example, the average soil loss for the convex slope length must be reduced to 3.3 tons per acre to provide the same degree of protection on the last segment of the convex profile as provided on the last segment of the uniform profile.

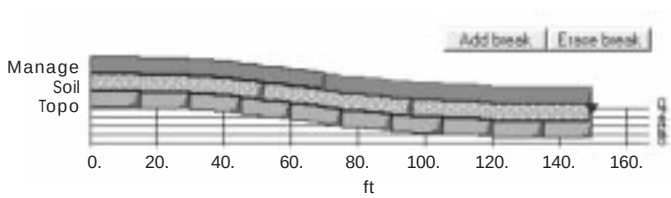
6.3. Topography

Information on topography is stored in the profile and worksheet components of the RUSLE2 database. Topographic information is field site specific in contrast to the other information in the RUSLE2 database. Topography is represented in RUSLE2 using the three layers for management, soil, and hillslope profile geometry (referred to as topography) illustrated in Figure 6.21. Segments are created for each layer by specifying the locations of the breaks between the segments. Inputs are selected for each management and soil segment, and values for steepness are entered for each segment used to describe the profile topogpraphy. Thus, RUSLE2 can consider different cover-management, soil and steepness variables along the slope, all independent of each other as indicated in Figure 6.21.

6.3.1. Basic Principles

RUSLE2 uses equation 5.4 to compute erosion variables along all hillslope profiles. For generality, assume that all RUSLE2 hillslope profiles are composed of multiple segments, like Figure 6.20. Each layer (management, soil, steepness) has its own segments. RUSLE2 assembles the segments from each of the three layers into a composite set of segments, which can be seen by using the RUSLE2 "detail, alphabetical" template. A composite segment end is located at a change in any one of the three layers.

Figure 6.21. Schematic of the three layers that represents a RUSLE2 hillslope profile.



6.3.1.1. Detachment

The computations that solve equation 5.4 start at the upper end of the hillslope profile and step down slope segment by segment, which "routes" the sediment downslope. The sediment load g_{in} entering a particular segment is known, either from the sediment load g_{out} out of the previous segment, or from being the first segment on the profile, where incoming sediment load is zero.

The amount of sediment detached (sediment produced) within a segment is computed with the equation:

$$D = r\,k\,S\,c\,P_c\,(x_i^{m+1} - x_{i-1}^{m+1})/[\lambda_u^m\,(x_i - x_{i-1})] \qquad \textbf{[6.8]}$$

where: **D** = detachment (mass/area), **r** = erosivity factor, **k** = soil erodibility factor, **S** = slope steepness factor, **c** = cover-management factor, $\mathbf{P_c}$ = contouring factor, $\mathbf{x_i}$ = distance to lower end of the segment, $\mathbf{x_{i-1}}$ = distance to the upper end of the segment, λ_u = length of the unit plot (either 72.6 feet or 22.1 meters), and **m** = slope length exponent. All variables are assumed to apply for the *ith* day and for a particular segment without explicitly showing subscripts except for segment number.

The slope length exponent m is computed from:

$$m = \beta/(1 + \beta) \qquad \textbf{[6.9]}$$

where: β = ratio of rill to interrill erosion, which in turn is given by:

$$\beta = \left[\frac{k_r}{k_i}\right]\left[\frac{c'_r}{c'_i}\right]\left[\frac{\exp(-0.05\,G_c)}{\exp(-0.025\,G_c)}\right]\left[\frac{(\sin\theta/0.0896)}{\left[3(\sin\theta/0.896)^{0.8}+0.56\right]}\right] \qquad \textbf{[6.10]}$$

where: the term $\mathbf{k_r/k_i}$ = the ratio of rill erodibility to interrill erodibility; $\mathbf{c'_r/c'_i}$ = the ratio for below ground effects for rill and interrill erosion, respectively; $\mathbf{\exp(-0.05G_c)/\exp(-0.025G_c)}$ = ratio of the ground cover effect on rill and interrill erosion, respectively; $\mathbf{(\sin\theta/0.0896)/[3(\sin\theta/0.896)^{0.8}+0.56]}$ = the ratio of slope effects for rill and interrill erosion, respectively; θ = slope angle; and $\mathbf{G_c}$ = percent ground cover.[22] The ratio k_r/k_i is computed as a function of soil texture where

the ratio is assumed to decrease as clay increases because clay makes the soil resistant to rill erosion. The ratio increases as silt increases because silt decreases the resistance of soil to rill erosion. The ratio c'_r/c'_i is computed as a function of soil biomass and soil consolidation to represent how rill erosion decreases as both soil consolidation and biomass increase. The term $\exp(-0.05G_c)/\exp(-0.025G_c)$ represents how ground cover has a greater effect on rill erosion than on interrill erosion. The term $(\sin\theta/0.0896)/[3(\sin\theta/0.896)^{0.8}+0.56]$ represents how slope steepness has a greater effect on rill erosion than on interrill erosion.

Equations 6.9 and 6.10 are not used when the R_{eq} relationships are used. A constant value of 0.5 is used for m for the R_{eq} zone.

The slope steepness factor is computed from:

$$S = 10.8 \sin\theta + 0.03 \qquad s<9\% \qquad \textbf{[6.11]}$$

$$S = 16.8 \sin\theta - 0.50 \qquad s\geq 9\% \qquad \textbf{[6.12]}$$

for all areas except the R_{eq} zone, where Equation 6.13 is used.

$$S = (\sin\theta/0.0896)^{0.6} \qquad s\geq 9\% \qquad \textbf{[6.13]}$$

The slope steepness factor S has a value of 1 for a 9 percent slope. Values for the S factor are less than 1 for slope steepness less than 9 percent, and greater than 1 for slope steepness greater than 9 percent. The slope steepness effect in RUSLE2 adjusts the soil loss values from the unit plot up or down depending on whether or not the field hillslope profile is steeper or flatter than the 9 percent steepness of the unit plot. Similarly, the slope length effect in RUSLE2 adjusts soil loss from the unit plot up or down depending on whether the slope length in the field is longer, or shorter than the unit-plot length of 72.1 feet (22.1 meters). Although Equations 6.10 - 6.13 are only a function of slope steepness, cover-management affects how slope steepness affects soil loss. However, neither empirical data nor theory are sufficient for incorporating those effects into RUSLE2 as a tool to guide conservation planning.

The slope length effect in RUSLE2 is used to compute detachment by position on the slope rather than being a slope length factor as in RUSLE1 and the USLE. Soil loss values in RUSLE2 are determined by integrating Equation 5.4 along the slope, where the slope length term in Equation 6.8 computes detachment for a segment where detachment is a function of the position of the segment along the hillslope profile. Also, the slope length term in RUSLE2 is a function of the amount of rill erosion relative to interrill erosion, which is expressed in the slope length exponent m. Interrill erosion is assumed to be caused by raindrop impact and is assumed to be independent of position along the hillslope profile. Rill erosion is assumed to be caused by surface runoff and is assumed to vary linearly along the profile because of the accumulation of runoff along the profile. The variation in the slope length exponent m in Equation 6.8 between 0 and 1 reflects the relative contribution of rill and interrill erosion. The exponent m is near zero when almost all of the erosion is by interrill erosion, such as on a flat slope, and m is near one when almost all of the erosion is from rill erosion, such as on a bare, steep slope. Cover-management also affects the slope length exponent m, because soil consolidation and soil biomass is assumed to reduce rill erosion more than interrill erosion and ground cover is assumed to reduce rill erosion more than interrill erosion. Therefore, just as RUSLE2 differs from RUSLE1 and the USLE in the temporal integration of factors, RUSLE2 also differs from them in the spatial integration and interrelationships of the factors. For example, the slope length factor in the USLE is independent of cover-management effects, but a change in cover-management conditions in RUSLE2 affects both cover-management and slope length factor values.

6.3.1.2. Sediment Transport Capacity

Sediment transport capacity (T_{cup} and T_{clow}) is computed at both the upper (x_{i-1}) and lower (x_i) ends of each segment using equation 5.2 and the discharge rates and slope steepness at the segment ends. The slope steepness at a segment end is the average of the segment steepness with the steepness of the adjacent segment. Equation 5.2 is based on the principle that transport capacity is related to shear stress applied to the soil by runoff where the variable K_T is a function of Manning's n, which is a measure of hydraulic roughness. Total shear stress of the runoff is divided between that acting on the soil and that acting on the roughness elements of standing live and dead vegetation, ground cover including live ground cover, plant litter, crop residue, and applied mulch, as well as surface roughness. The shear stress acting on the soil decreases as hydraulic roughness from cover and roughness increase. RUSLE2 computes values for

Manning's n as a function of the variables standing live and dead vegetation, ground cover and surface roughness.

Total shear stress of the flow is computed from the product of discharge (flow, runoff) rate and slope steepness, which is a measure of runoff erosivity. Runoff rate is computed from:

$$q = q_{i-1} + \sigma(x - x_{i-1}) \quad \textbf{[6.14]}$$

where: **q** = runoff rate (volume/width time), $\mathbf{q_{i-1}}$ = discharge rate at x_{i-1}, and σ = excess rainfall rate (rainfall rate - infiltration rate). Excess rainfall rate is computed using the NRCS runoff curve number method that computes runoff depth. RUSLE2 assumes that runoff rate is directly proportional to runoff depth computed by the curve number method.[23] RUSLE2 computes curve number values as a function of surface roughness, ground cover, soil biomass and degree of soil consolidation to represent the effect of cover-management on runoff. In general, RUSLE2 computes a decrease in runoff as these variables increase, except for soil consolidation that is interrelated with soil biomass. If soil biomass is very low, soil consolidation increases runoff (a characteristic of bare construction sites) and decreases runoff when soil biomass is high (a characteristic of high production pastures). The curve number method is configured within RUSLE2 to compute negative values for σ, so that runoff can decrease within a segment to represent runoff entering an area where infiltration exceeds rainfall. The runoff variable used in Equation 5.2 for q is a ratio of runoff at the location divided by runoff at Columbia, MO, for a moderate yielding clean-tilled continuous corn. Columbia is used a reference point because it is centrally located in the U.S. and represents "typical" weather values in the eastern U.S.. The clean-tilled corn represents a reference cover-management system.

6.3.1.3. Sediment Routing

Several cases must be considered in routing the sediment downslope (i.e., solving Equation 5.4 sequentially by segment starting at the upper end of the hillslope profile). In each case, a potential sediment load at the lower end of the segment is computed as:

$$g_{pot} = g_{in} + D(x_i - x_{i-1}) \quad \textbf{[6.15]}$$

where: $\mathbf{g_{pot}}$ = potential sediment load at the lower end of the segment (mass/width) and **D** = detachment on the segment (mass/area).

6.3.1.3.1. Case 1: Detachment over the Entire Segment

Detachment occurs over the entire segment when the transport capacity T_{cup} at the upper end of the segment is greater than the incoming sediment load g_{in} and the transport capacity T_{clow} at the lower end of the segment is greater than the potential sediment load g_{pot} at the lower end of the segment. Sediment load at the lower end of the segment is given by:

$$G_{out} = g_{in} + D(x_i - x_{i-1}) \quad \textbf{[6.16]}$$

where: **D** = detachment computed from Equation 6.8. Examples of this case occur on uniform and convex shaped hillslope profiles and the upper end on a concave profile. Profile shapes are discussed in section 6.3.2.

> **NOTE:** ***The proper mathematical solution for RUSLE2 is where output values are independent of the number of segments used to describe uniform portions of a hillslope profile. This criterion is met in RUSLE2 for the case where detachment occurs, but not where deposition occurs. The sediment load becomes finer with deposition along a slope segment, which is described in RUSLE2 by dividing those segments experiencing deposition into sub-segments. The RUSLE2 solution is an approximate one that is a function of the number of sub-segments. The number of sub-segments used in RUSLE2 is to choose the number to provide sufficient accuracy while minimizing computational time.***

6.3.1.3.2. Case 2: Deposition over the Entire Segment

RUSLE2 computes deposition over the entire segment when the incoming sediment load (g_{in}) exceeds transport capacity (T_{cup}) at the upper end of the segment and the segment is short (as illustrated in Figure 6.22), or when detachment D within the segment exceeds the increase in transport capacity with distance within the segment ($D > dT_c/dx$). The amount of sediment D_a that is deposited within the segment is computed with an equation derived from Equation 5.2. Sediment load at the lower end of the segment is computed from:

$$g_{out} = g_{in} + D_a(x_i - x_{i-1}) \quad \textbf{[6.17]}$$

RUSLE2 divides segments where deposition occurs into sub-segments where the sediment characteristics are updated along the segment as deposition occurs.

Figure 6.22. Narrow grass strip where deposition occurs over entire segment.

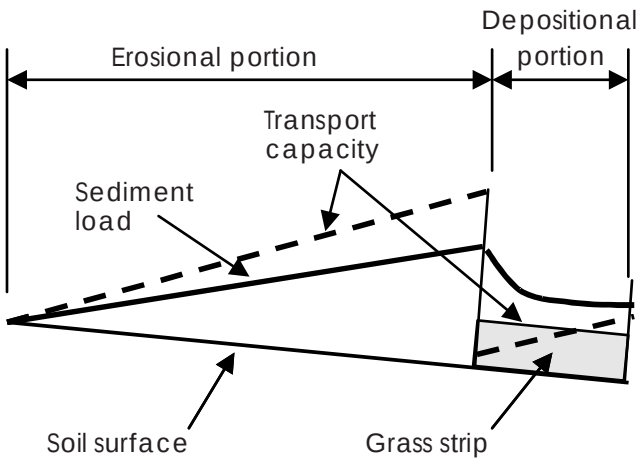
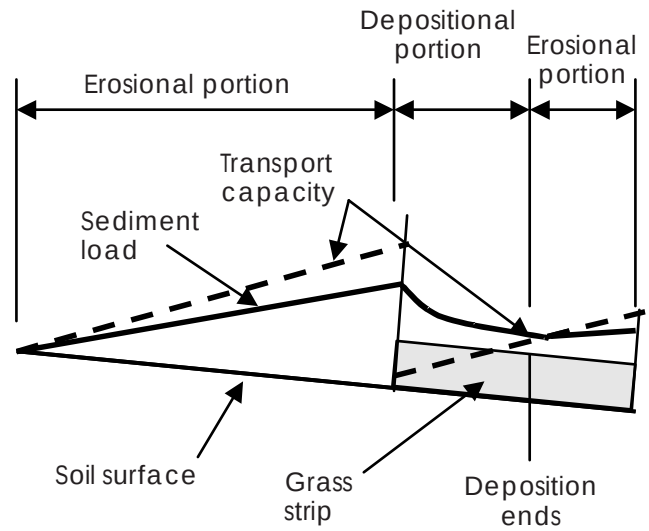


Figure 6.23. Grass strip sufficiently wide that deposition ends within segment and erosion occurs on lower portion of segment.



Deposition enriches the sediment load in fines, resulting in reduced deposition downslope. An example of this case is deposition in a narrow grass strip.

6.3.1.3.3. Case 3: Deposition Ends within the Segment

If the segment is sufficiently long (the grass strip is sufficiently wide) and the increase in transport capacity with distance is less than the detachment ($dT_c/dx < D$), deposition ends within the segment as illustrated in Figure 6.23. Sediment load exceeds transport capacity at the upper end of the sediment and transport capacity increases within the segment. RUSLE2 computes the location x_e, where deposition ends and sediment load equals transport capacity. Sediment load at the end of the segment is computed from:

$$g_{out} = g_{xe} + D_{>xe}(x_i - x_e) \quad \textbf{[6.18]}$$

where: $\mathbf{g_{xe}}$ = sediment load at the point where deposition ends and $\mathbf{D_{>xe}}$ = detachment on the lower end of the segment beyond the point where deposition begins, which is the sub-segment from x_e to x_i. Detachment $D_{>xe}$ is computed using Equation 6.8 where x_e is substituted for x_{i-1}.

6.3.1.3.4. Case 4: Deposition Begins within the Segment

Deposition begins within a segment when the transport capacity at the upper end of a segment is greater than sediment load ($T_{cup} > g_{in}$) and transport capacity at the end of the segment is less than the sediment load at the upper end plus the sediment production that potentially might occur within the segment ($T_{clow} < g_{pot}$). The location where deposition begins is designated as x_b, and the sediment load at that point is designated as g_b. RUSLE2 computes the deposition $D_{p>xb}$ on the lower portion of the segment beyond the location x_b, where deposition begins using the equations that compute deposition. The sediment load at the end of the segment is computed as:

$$g_i = T_{cxb} + D_{p>xb}(x_i - x_b) \quad \textbf{[6.19]}$$

where: T_{cxb} = transport capacity (and sediment load) at the location x_b where deposition begins. This case occurs on the lower end of concave hillslope profiles, where transport capacity decreases with distance along the profile and becomes less than sediment load. This case can also occur when rainfall and runoff rates are very low and the runoff enters a strip with a very high infiltration so that runoff rate and transport capacity decrease within the strip. If transport capacity decreases to below sediment load, deposition occurs within the segment.

6.3.1.4. Computing Soil Loss by Segment and Sediment Yield from Profile

RUSLE2 computes sediment load at the lower end of each segment. The sediment load at the end of the last segment is the sediment yield for the hillslope profile. Sediment yield is typically expressed in units of mass/area (tons/acre or t/ha), averaged over the length of the hillslope profile, assuming a unit width. Sediment yield is computed as sediment load at the end of the profile divided by the slope length. Soil loss

Figure 6.24. **Deposition begins within a segment on a convave slope.**

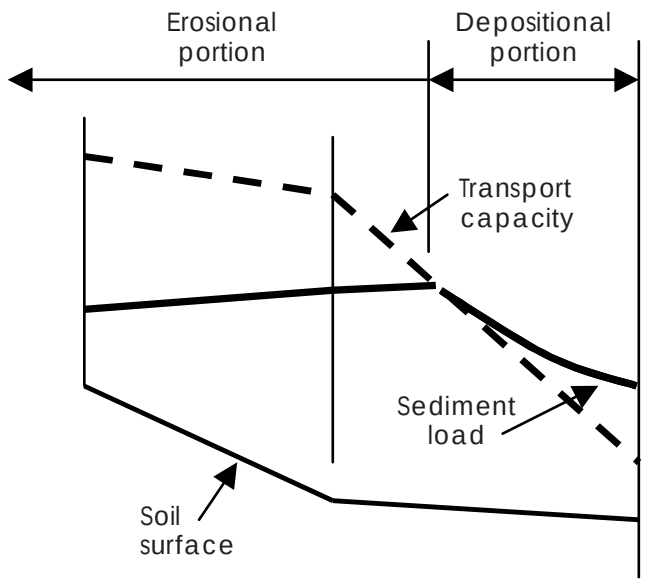
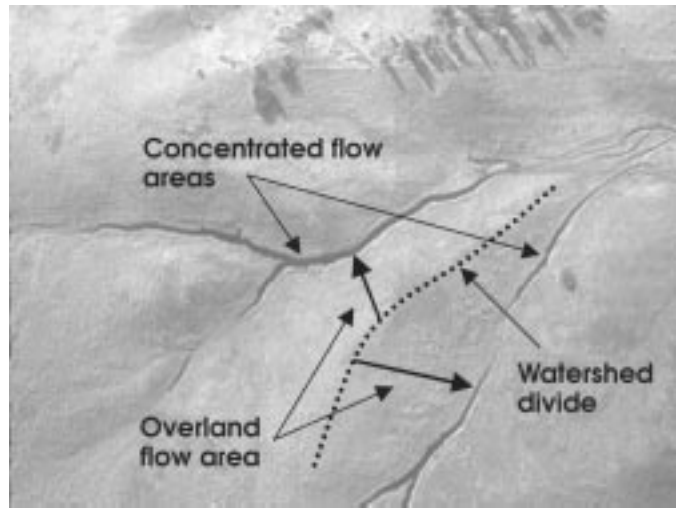


Figure 6.25. **A natural landscape with concentrated flow areas and divides where overland flow originates.**



for each segment is computed as:

$$a_i = (g_{out} - g_{in})/(x_i - x_{i-1}) \quad \textbf{[6.20]}$$

where: $\mathbf{a}_i$ = soil loss for the *ith* segment (mass/area). A positive value means that the segment experiences a net loss of sediment (detachment) and a negative value means that the segment experiences a net gain of sediment (deposition). Even though either net detachment or net deposition occurs for a segment, a part of the segment can experience net detachment while another part experiences net deposition, such as illustrated in Figures 6.23 and 6.24.

6.3.2. Representing Hillslope Profiles

6.3.2.1. General Considerations

A hillslope profile is selected and described in RUSLE2 to make a soil loss computation. Once the point on the landscape through which the hillslope profile is to pass is determined, the path of overland flow is traced from the origin of overland flow through the point to a concentrated flow area as illustrated in Figures 5.1 and 6.25. This flow path is traced perpendicular to the contour lines assuming the surface is flat without regard to how microtopography, such as ridges left by tillage, affects flow direction.

Overland flow path lengths are best determined by visiting the site, pacing flow paths and making measurements directly on the ground. Contour maps having intervals greater than 2 feet (1 meters) should be used cautiously, if at all, to determine profile lengths. Contour maps based on 10 feet (3 meter) intervals should not be used to determine profile lengths because these concentrated flow areas that end overland flow cannot be adequately delineated. Also, these maps do not provide the detail needed to identify depositional areas. Profile lengths are generally overestimated when contour maps are used to determine profile length.

Slope length and steepness values have, in some cases, been assigned to soil mapping units. These values may be acceptable for large scale regional conservation planning, but they should not be used for local conservation planning. Slope steepness varies over too wide of a range to be sufficiently accurate for conservation planning on a specific field site.

Profile lengths on many landscapes generally are less that 250 feet (75 meters), and usually do not exceed 400 feet (125 meters). Profile lengths longer than 1,000 feet (300 meters) should also not be used in RUSLE2 because the reliability of RUSLE2 at these long slope lengths is questionable—and overland flow often becomes concentrated on most landscapes before such lengths are reached. The longest plot used in the derivation of RUSLE2 was about 650 feet (200 meters). Allowing a 1,000 foot (300 meter) profile length is a generous extrapolation.

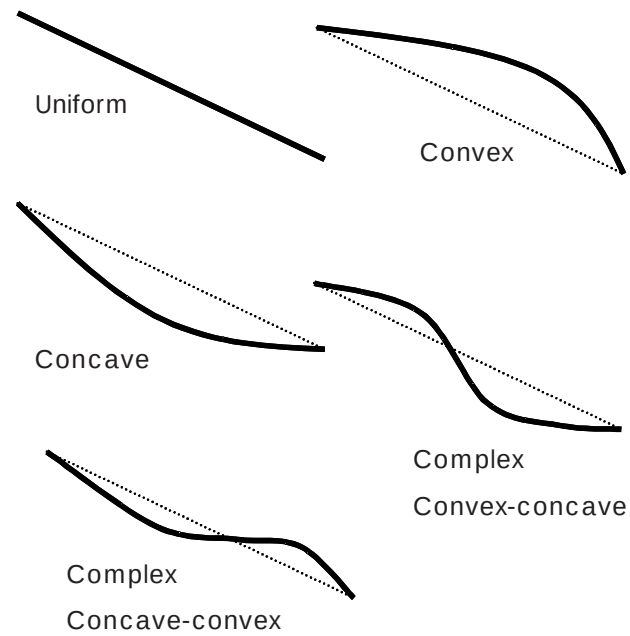
No minimum profile length exists for use in RUSLE2. A slope length as short as 0.001 feet (0.01 inches, 0.2 mm), which is essentially zero, can be used in RUSLE2 to represent beds and ridges as discussed in section 6.3.2.8.

Correspondingly, the maximum slope steepness that can be entered in RUSLE2 is 100 percent, which is a generous extrapolation from 30 percent—the maximum steepness of the plots used to derive RUSLE2.

RUSLE2 internally uses distance variables, including segment lengths, distance to lower end of segment, and overland flow path length in its computations as a horizontal measure. Measuring distance along a hillslope profile is easier in the field than measuring horizontally. However, distance measured from maps is a horizontal measure. The difference in the two measurements is small for slope steepness less than 20 percent.

NOTE: ***Either a horizontal or an "along-the-slope" measure of distance variables can be used to enter and display distance variables in RUSLE2.***

Figure 6.26. **Hillslope profile shapes.**



6.3.2.2. Profile Shapes

Hillslope profiles have various shapes as illustrated in Figure 6.26. Simple shapes are uniform, concave, and convex. A uniform shaped profile is one where steepness is the same everywhere along the profile. A convex profile is one where steepness increases everywhere along the profile from the upper to lower end. RUSLE2 computes detachment occuring everywhere along uniform and convex profiles such that the entire profile is an eroding hillslope. A concave profile is one where steepness decreases everywhere from the upper to lower end of the profile. If the lower part of a concave profile flattens sufficiently, transport capacity decreases to less than sediment load, and deposition occurs. These profiles have an upper eroding portion and a lower depositional portion. However, if the profile does not flatten sufficiently, deposition will not occur, and the entire profile is an eroding hillslope. That is, deposition does not occur on all concave shaped profiles.

Complex shaped hillslope profiles are composed of sections of the simple shapes. A complex convex-concave profile is one where the upper end is convex and the lower end is concave. Deposition occurs on the concave portion of the profile if steepness flattens sufficiently for transport capacity to become less than sediment load. If deposition occurs, the upper part of the profile is an eroding portion, and the depositional area is the depositional portion. Another complex shaped profile is the complex concave-convex profile. Deposition can occur on the concave portion if it flattens sufficiently. Runoff can flow across the depositional area onto the lower convex portion. If deposition occurs, this profile has an upper and lower eroding portion separated by the depositional portion.

6.3.2.3. Uniform Profile

In general, the best approach is to carry the overland flow path to a concentrated flow area and represent the entire hillslope profile, even if deposition occurs on the profile. RUSLE2 computes soil loss on the eroding portion of the slope and deposition on the depositional portion of the slope. However, the main application of RUSLE2 is conservation planning, where soil loss on the eroding portion of the slope is control to a rate less than the conservation planning criteria, which is usually soil loss tolerance (T), in the particular application. Also, RUSLE2 is used as a guide, not the decision making tool used to develop the conservation plan. In this application, an easy-to-make soil loss estimate is desired rather than the detailed analysis of the hillslope; and the eroding portion is represented with a uniform profile, as illustrated in Figure 5.2, where slope length ends at the location where deposition begins, and the steepness of the uniform profile is the average steepness of the eroding portion of the hillslope profile. In the case of convex profiles that have only an erod-

ing portion and not a depositional portion, as illustrated in Figure 5.3, the slope length is taken to a concentrated flow area and the steepness of the uniform profile is the average steepness of the convex profile.

When RUSLE2 is applied to a complex profile, like the one in Figure 5.2, a determination of where deposition begins must be made. The upper edge of deposition is visible and readily apparent on cropland soils susceptible to erosion, like a clean-tilled field where an erosive storm has occurred during the seedbed period. However, signs of deposition may not be visible where erosion and deposition are low because of heavy cover. Whether or not deposition occurs, and where it occurs, depends on the curvature of the profile. Deposition may not occur if the curvature is slight, and deposition may not occur even if the profile is strongly concave because of low erosion rates relative to the amount of runoff. For example, if the steepness of a profile decreases from 4 percent to 2 percent, most likely the 2 percent area would not be a slope length-ending depositional area. However, if the steepness upslope from the 2 percent area is 6 percent or more, the 2 percent area is most likely a slope-ending depositional area. If the upslope area is as steep as 10 percent, the slope length-ending depositional area may be as steep as 3 percent. The slope length-ending depositional area on a concave profile is usually located further down the slope than where the profile begins to flatten on a complex convex-concave profile. That is, unless the slope flattens significantly, deposition does not occur.

Figure 6.27. **Rule of thumb for location of upper edge of deposition on a concave profile.**

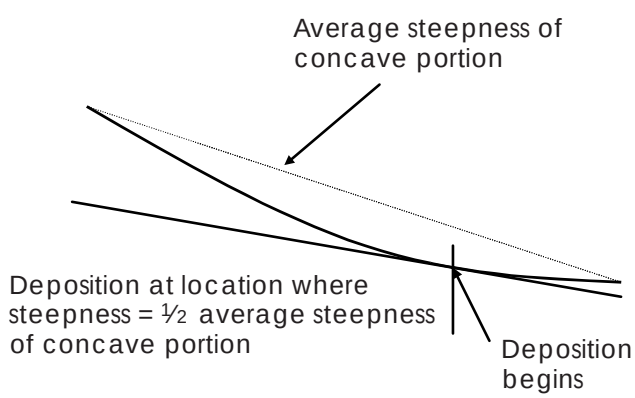


Figure 6.27 illustrates a "rule of thumb" to guide selecting a location where deposition begins. Deposition is assumed to begin where the steepness of the profile is one half of the average steepness of the concave portion of the profile. For example, assume a concave profile that decreases from 18 percent steepness at the upper end to 2 percent steepness at the lower end. The average steepness is 10 percent, and one half of the average steepness is 5 percent. Deposition begins at the location where the slope has flattened to a steepness of 5 percent, which would be about 20 percent of the way up the profile.

For a second example, assume a concave profile that decreases from 4 percent at the upper end to 2 percent at the lower end. The average steepness is 3 percent, and one half of the average steepness is 1.5 percent. Since the steepness at the lower end is greater than the steepness where deposition would occur, no deposition is assumed to occur on this slope.

Another approach that can be used to estimate where deposition begins is to enter the entire hillslope profile in RUSLE2 and let RUSLE2 compute the location where deposition begins. Deposition is indicated by negative soil loss values for the segments where deposition occurs. The location of the upper most segment having deposition is the location where deposition ends.

When a uniform shaped profile is used, a single segment is used to describe slope steepness (topography layer). The soil and management layers can be divided into as many segments as desired to describe variability along the profile. However, when a uniform shaped profile is assumed to simplify analysis, simplifying assumptions are also made for the soil and management layers. A single soil and a single management are assumed for the profile. Uniform width and spaced strips of a particular management can be placed on the profile to represent filter and buffer strip systems, as well as rotational strip cropping as support practices. The "field office simple slope" template is selected to use the simple, uniform slope option in RUSLE2.

Although a uniform slope is often used in conservation planning, it underestimates soil loss on convex shaped profiles and overestimates soil loss on concave shaped profiles. The difference is related to the degree of curvature. While representing nonuniform shaped profiles is preferred, proper interpretation of computed soil loss values is complex. See section 6.2.9 for additional discussion.

6.3.2.4. Complex Convex-Concave Profile

Figure 5.2 is a complex convex-concave hillslope profile. This profile is represented in RUSLE2 by dividing

Table 6.11. **Soil loss and sediment load along a complex convex-concave slope.**

DISTANCE TO LOWER END OF SEGMENT (FT)	SEGMENT LENGTH (FT)	SLOPE STEEPNESS (%)	SOIL LOSS (TONS/ACRE)	SEDIMENT LOAD (LBS/FT WIDTH)
0				0
28	28	2	4	5.2
64	36	4	11	23
107	43	8	28	78
149	42	6	25	126
181	33	4	-1.2	124
218	36	2	-29	76
250	32	1	-21	44

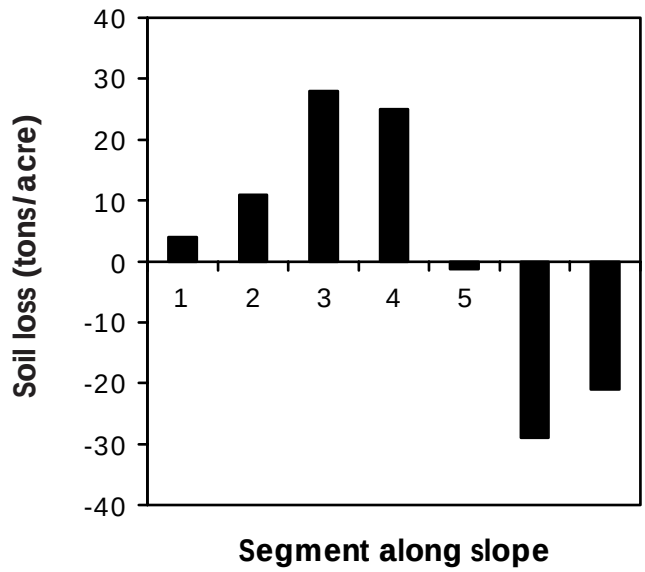
Sediment yield = 3.8 tons/acre

the steepness (topo) layer in several segments as illustrated in Figure 6.21. The potential for deposition always exists on concave shaped sections. More segments are needed to describe concave sections where deposition occurs than sections, convex or concave, where net detachment occur. The steepness of the last segment where deposition occurs should be chosen especially well because that segment can a great effect on sediment yield from the profile. Nonuniform shaped hillslope profiles can be analyzed using the RUSLE2 "field office summary" template and using the "add break" icon, illustrated in Figure 6.21, to create breaks at the locations where segments end.

Table 6.11 illustrates the entries and computed values for a complex convex-concave profile like that illustrated in Figure 5.2. Soil loss and sediment load are plotted in Figures 6.28 and 6.29. Positive soil loss values for a segment in Figure 6.28 indicate net detachment, while negative values indicate net deposition. Increase (positive slope) in sediment load with distance in Figure 6.29 indicates net detachment, and a decrease (negative slope) in sediment load with distance indicates net deposition.

Sediment yield from the profile is 3.8 tons per acre (8.4 tons per hectare), which is the sediment delivered from the site only if the RUSLE2 hillslope profile ends at the boundary of the site. RUSLE2 overland flow profiles typically end in concentrated flow areas (illustrated in Figures 5.1 and 6.25) that are within the boundary of the site being analyzed. Both erosion (ephemeral gully) and deposition can occur in the concentrated flow areas, so the sediment delivered from the overflow portion of the landscape—the sediment yield computed by RUSLE2—is a poor indicator of the sediment yield from the site.

Figure 6.28. **Soil loss along a complex convex-concave hillslope profile.**



The eroding portion of the profile extends from the origin of the profile to between 149 and 181 feet (45 and 55 meters), as can be determined from Table 6.11. RUSLE2 computes the soil loss on this portion of the slope as 18 tons per acre (40 tons per hectare). By

Figure 6.29. **Sediment load along a complex convex-concave hillslope profile.**

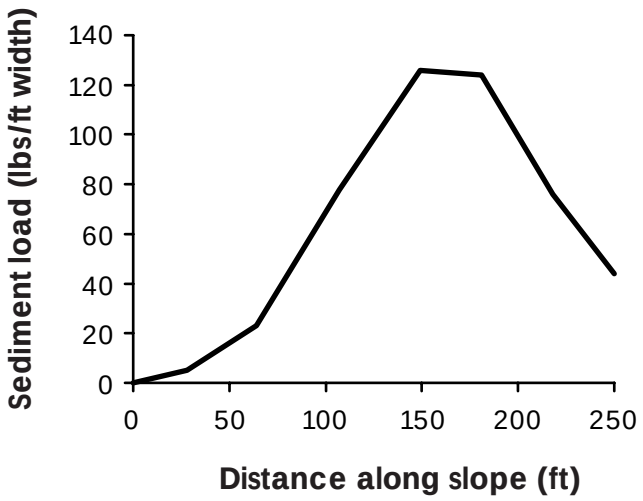
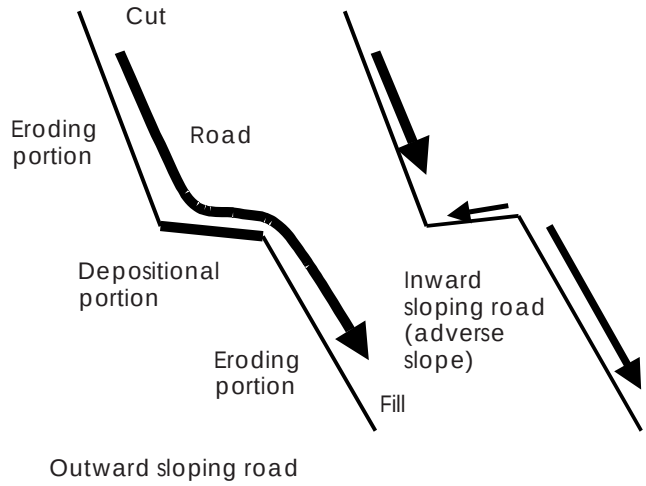


Figure 6.30. **Cut-road-fill hillslope illustrating how an inward and outward sloping road section effects overland flow path lengths and that deposition on the outward sloping road does not end overland flow path length.**



entering the complex profile, RUSLE2 automatically computes where deposition begins and computes the soil loss on the eroding portion of the slope. (See section 6.3.1.4 for information on soil loss and sediment yield type variables computed by RUSLE2 that are useful in conservation planning).

6.3.2.5. Complex Concave-Convex Profile

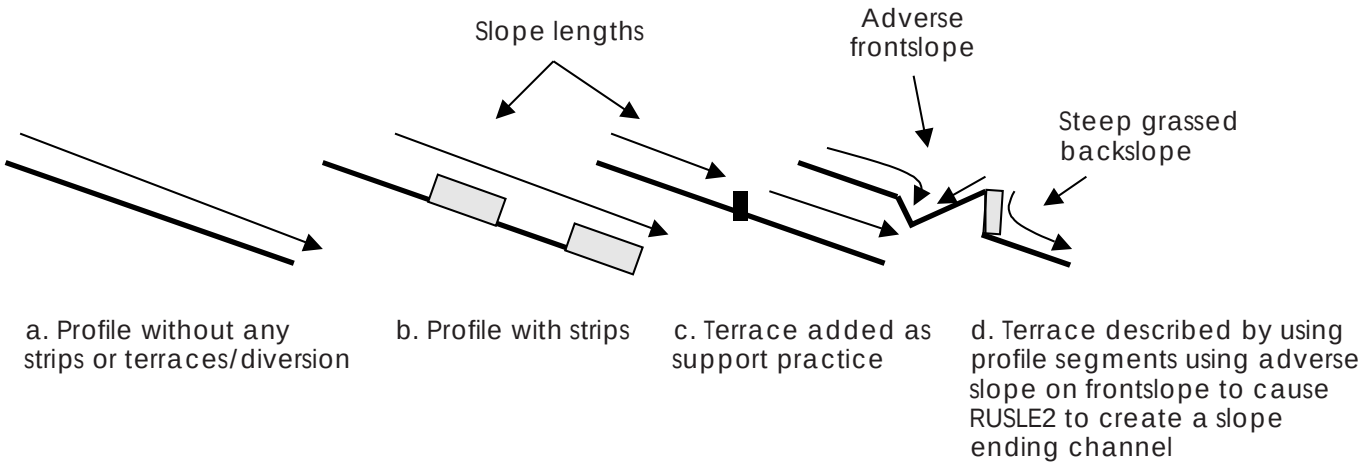
The cut-road-fill hillslope illustrated in Figure 5.4 approximates a complex concave-convex profile. Runoff from the cut slope is assumed to flow across the road onto the fill slope even though deposition occurs on the road. This deposition does not end slope length so far as computing soil loss from the fill slope. This hillslope profile is represented in RUSLE2, as illustrated in Table 6.12. Deposition is computed, as expected, on the relatively flat outward sloping road (Segment 2) and a much higher soil loss is computed on the fill slope (Segment 3) than on the cut slope (Segment 1) because of the greater runoff on the fill slope than on the cut slope.

Soil loss on the cut slope can be significantly reduced by intercepting and diverting runoff from flowing over that slope segment. A diversion could be placed at the top of the fill slope, a procedure illustrated in the following landfill example, but deposition would still occur on the road, which is undesirable. A better solution is to construct the road so that it slopes inward on adverse slope, as illustrated in Figure 6.30. This profile configuration can be obtained in RUSLE2, as illustrated in Table 6.12, by entering a negative steepness value for that segment. Sloping the road inward creates three slope lengths, one each for the fill slope, road and cut hillslope segments. RUSLE2 analyzes both profiles in Figure 6.30 without having to break the analysis

Table 6.12. **Soil loss on a cut-road-fill slope.**

SEGMENT #	DISTANCE TO LOWER END OF SEGMENT (FT)	SEGMENT LENGTH (FT)	SEGMENT TYPE	STEEPNESS (%)	SOIL LOSS (TONS/ACRE)	SEGMENT TYPE	STEEPNESS (%)	SOIL LOSS (TONS/ACRE)
1	75	75	fill	33	162	fill	33	162
2	95	20	outward sloping	2	-493	inward sloping	-2	5.8
3	170	75	cut	33	353	cut	33	162
			Sediment yield = 169 tons/acre			Sediment yield = 143 tons/acre		

Figure 6.31. How vegetative strips and terraces are described in RUSLE2 and how these practices affect slope lengths assumed by RUSLE2.



into parts. Segments that describe each hillslope profile are entered into RUSLE2, and RUSLE2 correctly handles the overland flow path lengths.

Entering an adverse slope for the road causes RUSLE2 to create a channel at the intersection of the cut slope and the road, intercepting runoff from the cut slope and collecting runoff from the road. The runoff on the fill slope originates at the top of the fill slope. The sediment yield for the two profiles in Figure 6.30 is the total sediment delivered from each profile.

6.3.2.6. Overland Flow Path Lengths with Grass Strips and Terraces

The approach used to analyze a hillslope profile where grass strips or terraces are added as a support practice is to first describe the hillslope profile without the strips or terraces. Even though grass strips induce deposition, the overland flow path length does not end at the deposition because the runoff continues through the strip as overland flow. A hillslope profile with multiple grass strips that induce deposition has only one overland flow path length, as illustrated in Figure 6.31b. **Deposition at a grass strip does not end the path length with a new one beginning below the strip.**

NOTE: ***Cover-management segments do not end overland flow slope lengths.***

RUSLE2 ***creates a channel (concentrated flow area) a segment with a positive slope and one with a negative (adverse) slope. This channel ends the overland flow path length.***

In contrast, terrace and diversion channels intercept runoff in concentrated flow areas that end overland flow path length. A new path length begins at the terrace ridge because that is where overland flow originates that flow across the next download terrace interval. Terraces and diversions can be described in one of two ways in RUSLE2. One approach is used in most conservation planning. RUSLE2 assumes that the terrace/diversion channel and ridge are infinitely thin, as illustrated in Figure 6.28c. This approach is used in RUSLE2 in those templates where terraces/diversions are added as a support practice. The other approach is to describe the actual hillslope profile configuration, including the cover-management on each segment, such as the grass on the steep backslope. The overland flow path length is the path length without the terraces/diversions. The segments are added to create the profile illustrated in Figure 6.28d. RUSLE2 automatically creates a channel where segments with a positive and a negative (adverse) steepness intersect. This channel ends the overland flow path. RUSLE2 determines the appropriate slope lengths without the analysis having to be broken into parts.

RUSLE2 can compute the deposition that occurs in a terrace or diversion channel, but it cannot compute the erosion that might occur in these channels and similar concentrated flow areas.

6.3.2.7. Diversion to Intercept Runoff above Steep Slopes

Erosion is high at the end of convex shaped hillslope profiles and where runoff from a long slope flows onto a steep slope like the sideslope of a landfill. Placing a diversion at the top of the sideslope, as illustrated in

Figure 6.32. Landfill with relatively flat top and steep side slope, with and without a diversion.

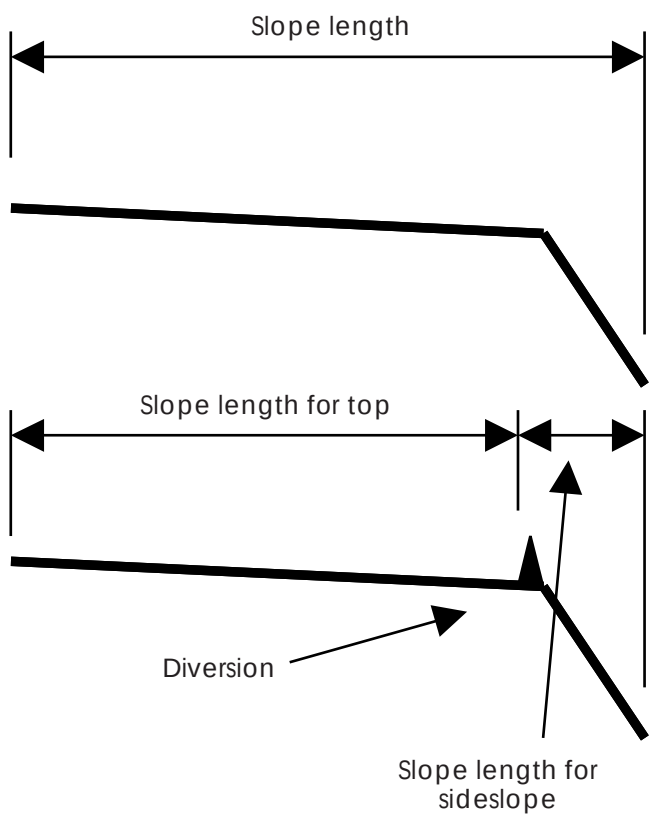


Figure 6.33. Ridge and bed systems.

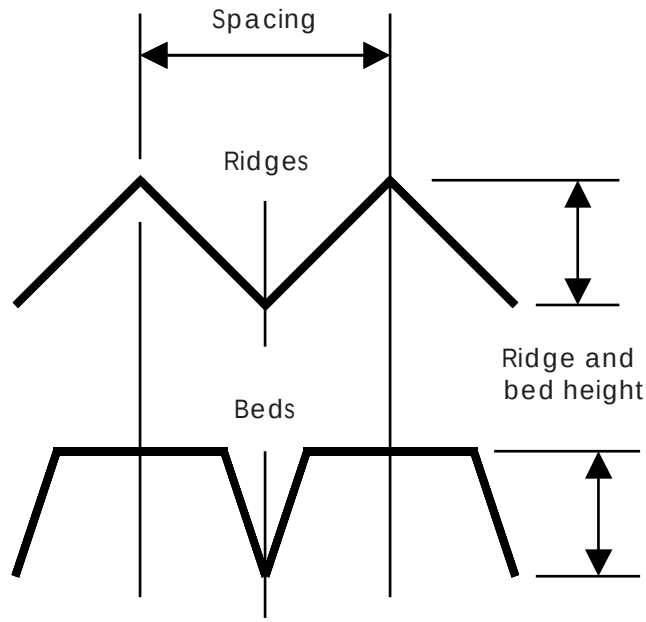


Figure 6.32, is an effective practice for reducing soil loss on the steep slope, as shown in Table 6.13. The entire hillslope description is entered into RUSLE2 and then a diversion is applied at the top of the steep sideslope. RUSLE2 automatically ends the slope length for the relatively flat top slope and begins a new slope length at the top of the steep sideslope. As expected, the diversion did not reduce soil loss on the top of the landfill, but significantly reduces soil loss on the sideslope.

6.3.2.8. Ridge-Furrow Description

RUSLE2 can accommodate slope lengths as short as 0.001 feet (0.01 inch, 0.25 mm)—which is essentially a zero slope length—and allows application of RUSLE2 to ridge-furrow and bed systems, like those used in vegetable production and illustrated in Figure 6.33. RUSLE2 can also analyze the placement and removal of plastic on parts of the beds. The overland flow path length for both the ridge-furrow and bed systems is one half of the spacing of the ridges and beds. In this example, 20 percent is assumed for the steepness of the ridge sideslope, and 1 percent is assumed for the steepness of the top of the beds and 50 percent is assumed for the steepness of the bed sideslope. An adverse steepness (negative values) is used for the segments on one side of the beds. The positive steepness of one sideslope intersecting with the negative (adverse) steepness on the adjacent ridge or bed causes RUSLE2 to create a channel that ends the overland flow path length. The grade assumes for the default channel is so steep that no deposition occurs. However, the actual grade can be entered so that RUSLE2 can compute deposition that occurs in the

Table 6.13. Soil on a landfill with and without a diversion at the top of the steep sideslope.

SEGMENT	DISTANCE TO END OF SEGMENT (FT)	STEEPNESS (%)	SOIL LOSS (TONS/ACRE) WITH DIVERSION	SOIL LOSS (TONS/ACRE) WITHOUT DIVERSION
1	250	2	9	9
2	300	33	538	130

furrows between the ridges or beds. Configuring the ridges and beds as the overland flow path and "hillslope profile" is used when the ridges and beds are so high that flow is unquestionably contained in the furrows between the ridges and beds until it reaches a well defined concentrated flow area (see Table 6.14). RUSLE2 can also compute the deposition that occurs in the furrows, but not any erosion by flow in them.

This method of configuring ridges and furrows should not be used to represent the ridges and furrows left by common tillage equipment like tandem disks, chisel plows, and field cultivators. With these implements, row breakovers and travel distances of the flow in the furrows between breakovers are random and vary between a few feet and a few 10's of feet, and the location of the breakovers cannot be definitively determined after the ridges are formed but before an erosion event. This situation is one where the usual contouring relationships apply in RUSLE2. The overland flow path is determined assuming a flat soil surface so that runoff flows perpendicular to the contour lines.

RUSLE2 does not give the same results for both approaches. The approach of explicitly describing the configuration of the ridges and beds works when the ridges contain the flow until a major well-defined concentrated flow area is reached. Although RUSLE2 can estimate deposition in furrows on a relatively flat grade, RUSLE2 cannot estimate erosion in the furrows, which RUSLE2 has represented as channels.

6.3.3. Influence of Upslope Areas

RUSLE2 is sometimes applied to a field site that is downslope from an area that contributes runoff to the site. The recommended approach is to represent the entire overland flow path even though the upslope area is not a part of the analysis area. The soil loss computed for the downslope area should not be compared to soil loss tolerance, but to the procedure described in section 6.2.9., where a ratio of soil loss to T value adjusted for position on the slope is computed. A conservation practice should be chosen that reduces this ratio to one (1).

RUSLE2 takes into account cover-management conditions on an upslope area for computing transport capacity on downslope segments where cover-management is quite different from the upslope area. However, RUSLE2 does not fully take into account how reduced runoff from the upslope area reduces detachment on the downslope segment. In some applications, RUSLE2 is applied to a field downslope from an upslope area that is very different from the field. The following approach can be used to take into account how reduced runoff from the upslope segment affects detachment on the downslope segment. If runoff production on the upslope segment is less than that on the downslope segment, the overland flow path length to the upper edge of the downslope segment should be shortened. An example is an undisturbed forest on the upslope area where the overland flow path length begins at the upper edge of the site because no surface runoff is assumed to occur from the undisturbed forest. If the upslope area is pasture and only produces half the runoff that a downslope field produces, the overland flow path length at the upper edge of the field should be one half the distance of the slope length across the pasture area.

Conversely, if the upslope area produces more runoff than does the field, the overland flow path length at the upper edge of the field should be greater than the actual distance in proportion to the differences in runoff potential for the two areas.

Table 6.14. **Soil loss for ridges and beds.**

RIDGES				BEDS			
SEGMENT #	SEGMENT LENGTH (FT)	STEEPNESS (%)	SOIL LOSS (TONS/ACRE)	SEGMENT #	SEGMENT LENGHT (FT)	STEEPNESS (%)	SOIL LOSS (TONS/ACRE)
1	1.5	20	20	1	0.9	1	3
2	1.5	-20	20	2	0.6	50	27
				3	0.6	-50	3
				4	0.9	1	27
Soil loss = 20 tons/acre				Soil loss = 13 tons/acre			

6.4. Cover- Management

6.4.1. Basic Principles

Equation 6.7 estimates soil loss for the unit plot, which is a fallow (no vegetation) condition periodically tilled up and down slope to break the crust and to control weeds. This special condition is used to define and determine soil erodibility factor values (see section 6.2.1.). Equation 6.7 is RUSLE2's starting point for computing soil loss. A cover-management factor c is introduced to "adjust" the unit plot soil loss to represent the site-specific field conditions where RUSLE2 is being applied. The cover-management factor c in Equation 6.8 represents how soil (other than that represented by the unit plot condition), vegetation, and residue (material on and in the soil) affect soil loss. The cover-management factor c is the main factor, among other factors, that RUSLE2 uses to represent how land use and management affect soil loss. For example, land use and management also affect RUSLE2's topographic factor as described in section 6.3.1.

NOTE: RUSLE2 ***uses an index-based method to estimate soil loss rather than explicitly modeling erosion processes.*** **RUSLE2** ***describes the effects of erosion processes without mimicking the processes. As a consequence,*** **RUSLE2** ***involves specific definitions and rules that must be followed, even when logic suggests something different.***

The cover management factor c is a soil loss ratio, which is soil loss from the given cover-management condition divided by the soil loss from a unit plot at the same location on the same soil and slope length and steepness as the site-specific field condition. This soil loss ratio describes how cover-management affects both erosivity and erodibility. For example, vegetation affects erosivity by reducing the erosive forces applied to the soil by raindrop impact and surface runoff. Both live and dead roots and organic material in the soil increase infiltration, which reduces erosivity by reducing runoff. These materials affect erodibility by decomposing in the soil to produce chemical bonding agents that increase the soil's resistivity to detachment. Soil mechanical disturbance that creates a very rough soil surface that ponds water reduces the erosivity of both raindrop impact and surface runoff. Large soil clods that form the roughness peaks reduce erodibility by being resistant to detachment in comparison to a mechanical disturbance that finely pulverizes the soil. Thus, the effects of erosivity and erodibility are included in other RUSLE2 factors besides the erosivity and erodibility factors in Equation 6.7.

RUSLE2 is powerful because it is land use independent. It can be applied to any land use where mineral soil is exposed to raindrop impact and overland flow is generated by rainfall intensity exceeding infiltration rate, commonly referred to as Hortonian overland flow. RUSLE2 can be applied to crop, pasture, hay, range, disturbed forest, mined, reclaimed, construction, landfill, waste disposal, military training, park, wild and other lands. RUSLE2 does not apply to undisturbed forestlands and lands where no mineral soil is exposed and surface runoff is produced by a mechanism other than rainfall excess. Because RUSLE2 is land use independent, it not only applies to a broad range of conditions, it also applies to transitions between land uses. For example, a lightly disturbed military training site may behave much like a pasture or rangeland, a moderately disturbed site may behave like a cropped field, and a highly disturbed site may behave like a very rough construction site. A "fresh" landfill and a recently reclaimed mine site not yet vegetated may behave like a freshly graded construction site, but become like pasture or range land over time. In contrast, models that are limited to specific land uses typically do not produce the same soil loss values where two land uses come together, which is not a problem with RUSLE2.

A subfactor method used in RUSLE2 to compute values for the cover-management factor c gives RUSLE2 its land use independence. This method uses subfactors that are universally important in how any cover-management system affects interrill and rill erosion. The RUSLE2 subfactors, listed in Table 6.15, are canopy, ground cover, soil roughness, ridge height, soil biomass, soil consolidation,[24] and antecedent soil moisture. Land use and management affect one or more of these subfactors. RUSLE2 assigns a value to each subfactors for each day and uses Equation 6.21 to compute a value for the cover-management factor c in Equation 6.8.

$$c = C_c G_c S_r R_h S_b S_c A_m \qquad \textbf{[6.21]}$$

where: $\mathbf{C_c}$ = canopy subfactor, $\mathbf{G_c}$ = ground cover subfactor, $\mathbf{S_r}$ = soil roughness subfactor, $\mathbf{R_h}$ = ridge height subfactor, $\mathbf{S_b}$ = soil biomass subfactor, $\mathbf{S_c}$ = soil consolidation subfactor and $\mathbf{A_m}$ = antecedent soil moisture subfactor.

Table 6.15. Subfactors Used to Represent Cover-Management Effects in RUSLE2.

SUBFACTOR	SYMBOL	COMMENTS
Canopy cover	C_c	Influence of above ground vegetative material not in contact with soil surface, includes both live and dead vegetation.
Ground cover	G_c	Material in contact with soil surface, includes both live and dead plant material and other material like mulch and manure applied to the soil surface.
Soil (surface) roughness	S_r	Random roughness created by a mechanical soil disturbance, includes peaks and depressions that are randomly shaped and located without an orientation to runoff direction.
Ridge height	R_h	Formed by a mechanical soil disturbance, creates furrows between ridges that redirect flow if not oriented up and down hill.
Soil biomass	S_b	Includes plant and other organic material in the soil that have been incorporated by a mechanical soil disturbance, grown there as live roots that become dead roots, or moved into the soil by worms or other organisms.
Soil consolidation	S_c	Refers to how a mechanical soil disturbance loosens the soil to increase soil loss and the degree to which soil loss has decreased following a mechanical soil disturbance.
Antecedent soil moisture	A_m	Used in the NWRR, refers to how previous vegetation has reduced soil moisture so that runoff and erosion is decreased later on (see section 6.1.8.).

6.4.2. Cover-Management Subfactors

This section describes each cover-management subfactor and how RUSLE2 computes a value for each subfactor.

6.4.2.1. Canopy

Canopy is live and dead vegetative cover above the soil surface that intercepts raindrops but does not contact the surface runoff. The portion of the **above ground plant biomass** touching the soil surface is treated as **live ground cover.**

6.4.2.1.1. Canopy Effects

The canopy intercepts raindrops. Some of the intercepted rainfall reforms as waterdrops that fall from the canopy. The erosivity of these drops is directly related to their impact energy. The impact energy of a waterdrop is one half of the produce of mass, determined by drop diameter, and the square of impact velocity, determined by fall height. In contrast to raindrops that vary over a wide size range, water drops falling from a canopy are all nearly of an equal size (about 3 mm) that is significantly larger than the median raindrop size (about 1.5 mm). Even though the mass of each waterdrop falling from a canopy is greater than the mass of most raindrops, the impact velocity of waterdrops falling from canopy is generally much lower than the impact velocity of raindrops because of the low fall heights from plant canopy. However, if the bottom of the canopy is greater than about 30 feet (10 meters), the erosivity of waterdrops falling from canopy is greater than that of raindrops because of the increased mass of the drops falling from the canopy.

Some of the rainwater intercepted by the canopy flows along stems to the soil surface. While this water has no erosivity to detach soil particles by waterdrop impact, it provides water for runoff, but the delay caused by the water flowing along the stems to the soil surface reduces peak runoff rate, which in turn reduces runoff erosivity. Dense canopies retain a significant amount of water that never reaches the ground because it is evaporated after the storm. While this water is not significant for large storms, it can significantly reduce runoff amounts for small storms. Finally, transpiration, which is related to the leaf area of the canopy, reduces soil moisture, which in turn increases infiltration and reduces runoff.

The equation used to compute a value for the canopy subfactor is:

$$C_c = 1 - f_c \exp(-0.1 h_f) \qquad \textbf{[6.22]}$$

where: $\mathbf{f_c}$ = canopy cover (fraction) and $\mathbf{h_f}$ = effective fall height (feet).

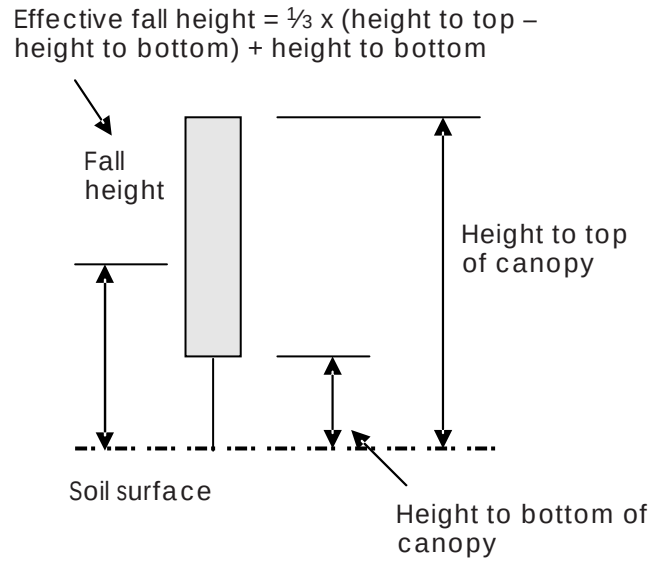
6.4.2.1.2. Canopy Cover

The two canopy variables of fraction (percent) of the soil surface covered by canopy in plan view and effective fall height are used to describe the effect of canopy on soil loss. The fraction of the soil surface covered by canopy is 1 minus the fraction of open space, which is the space through which a raindrop can fall to the soil surface without being intercepted by the plant canopy. Open space can be seen by looking down on the canopy from above and identifying the open space between the outer perimeter of the individual plant canopies and the open space within the outer perimeter of individual plant canopies.

6.4.2.1.3. Effective Fall Height

Waterdrops fall from various heights within the plant canopy, and some of the drops are intercepted by lower canopy. The total impact energy of these waterdrops is the sum of the impact energy of each drop that falls from canopy to the soil surface. Effective fall is the single fall height that gives the total energy if all drops fell from a single height. Effective fall height varies with plant maturity and shape, density gradient with the canopy, and heights to the top and bottom of the canopy. If the canopy shape is cylindrical and canopy density is uniform with height, the fall height is assumed to be one third of the way up from the bottom of the canopy as illustrated in Figure 6.34. The lower than average height reflects the likelihood that waterdrops falling from higher in the canopy are intercepted by lower canopy.

Figure 6.34. **Effective fall height for a cylindrical shaped canopy of uniform density.**



Canopy shape and density gradient of the canopy material with height affects effective fall height because of how lower canopy can intercept waterdrops falling from higher in the canopy. Effective fall height is low where the canopy material is concentrated low in the canopy because of shape and density gradient as illustrated in figures 6.35 and 6.36. If most of the leaves and branches of the plant are concentrated in the upper portion of the canopy, the effective fall height is one-half to two-thirds of the distance from the bottom to the top of the canopy. RUSLE2 includes a procedure that uses the graphical

Figure 6.35. **Effect of canopy shape on fall height.**

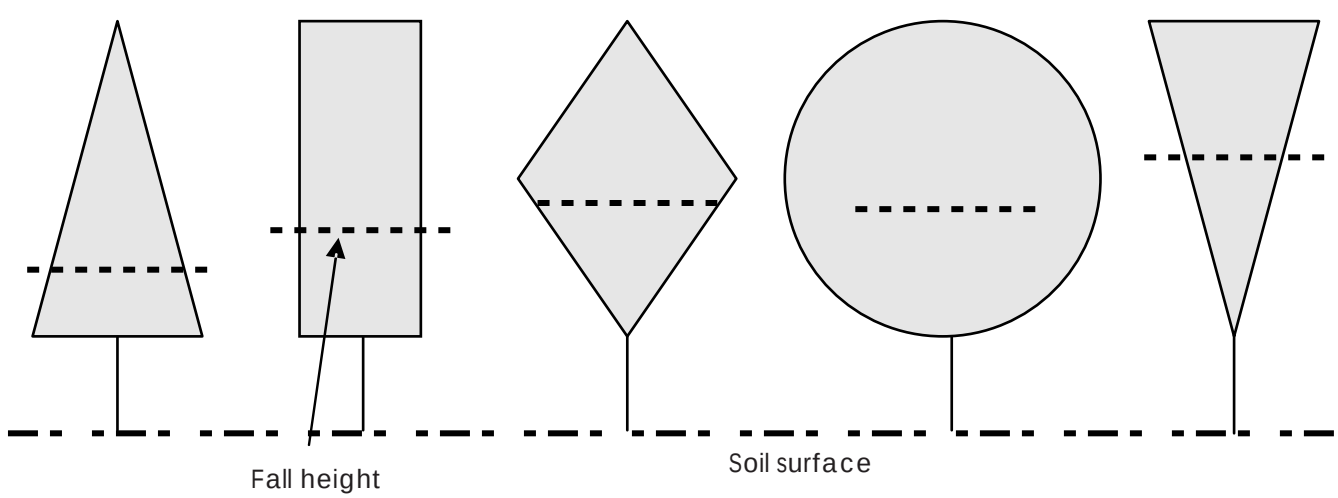
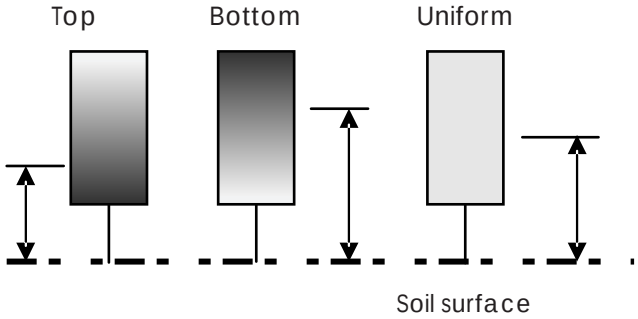


Figure 6.36. Effect on canopy density distribution on fall height.



shapes of these figures to assist in the assigning of effective fall height for any particular vegetation throughout its growth.

Fall height can also be measured by using a transect, where a rod is lowered through the canopy to the ground at regular intervals along the transect. The height to the lowest part of the canopy touching the rod is measured. Because the effect of fall height in Equation 6.22 is non-linear, the heights cannot be averaged to determine an effective fall height. The proper appr-oach is to compute a canopy subfactor value using Equation 6.22 using each height and assuming that $f_c = 1$. These subfactor values are averaged and the effective fall height is computed from:

$$h_{fe} = -\ln(1 - C_{ca})/0.1 \qquad \textbf{[6.23]}$$

where: $\mathbf{h_{fe}}$ = effective fall height (feet) and $\mathbf{C_{ca}}$ = average canopy subfactor.

NOTE: RUSLE2 ***describes a single plant community at any point in time using a single value for each variable. That is,*** **RUSLE2** ***cannot take components of a plant community and aggregate values for each component part into a composite value. The user directly assigns the composite value.***

6.4.2.1.4. Understory

Some plant communities have distinct canopy components of over and understories. Examples include: grass under shrubs on a rangeland; grass under vines on a vineyard; a legume interseeded in a small grain; a rye cover crop interseeded in corn; and volunteer weeds that begin to grow as crops approach maturity. Where multiple types of plants having different canopy characteristics grow together, consideration must be given to overlapping canopy in determining an effective fall height. The understory is often dominant in determining fall height especially if the understory is dense.

6.4.2.1.5. Interaction With Ground Cover

The portion of the canopy that is above ground cover (see section 6.4.2.2) is assumed to have no effect. Thus, the effective canopy cover is computed from:

$$f_{ce} = f_c\,(1 - f_g) \qquad \textbf{[6.24]}$$

where: $\mathbf{f_{ce}}$ = effective canopy cover (fraction) and $\mathbf{f_g}$ = portion of soil surface cover by ground cover (fraction). Equation 6.24 causes the canopy cover effect to equal the ground cover effect when fall height becomes zero.[25]

6.4.2.1.6. Effect of Production Level (Yield)

Values are entered in the vegetation component of the RUSLE2 database to describe how vegetation variables, including canopy vary through time for a particular yield (production level). RUSLE2 adjusts values for canopy and other vegetation variables for the yield appropriate for the specific site where RUSLE2 is being applied. Thus, a vegetation description is not required for each yield.[26] RUSLE2 assumes that canopy cover varies with the square root of yield and fall height with yield to the 0.2 power. However, RUSLE2 does not vary plant values as a function of population or row spacing. The effects of row spacing are considered in RUSLE2 by having a vegetation description for each row spacing. If canopy characteristics vary significantly between crop varieties, plant communities, or management practices, a vegetation description must be constructed to reflect each significant difference.

NOTE: RUSLE2 ***does not "grow" vegetation as a plant model "grows" vegetation. The user describes vegetative growth by entering values in the vegetation component of the*** **RUSLE2** ***database as plant variables like canopy vary through time.***

Values for above ground biomass at maximum canopy are entered in RUSLE2, so that RUSLE2 can compute above ground biomass as a function of canopy cover values through time.[27]

6.4.2.1.7. Senescence

Canopy cover increases during the growth period when plants are accumulating above ground biomass. As plants approach maturity, some vegetation, like soybeans and perennial grasses, lose canopy

NOTE: ***RUSLE2 assumes that any decrease in canopy cover within a vegetation description is senescene. Any change in canopy cover associated with an operation is handled by the values used to describe that particular operation.***

cover by senescence, and other plants, like cotton, lose canopy cover by being defoliated with chemicals. This loss of canopy cover transfers biomass from standing vegetation to plant residue (litter) on the soil surface. Once canopy material falls to the soil surface, RUSLE2 begins to compute its decomposition. Some plants, like corn, lose canopy cover by leaves drooping without falling to the soil surface, which RUSLE2 also considers.

The other way that canopy is lost is by operations that remove live biomass or remove residue after the vegetation has been killed. Harvest, shredding, mowing, grazing, burning and frost are operations that typically reduce canopy cover. See section 6.4.2.5.1. for a description of how RUSLE2 represents canopy loss by operations.

6.4.2.1.8. Assigning Values for Canopy

Core values for canopy and other plant characteristics are given in Appendix ?? (Not available in this draft). Core values are used as a guide in assigning values to new vegetation descriptions entered in the RUSLE2 database.

6.4.2.2. Ground Cover

Ground cover, which is material in contact with the soil surface, slows surface runoff and intercepts raindrops and waterdrops falling from the canopy. Ground cover includes all material that touches the soil surface. Examples are rock fragments, portions of live vegetation including basal area and plant leaves that touch the soil, crypto-gams, crop residue, plant litter, and applied materials, including manure, mulch and manufactured erosion control products like blankets. Ground cover is probably the single most important variable in RUSLE2 because it has more effect on soil loss than almost any other variable, and applying ground cover is the simplest, easiest and most universal way of reducing soil loss.

NOTE: ***Operations in RUSLE2 do not affect rock cover treated as a part of the soil and entered in the soil component of the RUSLE2 database. Rock fragments added as an external residue are manipulated just as any other "residue" by operations in RUSLE2.***

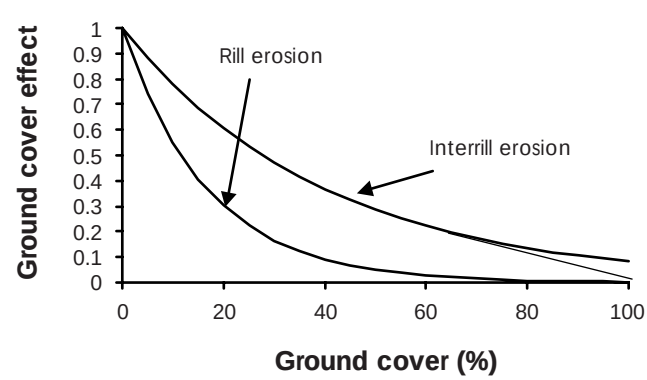
To be counted as ground cover, the material must remain in place and not be moved downslope by surface runoff during a rainstorm. Also, the material must contact the soil surface sufficiently well that runoff does not flow between the material and the soil to cause erosion. Rock fragments on the soil surface are a special case. Generally, rock fragments must be larger than 5 mm with coarse textured soils in arid and semi-arid regions where runoff is low, and larger than 10 mm in other regions, to be counted as ground cover. Rock fragments on the soil surface can be treated in one of two ways. They can be considered to be a part of the soil, and a rock cover value is entered in the soil component of the RUSLE2 database (see section 6.2.6). Rock fragments can also be "applied" as an "external residue" (material added to the soil surface or placed in the soil).[28]

6.4.2.2.1. Ground Cover Effect

Ground cover reduces soil loss by protecting the soil surface from direct raindrop impact, which reduces interrill erosion. Ground cover also slows surface runoff and reduces its detachment and transport capacity, which reduces rill erosion. If ground cover is low (less than about 15 percent), and ground cover pieces are long and oriented across slope, ground cover reduces soil loss by causing deposition in numerous small ponds behind ground cover pieces. As ground cover increases, deposition ends and ground cover reduces runoff detachment capacity, which reduces rill erosion. The ground cover effect for both interrill and rill erosion is illustrated in Figure 6.37.

Ground cover reduces rill erosion more than interrill erosion. That is, the ground cover subfactor is less for rill erosion than for interrill erosion for a given ground cover percent as illustrated in Figure 6.37. The net or overall effectiveness of ground cover depends on the

Figure 6.37. **Effect of ground cover on rill and interrill erosion.**



relative contributions of rill and interrill erosion. The ground cover subfactor value is reduced when rill erosion makes the greater contribution to soil loss.

Factors that affect the relative contributions of rill and interrill erosion affect the ground cover subfactor. These variables include soil condition, ground cover ("residue") type, and the anchoring and bonding of ground cover to the soil. Obviously, ground cover provides the greatest erosion control when it is well anchored and bonded to the soil, which occurs most often on cropland. Conversely, ground cover (mulch) is least effective on construction sites where mulch pieces bridge across soil roughness so that runoff flows under the mulch and where poorly anchored mulch is moved by runoff. RUSLE2 partially represents these effects by giving greater credit to ground cover when increased soil biomass is present.

These entirely mechanical effects reduce the forces applied to the soil by waterdrop impact and surface runoff. An indirect effect is ground cover's effect on infiltration and runoff. Infiltration rate can be very high and runoff low on a freshly tilled soil without a surface seal.[29] If ground cover is placed on the soil before a crust is formed, the ground cover will reduce seal formation and will help maintain high infiltration and low runoff. Thus, ground cover has a lesser effect on reducing soil loss when placed on a soil after it becomes crusted or placed on a soil where internal soil properties, such as a high clay content or high bulk density, control infiltration. A given amount of ground cover reduces soil loss more for cover-management systems, such as no-till cropping, that maintain high soil biomass, improve soil quality, and reduce crusting. An interaction between soil biomass and soil consolidation is a major variable used by RUSLE2 to compute values for the ground cover subfactor.

Size and shape of ground cover material vary widely from round rock fragments to thin, flat leaves to long slender pieces of unchopped wheat residue to long and bigger diameter unchopped corn stalks to even larger pieces of woody debris left by logging operations. The portion of the soil surface covered is used as a single variable to describe the effect of ground cover on soil loss. Even though the geometry of individual ground cover pieces can vary greatly, even for the same type of ground cover such as soybean residue, the portion of the soil surface covered, as used in Figure 6.37, integrates the effects of varying geometry of ground cover pieces on soil loss. For example, above ground residue from a typical agricultural crop includes leaves, pods, hulls, cobs, stems, and stalks and fine and coarse roots for below ground "residue." "Residue" on a disturbed forest range from leaves and needles to broken tree limbs. Furthermore, certain operations, especially harvest operations, frequently reduce size of residue pieces. One of the inputs in the residue component of the RUSLE2 database is the selection of a residue type based on size and toughness of the ground cover material.

NOTE: RUSLE2 ***does not compute a composite subfactor value by computing a subfactor value for each ground cover type and then multiplying those values, which is an improper mathematical operation. Therefore, the value for rock fragment cover must be combined with other group cover values considering overlap rather than using a soil erodibility factor value already adjusted for rock cover, which is quite incorrect.***

Ground cover at a specific site can also be composed of several types of residue, such as rock fragments, live ground cover (basal area and plant leaves) and plant litter. Some of the residue types such as plant litter overlap other types such as rock fragments. RUSLE2 also assumes that live ground cover overlaps other types of ground cover, which is true for plant leaves, but not for basal area. The important variable is the net portion of the soil surface that is covered, which is used to compute a value for the ground cover subfactor. The best way to visualize the net fraction of the soil surface that is covered is to determine the fraction of bare, exposed soil and subtract that value from one. RUSLE2 accounts for the overlap of individual ground cover pieces instead of adding the cover provided by each ground cover type.

RUSLE2 tracks and accounts for ground cover on a mass per unit area basis (e.g., tons per acre, or tons per hectare). RUSLE2 converts mass (weight) values to a percent (fraction) of the soil surface covered (see section 6.4.2.2.4), accounts for overlap, and uses a net (effective~~) ground~~ cover value to compute a value for the ground cover subfactor. Although RUSLE2 tracks ground cover by mass, RUSLE2 displays ground cover in percent (fraction) to aid conservation planning that is often based on maintaining a certain ground cover percent.

6.4.2.2.2. Equation for Ground Cover Subfactor

The main equation used in RUSLE2 to compute a value for the ground cover subfactor is:

$$G_c = \exp(-b_{fc}) \quad \textbf{[6.25]}$$

where: **b** = a coefficient that describes the relative effectiveness of ground cover, which varies by specific condition. For example, a 50 percent ground cover can reduce soil loss by 95 percent under some conditions, while only reducing soil loss by 65 percent under other conditions. Values for b in RUSLE2 range from about 0.025 for the interrill erosion ground cover effect to 0.06 for the rill erosion ground cover effect, as illustrated in Figure 6.37. The b value used by RUSLE2 in Equation 6.25 varies by day as the ratio of rill to interrill erosion varies as a function of the variables in Equation 6.10. RUSLE2 computes a b value using equations based on relative soil loss as:

$$a_{t*} = a_{ib*} \exp(-0.025_{fg}) + a_{rb*} \exp(-0.06_{fg}) \quad \textbf{[6.26]}$$

$$b = -1n \left[\frac{a_{t*}}{a_{rb*} + a_{ib*}} \right] / f_g \quad \textbf{[6.27]}$$

where: $\mathbf{a_{t*}}$ = total relative erosion with ground cover, $\mathbf{a_{ib*}}$ = relative interrill erosion on a bare soil with all other conditions the same, as when cover is present, and a_{rb*} = relative rill erosion on the same bare soil with all other conditions the same. Values for relative interrill and rill erosion in Equations 6.26 and 6.27 are computed using the variables in Equation 6.10. These equations capture the main effects of how b values are affected daily by soil, cover-management, cover-management system, and slope steepness.

NOTE: RUSLE2 ***b values are always comparable to b values reported in the literature. In many cases, literature b values are based on plotting soil loss versus percent ground cover without considering any other variables such as soil roughness, soil biomass, and soil consolidation as does*** **RUSLE2.** ***Values determined on that basis cannot be compared with*** **RUSLE2** ***b values. Also, reported b values are as large as 0.1, which are larger than can be obtained by*** **RUSLE2.** ***These high b values seem to represent extremes rather than the typical condition represented by*** **RUSLE2.**

Equation 6.27 is modified for soil on steep slopes with no soil biomass to represent ground cover being less effective for controlling soil loss under those conditions. This modification reflects how mulch is less effective on steep construction-like slopes than crop residue and plant litter on crop, range, pasture, and disturbed forestland.[30] The equations are also modified to take into account how ground cover types like rock and small residue pieces that conform closely to the soil surface reduce soil loss more than long pieces of ground cover that bridge across roughness elements like soil clods. This effect is greatest on steep, construction-like soil and slope conditions.

Another modification to the equations is that RUSLE2 assumes an interaction between random surface roughness and ground cover such that the effectiveness of ground cover is reduced as surface roughness increases. For example, ground cover in the bottom of a depression filled with ponded water does not reduce soil loss as much as does the same amount of ground cover on a flat soil surface.

RUSLE2: ***residue pools:***

1. **Standing (canopy cover)**
2. **Flat (ground cover)**
3. **Buried**

These equations compute a low b value for flat slopes where interrill erosion dominates, a high b value on steep slopes where rill erosion dominates, and an increased b value on no-till and other soils conditions where increased ground cover increases infiltration. The interaction of soil consolidation and soil biomass is used to indicate conditions where ground cover increases infiltration. Equations 6.26 and 6.27 also compute increased b values for soils susceptible to rill erosion based on soil texture and decreased b values for soils that are less susceptible to rill erosion because of soil consolidation.

6.4.2.2.3. How Ground Cover Is Added to and Removed from the Soil Surface

Ground cover is added to the soil surface by live vegetation (live ground cover), senescence causing canopy material to fall to the soil surface, natural processes causing standing residue falling over, an operation (e.g., harvest)[31] flattening standing re-sidue, an operation (e.g., tillage), resurfacing previously buried residue, or an operation applying material ("external residue such as manure, mulch, manufactured erosion control products)" to the soil surface. Ground cover is removed when plant growth stops leaves or other live plant parts from touching the soil surface, an operation (e.g., tillage) buries ground cover, or an operation (e.g., straw baling, burning) remove sground cover.

Values for live ground cover are entered as needed in the vegetation description for each plant community in the vegetation component of the RUSLE2 database (see section 6.4.2.1.6.). Live ground cover is controlled

NOTE: RUSLE2 ***rules for transfer of residue among pools:***

1. Residue is added to the soil surface by senescence, standing residue falling over by natural processes, killing live vegetation, or adding "external residue."

2. Senescence transfers biomass from live canopy to the soil surface, adding ground cover (flat residue.)

3. Live vegetation cannot be flattened or buried.

4. Killing live vegetation creates standing residue (dead plant material.)

5. Standing residue can become flat residue by falling over from natural processes.

6. An operation can flatten standing residue to flat residue.

7. Only flat residue can be buried (standing residue must first be flattened before it can be buried.)

8. Flat residue can only be buried by an operation that "disturbs" the soil.

9. Half of the decomposed flat residue becomes buried residue in the upper 2 inch (50 mm) soil layer where it decomposes again.

10. Only buried residue can be resurfaced.

11. Buried residue can only be resurfaced by an operation.

entirely by these values, and live ground does not decompose. The mass of live ground cover is accounted for in the above ground biomass of the "live" vegetation. Senescence transfers material from the live canopy to the soil surface where it is residue (ground cover). Once on the soil surface, this residue decomposes as a function of daily rainfall, daily temperature and type of material (see section 6.4.2.5.3. for information on decomposition).

When "live" vegetation is "killed," it becomes standing residue. Over time this residue falls over because of natural processes and becomes ground cover. The rate that standing residue "falls" is proportional to decomposition rate at the base of the dead standing vegetation. Standing residue decomposes at a much slower rate than flat or buried residue because of no soil contact to provide moisture to accelerate decomposition.[32] Standing residue can also be converted to ground cover (flat residue) by a "flattening" process in an operation. Flat residue is lost by decomposition and burial by operations. Buried residue is also reduced by decomposition, and buried residue can be resurfaced, which adds material to ground cover. External residue can also be added to the soil surface by an operation. See section 6.4.2.5.4. for a description of how operations manipulate ground cover.

6.4.2.2.4. Conversion of Residue Mass to Portion of Soil Surface that is Covered

RUSLE2 uses the following equation to convert residue mass to portion of the soil surface that is covered:

$$f_g = 1 - \exp(-\alpha M_g) \qquad \textbf{[6.28]}$$

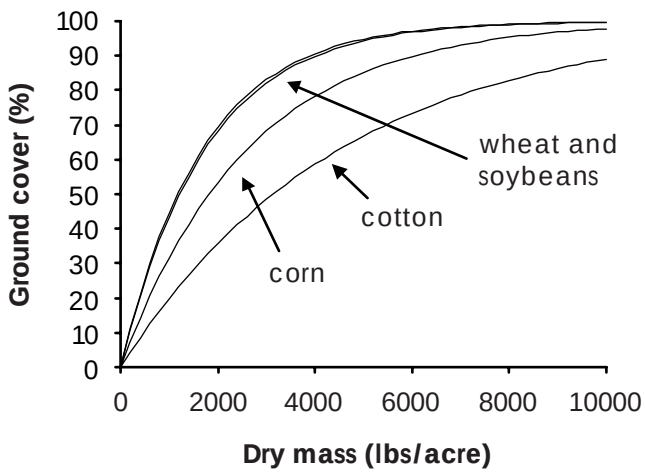
where: α = a coefficient that is a function of the residue type (units depend on the units of M_g) and $\mathbf{M_g}$ = residue mass per unit area (e.g., lbs/acre, kg/ha) expressed on a dry matter basis. Figure 6.38 shows a plot of Equation 6.28 for four residue types.

NOTE: ***The information in each RUSLE2 database component and the rules for manipulating RUSLE2 variables are a "language" or procedure used to describe field conditions through time. The objective in RUSLE2 is to describe field conditions as they exist, not to model processes. The implicit check that should always be made before making a RUSLE2 computation is whether the user created description matches the actual field situation. RUSLE2 user your field description to estimate soil loss and other erosion variables.***

RUSLE2 uses three data points entered in the residue component of the RUSLE2 database to determine a value for α in Equation 6.28 for each residue type. These data points are the mass of residue to provide 30 percent, 60 percent and 90 percent ground cover, respectively. A single data point (mass, cover), two data points, or all data points can be entered and RUSLE2 will use a single data point or an average if multiple data points are entered. If only a single value is entered, enter a mass value for 60 percent ground cover, and the next best choice is a mass value for 30 percent ground cover. A single data point for 90 percent should be avoided because the mass-cover curve is very flat for 90 percent ground cover, which results in considerable error when extrapolated to small ground cover values. The best combination of two data points is 30 percent and 60 percent, and the poorest combination is one that involves a data point for 90 percent ground cover.

Figure 6.38 illustrates differences in residue types. Cotton residue is almost totally composed of very coarse, woody stems, which requires a large mass of these residue pieces to produce a given ground cover. The other extreme is soybean residue, which is a mixture of several plant components including leaves, stems, and pods that contained the soybeans. The curve for wheat residue is similar to the one for soybean residue, but in this case, not a particularly large mass of hollow wheat stems is required to provide significant ground cover. Also, a significant amount of

Figure 6.38. Relationship of ground cover to dry mass for four types of residue.



wheat residue is composed of leaves. Corn residue is intermediate. Much of the corn residue is large stalks that are solid, but less dense than cotton stems. Also, much of the corn residue is composed of leaves.

The best approach to determine values to enter into RUSLE2 to describe the mass-ground cover relationship for a residue is to select values based on information in the "core database" in Appendix ?? (Not available in this draft) rather than making field measurements. Field data are highly variable and should be avoided (see section 6.4.2.2.6.).

Be slow in developing residue descriptions for different crop varieties. Differences often represent unexplained variability rather than real differences.

The variability in measured mass-ground cover values is partly caused by RUSLE2 representing residue as a single composite residue rather than as individual components. A small mass of leaves gives a much greater percent ground cover than does the same mass of stems. Therefore, the relationship between cover and mass depends on the relative proportion of leaves and stems, or other residue components. This relationship changes through time because each residue component decomposes at differing rates. For example, leaves decompose much more rapidly than do stems. Consequently the mass-cover relationship is very different immediately after harvest when many leaves are present than later after the leaves have decomposed to leave only stems. Also, the mass-cover relationship for a residue type can appear to differ by location, when in reality the mass-cover relationship is reflecting how the proportion of leaves to stems varies by time and location.

The residue values in the RUSLE2 core database were primarily chosen to ensure soil loss estimates that compare well with measured soil loss values in research studies.[33] Also, the core database values were chosen to represent the overall mass-ground cover relationship for the first year after harvest rather than fitting ground cover values at a specific point in time. The core database values were chosen to compute soil loss as a function of main effects rather than secondary effects associated with residue. Trying to fit secondary effects, especially with limited data, is more often than not fitting unexplained variability. The core database values represent several data sets rather than focusing on a single data set.

6.4.2.2.5. Spatially Non-Uniform Ground Cover

Ground cover is often non-uniform by being concentrated in strips or patches. Examples of non-uniform ground cover are narrow strips that have been mechanically disturbed by tillage and planting equipment, strips of residue left by harvest operations, natural processes that cause residue to collect in row middles, "patches" of highly disturbed areas left by logging and military training operations, and grass/shrub "clumps" on rangeland. RUSLE2 can compute soil loss for these non-uniform conditions using alternating cover-management systems along a hillslope profile. An example is the patchiness common to rangelands, disturbed forest lands, and landfills where soil and vegetation vary along a slope. One cover-management system represents a patch with increased cover created by using less intensive operations that leave more ground cover; and a second cover-management system represents a patch created by using operations with increased soil disturbances that leave less ground cover. Another example is strips of residue left by a combine, where a straw spreader was not used. On one cover-management system, operations remove flat residue and leave only standing stubble. The other cover-management system takes the residue removed by the first cover-management

NOTE: ***Within a given cover-management system, RUSLE2 assumes that ground cover is uniformly distributed. RUSLE2 values for flattening, burial, and resurfacing ratios used to describe operations represent the entire area and not just the local area where the residue is altered, such as in a tilled strip where seeds are planted.***

system and adds it as "external residue" to the second strip. Even very narrow, disturbed strips—on the order of inches (10's of mm) and 3 feet (1 meter) wide—less disturbed strips can be analyzed with RUSLE2, but analyzing such narrow strips is time consuming and tedious.

6.4.2.2.6. What to Do when RUSLE2 Computes a Ground Cover that Is not the Expected Value

Thne residue cover value immediately after planting is a key variable used in conservation planning on cropland and in compliance to determine whether a conservation plan has been properly implemented. The residue cover value computed by RUSLE2 immediately after planting is an important RUSLE2 output. This value should be sufficiently close to values observed in the field for clients to accept RUSLE2 estimates. Several factors should be considered in comparing RUSLE2 residue cover values with field observations. RUSLE2 computes "typical," average annual daily residue cover values, rather than residue cover at any particular time and site. Residue cover values measured at a particular site vary greatly from year to year, requiring at least three years of measurements, where a range of yields (production levels) and weather conditions have occurred to obtain a measured value comparable to RUSLE2 estimates. Also, residue cover varies greatly from location to location within a field site requiring at least 10 measurements at that particular site. Residue cover is frequently measured using a transect.

Great care must be taken when the cover is non-uniform in strips and patches. This helps ensure that the sample density is sufficient when measuring residue cover using the bead-string, or a similar method, especially if the strips are narrow and the residue cover in one of the types of strips is heavy. In fact, the best way to measure residue cover for these conditions is to use transects within each type of strip and weight the values based on the area represented by each type of strip. However, keep in mind that the mass-cover and erosion equations are highly nonlinear, which may require applying RUSLE2 to the site as a system of strips as described in section 6.4.2.2.5. Be aware of differences caused by non-linearities.

Also, the error in residue measurements can be large for residue cover values less than about 20 percent. Sometimes, residue mass is estimated based on measurements of residue cover percentages and curves like those in Figure 6.38. The error in mass can be large, sometimes by as much as a factor of two for residue cover values greater than 75 percent, because of the flatness of the mass-cover curve at high cover values where the residue mass can change by a large amount with only a small change in ground cover.

Very carefully compare the values determined from the field measurements with values in the "core database" and values reported in the literature. Ask yourself the following questions: "Are the measured values consistent and reasonable when all of the data as a whole are considered?" and "If the measured values differ significantly from the other values, can the differences be explained in a reasonable way?"

If one concludes that RUSLE2 is not computing the desired residue cover, what does one change to obtain the desired value? The first point to realize is that getting a good comparison between a RUSLE2 residue cover estimate and a measured value at a particular point in time does not ensure a good soil loss estimate. The best soil loss estimate is obtained by a good fit of residue cover over at least the one-fourth to one-third period during the most erodible part of the year.

NOTE: ***Don't make changes just to get a better fit to local conditions. Always compare against a broad data set. Look at RUSLE2 estimates as representing main effects and typical conditions in a conservation planning context, not in a research context. Make sure that data being fit are high quality, and collect as much supplemental data as possible, including yield, residue mass, and how residue cover varies during the year.***

The factors that need to be considered in a systematic, stepwise manner in adjusting RUSLE2 to compute a different residue value are: (1) the amount of residue at harvest; (2) the distribution between standing and flat residue at harvest; (3) the mass-ground cover relationship; (4) the decomposition coefficient value; and (5) values for the burial and resurfacing ratios of the operations that bury the most residue at critical times. Estimated residue cover and soil loss values should be checked at each step. Sometimes changes in a particular variable have unexpected effects. For example, changing the value for the decomposition coefficient affects not only ground cover, but buried residue and dead roots as well.

6.4.2.3. Soil (Surface) Roughness

Soil (surface) roughness, illustrated in Figure 6.39, refers to the random peaks and depressions left by soil

Figure 6.39. **Photograph of a soil surface where a roughness of 1.0 inch has just been created by a mechanical disturbance.**

(Photo not available in this draft)

disturbing operations. This roughness is referred to as random roughness because it does not affect the general flow direction, in contrast to oriented roughness (ridges and furrows) that redirects the runoff. Characteristics of the roughness at the time of its creation depend on soil properties, the type of soil disturbing operation, and the amount of soil biomass. Different types of soil disturbance produce widely differing distributions of aggregates and clod sizes depending on soil conditions. Surface roughness decays over time to a smooth surface, except for a few persistent clods on some soils.

6.4.2.3.1. Soil (Surface) Roughness Effect

Surface roughness affects soil loss in several ways. The depressions formed by surface roughness pond water and slow runoff, which reduces the erosivity of both impacting waterdrops and surface runoff. Transport capacity of flow through the depressions is very low, which causes local deposition. Surface roughness decays over time as deposition fills the depressions with sediment, detachment as a part of interrill erosion wears away the roughness peaks, and the presence of rain water causes the soil to subside.

Soil clods that are resistant to detachment are the main geometric elements that form the roughness as illustrated in Figure 6.39. The fine soil particles produced during the creation of the roughness are often left in the depressions where they are protected from erosion. Thus, erodibility of a rough soil surface is less than that of a smooth, finely pulverized soil surface. However, the degree that a soil forms clods depends on soil texture and soil moisture at the time of the soil disturbance, although RUSLE2 does not consider the effect of soil moisture on soil roughness. Clods are smaller and less stable for coarse textured soils than for fine textured soils. Large clods also produce deeper depressions.

Surface roughness increases infiltration, which reduces runoff, partly because of increased soil porosity. Also, a cloddy, rough soil resists sealing and crusting in relation to a finely pulverized soil that can readily seal and crust. Thus, a rough surface reduces soil loss because of decreased runoff. Surface roughness is often a measure of cloddiness left by a soil disturbance.

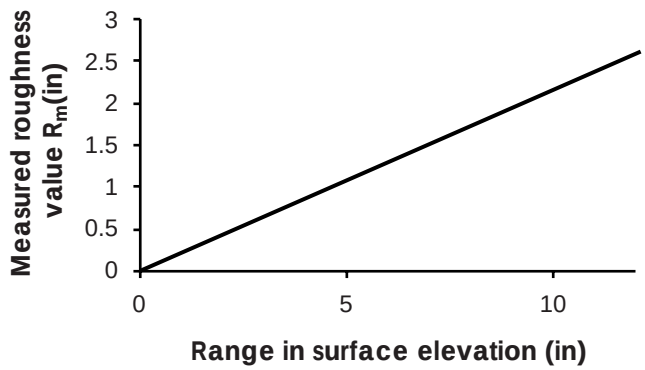
RUSLE2 considers a "short term roughness" and a "long term" roughness. "Short term" roughness is created by operations that disturb the soil like tillage equipment and earth moving machines. "Long term" roughness evolves over time after the last mechanical soil disturbance on lands like pasture, range, and landfills. This roughness is related to vegetation type (bunch versus sod forming), plant roots near the soil surface, local erosion and deposition by both water and wind erosion, and animal traffic. A value for this long term roughness is entered into RUSLE2 to capture the long term roughness effect. RUSLE2 simultaneously keeps track of the decay of "short term" roughness and evolution of long term roughness that is assumed to develop over the "time to soil consolidation" (see section 6.2.8).

6.4.2.3.2. Roughness Measure

RUSLE2 uses a roughness index that is the standard deviation of the micro surface elevations about the mean elevation as a measure of soil roughness. Machines like scarifiers, moldboard plows, and heavy offset disks tend to create rough soil surfaces [e.g., R_m > 1.5 inch (35 mm), R_m = field measured roughness value], while machines like rotary tillers pulverize the soil and leave a smooth soil surface [e.g., R_m < 0.2 in (5 mm)]. Machines like bulldozers and road graders that use blades to cut the soil also leave a smooth surface with a low roughness value.

NOTE: ***Roughness values entered into RUSLE2 are selected from the "core database," not from field measurements at the site where RUSLE2 is being applied. See section 6.4.2.3.3.***

Figure 6.40. **Relation of measured surface roughness value to range in elevation from highest roughness peak to deepest depression.**



Micro-relief meters are used in research to measure soil surface roughness. These meters generally involve measuring micro surface elevations over a grid by either lowering pins to the soil surface or by using a laser system.[34] Because roughness index values can be a function of the grid spacing, a standard spacing of 1 inch (25 mm) should be used to determine roughness index values for RUSLE2. A plane should be fitted to the elevation data and deviation taken with respect to the plane to remove the effects of land slope. Also, the effect of ridges (oriented roughness) should be avoided or taken out of the data by analysis as well.

Figure 6.40 provides an approximate estimate of soil surface roughness if a microrelief meter is not available. The procedure is to determine the range in surface elevation from the highest roughness peak to the bottom of the deepest depression, which can be measured by laying a 6 feet (2 meter) straight edge across the roughness peaks.[35] A third approach for estimating a surface roughness value is to compare the surface with the photographs in Appendix ?? (Not available in this draft) for soil surfaces having a range of measured roughness values.

NOTE: ***The method of laying a roller chain on the soil surface and estimating roughness by how much the horizontal measurement is shorter than the chain length should not be used to measure roughness for RUSLE2 because it does not capture all roughness features important in RUSLE2.***

Field measurements of roughness can vary greatly for a particular operation, such as a moldboard plow. Roughness is affected by the amount of soil biomass, the presence of standing stubble, whether live vegetation is present, soil moisture content at the time of tillage, whether the soil has "mellowed" from over winter weathering, speed of the operation, and soil texture. The roughness values used in RUSLE2 capture the main effects of the type of operation, soil texture, and amount of soil biomass for a "typical" condition and not all of the detailed variations. See section 6.4.2.3.3 for adjustments that are required for soil texture and soil biomass to convert measured roughness values to input values entered in the operation component of the RUSLE2 database.

6.4.2.3.3. Soil Surface Roughness Subfactor

Values for the RUSLE2 soil surface subfactor are computed using an adjusted roughness value that has been adjusted for soil texture and soil biomass from an input roughness value for the operation that creates the roughness. The equation for the soil roughness subfactor is:

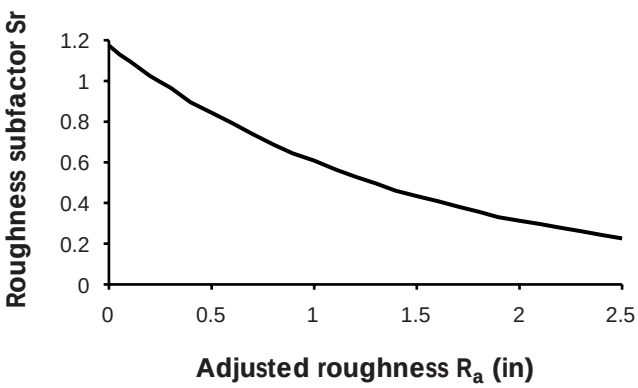
$$S_r = \exp[-0.66(R_a - 0.24)] \qquad \textbf{[6.29]}$$

where: $\mathbf{R_a}$ = a roughness index value that has been decayed from an initial roughness value. The 0.24 inch (6 mm) value in Equation 6.29 represents the roughness value assumed for unit plot conditions so that the value of the surface roughness subfactor $\mathbf{S_r}$ = 1 for unit plot conditions. All cover-management subfactor values are relative to unit plot conditions described in section 6.4.1. Roughness subfactor values are less than 1 when the surface roughness of the site specific condition is greater than that of the unit plot, and greater than 1 when the site specific surface roughness is smoother than the surface roughness of the unit plot. An example of a soil surface that is smoother than the unit plot is one that has been finely tilled with a rotary tiller where vegetables are seeded. The soil surface roughness subfactor value is greater than 1, as illustrated in Figure 6.41 A soil surface rougher than the 0.24 inches (6 mm) of the unit has soil surface roughness subfactor values less than 1 as illustrated in Figure 6.41, and can be lower than 0.2 on extremely rough soil surfaces.

NOTE: ***The input roughness value assigned to an operation is the roughness that the operation would create on a silt loam soil where the soil biomass is very high.***

The adjusted roughness value R_a that RUSLE2 uses in Equation 6.29 to compute the roughness subfactor values, as illustrated in Figure 6.41, begins with an input roughness value assigned to the operation that creates the roughness. Input roughness values are

Figure 6.41. Relation of roughness subfactor to roughness index.



entered in the operation component of the RUSLE2 database for each operation that includes a "disturbs the soil" process.

Before RUSLE2 uses an input roughness value in equation 6.29, it uses equations to compute adjustment factors for soil texture and soil biomass. Table 6.16 lists the adjustment factors for soil texture based on the sand, silt and clay content for the midpoint of the class in the textural triangle. RUSLE2 uses the sand, silt and clay content entered for the soil, or if only a textural class is entered, RUSLE2 uses the sand, silt, and clay for the midpoint of textural class (see section 6.2.4). The first step is to multiply the input roughness by the roughness adjustment factor. As Table 6.16 illustrates, the roughness adjustment factor is greater for fine textured soils, ones with a high clay content, and is lesser for coarse textured soils, ones with a high sand content. That is, RUSLE2 uses a high soil surface roughness value for soils high in clay than for soils high in sand. The input roughness factor value is essentially one for medium textured (silt loam) soils because the input roughness value is based on a silt loam soil.

Table 6.16. Factor to adjust input roughness as a function of soil texture.

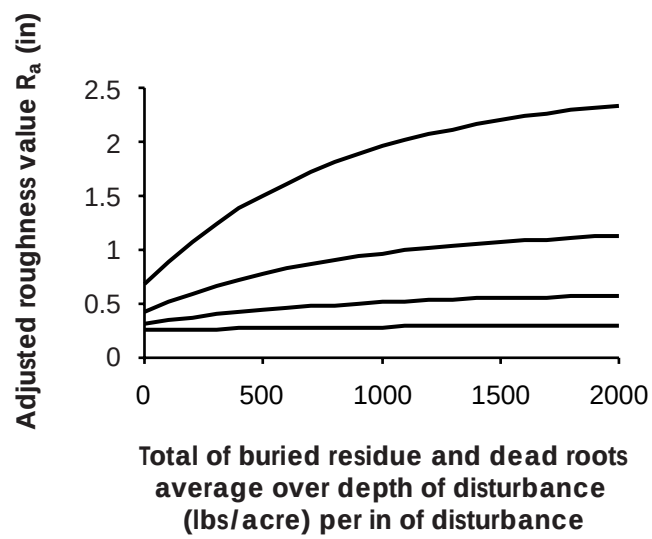
SOIL TEXTURE CLASS	ADJUSTMENT FACTOR
Clay	1.39
Clay loam	1.22
Loam	1.05
Loamy sand	0.78
Sand	0.69
Sandy clay	1.25
Sandy clay loam	1.13
Sandy loam	0.90
Silt	0.81
Silt loam	1.02
Silt clay	1.33
Silt clay loam	1.23

The second adjustment to the input value is an adjustment for the average amount of soil biomass over the depth of soil disturbance. The soil biomass that is included in this adjustment includes buried residue and dead roots after the disturbance. Equation 6.30 is used to adjust the input roughness value after it has been adjusted for soil texture.

$$R_a = 0.24 + (R_{it} - 0.24)\{0.8[\exp(-0.0012B_{ta})]+0.2\} \quad \textbf{[6.30]}$$

where: $\mathbf{R_a}$ = the adjusted roughness value (in) used in Equation 6.29, $\mathbf{R_{it}}$ = the roughness input value (in) after it has been adjusted for soil texture and $\mathbf{B_{ta}}$ = the total mass of buried residue and dead roots averaged over the soil disturbance depth after the operation (lbs/acre per inch depth). Figure 6.42 illustrates how the input roughness value is adjusted for soil biomass.

Figure 6.42. Input roughness value R_{it} adjusted for soil biomass.



The effect of soil biomass on roughness can be observed by comparing roughness after a sod field is plowed with the roughness after a field in continuous low residue vegetable cropping is plowed. This difference in roughness can also be observed when a permanent grass strip beside a continuously cropped

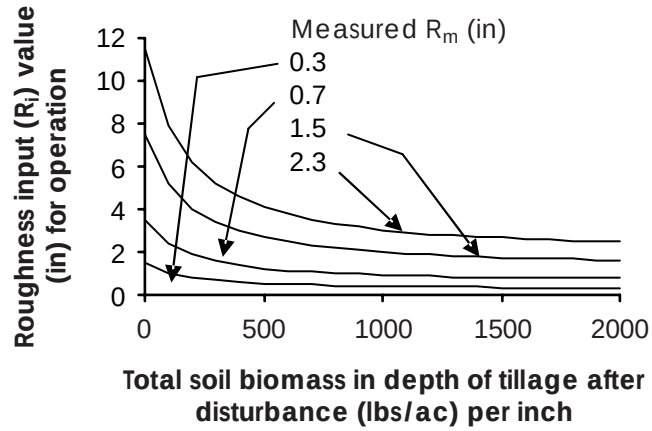
field is plowed. The soil surface roughness is much larger on the sod field and grass strip than on the continuously cropped fields. The soil plowed out of sod turns up in "chunks," as if it is held together by roots. A similar effect occurs in chisel plowed wheat stubble fields. This effect in a sod field on soil loss is significant.

According to Table 5-D in AH537[36], soil loss immediately after a moldboard plow from a sod field is one-fourth of that immediately after a moldboard plow in a continuous row cropped field. The degree of the effect depends on the sod yield (production level), with the amount of roots and buried residue directly depending on yield. The roughness for a moldboard plow in a continuous cropped corn field is also a function of yield, as shown in Table 5 in AH537. For example, the surface roughness subfactor value is about 0.55 for a 110 bushel per acre yield, and about 0.75 for a 50 bushel per acre yield. This effect is also illustrated in Table 5 in AH537, where the residue is removed. For example, the soil surface roughness subfactor is about 0.90 where the residue is removed for a 110 bushel per acre corn yield, while it is about 0.55 where the residue is not removed. The values in Tables 5 and 5-D in AH537 are based on measured soil loss data. Another illustration of how soil biomass affects the soil surface roughness is that a soil surface is noticeably smoother after tillage following soybeans than tillage following corn.
When roughness data from field research are analyzed to develop input roughness values for RUSLE2, field measured values R_m must be adjusted for soil texture using Table 6.16 and for soil biomass using Figure 6.43. The best approach is to make roughness measurements under high soil biomass conditions.

As illustrated in Figure 6.43, biomass does not have much effect on the soil surface roughness value for soil biomass values (buried residue plus dead roots) greater than 1,000 pounds per acre per inch depth of disturbance. Roughness measurements made with yields of 200 bushels per acre corn, 70 bushels per acre wheat, and 4 tons per acre on hay (or pasture) land are conditions where measured roughness needs little, if any, adjustment for soil biomass. The following example illustrates how to use Figure 6.43 to adjust a measured roughness value for biomass. Assume that the measured roughness is 1.5 inches (40 mm) and the average soil biomass is 500 pounds per acre per inch depth of disturbance after the operation. A value of about 3.2 inches (80 mm) is read from Figure 6.43, which would be the input roughness value for the operation that produced this roughness on a silt loam soil.

NOTE: ***Perhaps more than any other RUSLE2 variable, roughness values from the "core database" should be used rather than using roughness values measured at the specific site for input into RUSLE2.***

Figure 6.43. **Conversion of a measured roughness value (R_m) to a roughness input value (R_i) (silt loam soil).**



The input roughness values in the operation component of the RUSLE2 database are greater than are typically measured in the field because of the biomass effect. Roughness values computed by RUSLE2, rather than input values, should be compared to measured roughness values. Even then, field measured roughness values may not match those computed by RUSLE2. The first RUSLE2 priority is to compute soil loss values as a function of main effects. The RUSLE2 surface roughness subfactor captures more than just the physical effect of roughness geometry on soil loss. It also captures the effect of soil management as represented by soil biomass on aggregate size distribution and stability and their effect on infiltration and erodibility. Priority is given to capturing these effects rather than reproducing roughness values that can be measured in the field.

6.4.2.3.4. Roughness Decay

At the time that an operation creates roughness, RUSLE2 computes an initial adjusted roughness based on the input roughness value for the operation. The input value is adjusted for soil texture and the amount of buried residue and dead roots in the depth of soil disturbance after the operation. RUSLE2 decays this adjusted roughness value each day based on daily rainfall amount and interrill erosion. Rainfall amount is

used to compute the rapid subsidence of roughness caused by soil wetting. Roughness decay by interrill erosion represents impacting waterdrops wearing away soil peaks and filling depressions with sediment. Interrill erosion is computed using daily rainfall erosivity, canopy cover, and ground cover. A value of 0.025 is used in Equation 6.24 to compute the effect of ground cover on interrill erosion. Soil surface roughness persists when rainfall erosivity is low and canopy and ground cover are high to reduce interrill erosion. About 40 percent of the total roughness decay is from subsidence with rainwater and the remainder is from interrill erosion.

Roughness decays over time to a "final" roughness that is entered as an input for each operation having a "disturb soil" process (see section 6.4.2.5.4.). A value of 0.24 inches (6 mm) is typically used for final roughness to represent the long term persistence of a few exceptionally stable soil clods. Although the value for final roughness should be a function of soil texture, a value of 0.24 inches (6 mm) is used for all soils. A major reason for using the 0.24 inch (6 mm) value for all soils is to compute a surface roughness subfactor value of 1.0 to correspond to the subfactor values for the unit plot for all soils when all roughness has decayed.

However, a final roughness less than 0.24 inches (6 mm) is used in RUSLE2 to represent operations such as grading and rotary tillers that leave a smoother surface than existed on the unit plot. When final roughness values less than 0.24 inches (6 mm) are entered, an "initial" roughness value equal to the final roughness value should be entered. However, if the "initial" value is greater than the "final" value, RUSLE2 will decay roughness from the initial value to the final value.

NOTE: ***Sometimes the way that RUSLE2 computes roughness needs to be overridden. Set the initial and final roughness values to the same value and RUSLE2 will use a constant roughness value. Causing RUSLE2 to set initial roughness to a measured value requires that the input roughness value be adjusted by trial and error until RUSLE2 computes the desired initial roughness.***

The rate of roughness decay is not a function of soil conditions in RUSLE2. Because initial roughness is a function of soil texture and soil biomass, the effect of soil conditions on roughness at any time in RUSLE2 is considered to be sufficiently well captured.

6.4.2.3.5. Effect of Existing Roughness (Tillage Intensity Effect)

The initial surface roughness value that RUSLE2 computes for an operation can depend on existing roughness for certain conditions.[37] For example, if a spike tooth harrow or similar light implement is used on a very rough soil surface, the harrow may have little effect and leave a soil surface that is only slightly smoother than before the operation. However, if the harrow follows a tandem disk that has already left the soil surface fairly smooth, the harrow will further smooth the soil surface. The soil surface will be smoother when the harrow follows a tandem disk that leaves the surface moderately smooth than when the harrow follows a moldboard plow that leaves a rough soil surface. Therefore, the roughness following the harrow depends on the roughness that existed when the harrow was used. An implement like the harrow is assigned a tillage intensity factor of about 0.4, which means that the harrow can only "wipe out" about 40 percent of the existing roughness, or conversely, 60 percent of the existing roughness remains after the operation.

NOTE: ***A tillage intensity of one (1) does not necessarily infer that the operation leaves a rough surface.***

In contrast, the roughness left by an aggressive implement like a moldboard plow or heavy offset disk is completely independent of the existing roughness. These implements are assigned a tillage intensity of 1.0, which means that the implements completely wipe out any existing roughness. Another implement that has a tillage intensity factor of 1.0 is a large rotary tiller. In contrast to the moldboard plow and offset disk that have a tillage intensity factor of 1.0 and leave the surface rough, the rotary tiller leaves a smooth surface even though it has a tillage intensity value of 1.0.

NOTE: ***Input roughness values in the operation component of the RUSLE2 database are for roughness created by the operation on a smooth soil surface.***

If the soil surface roughness at the time of an operation is smoother than the surface roughness that is created by an operation on a smooth soil surface, the surface roughness computed by RUSLE2 is not affected by the tillage intensity factor.

6.4.2.3.6. How RUSLE2 Handles Roughness when Soil Disturbance Is in Strips

Some operations like strip tillage, manure injection, and planting only disturb a portion of the soil surface. The input roughness value for these operations applies only to the portion of the soil surface that is disturbed. RUSLE2 does not average the roughness values for the disturbed and undisturbed portions to determine an average roughness value because of non-linearity in Equation 6.29. Instead RUSLE2 computes a roughness subfactor value for each strip and computes a composite roughness subfactor value based on the portion of the surface disturbed by the operation. This composite roughness subfactor value is used in Equation 6.29 to compute an effective roughness value for the entire surface. This effective roughness is then decayed based on rainfall amount and interrill erosion as described in section 6.4.2.3.4.

NOTE: ***The approach used to handle roughness with strips differs from the way that ground cover in strips is handled, where input values for flattening, burial, and resurfacing ratios apply to the entire area.***

6.4.2.3.7. Assigning Roughness Values

Input roughness values for soil disturbing operations are assigned by selecting a value from the RUSLE2 "core database" given in Appendix ?? (Not available in this draft) by comparing characteristics of an operation with characteristics of operations in the core database. Basing input values on the core database values helps ensure consistency between RUSLE2 applications. If no operations are in the core database that are sufficiently close to your operation, consult the research literature and use the largest possible database to estimate input roughness values and apply the adjustment procedures described in section 6.4.2.3.3. Field measurements should be careful and sufficient to deal with spatial and temporal variability.

NOTE: ***Field measurements should not be made at the specific site where RUSLE2 is being applied to determine an input roughness value for RUSLE2.***

6.4.2.4. Ridges

This section describes how ridges affect sediment production. Ridges, and the furrows that separate them, are referred to as oriented roughness because they redirect runoff from a direct down hill direction (perpendicular to the contour) when the ridges are oriented in direction besides directly up and down slope. Orienting ridges parallel with the contour is an important conservation (support) practice known as contouring, which can significantly reduce soil loss if the ridges are sufficiently high. Contouring is discussed in section ?? (This section not available in this draft).

6.4.2.4.1. Ridge Subfactor Effect

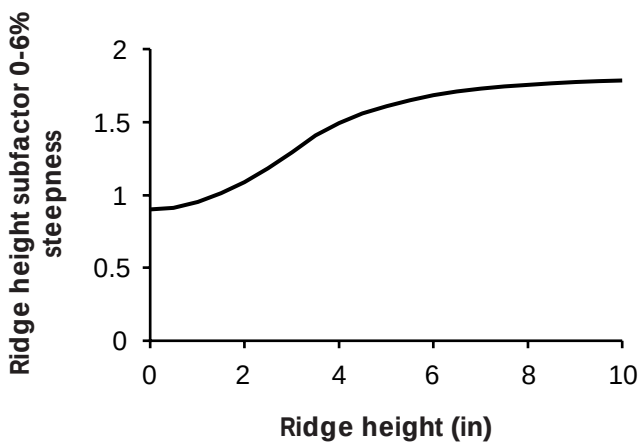
Ridges increase soil loss by increased detachment by interrill erosion on ridge sideslopes. Measured soil loss can be as much as twice the soil loss from a level soil surface for land slopes up to 6 percent.[38] The increase in soil loss caused by ridges is related to ridge sideslope steepness where interrill erosion increases according to $3(\sin\theta_i)^{0.8}+0.56$ as θ_i = the angle of the ridge sideslope increases. This equation computes interrill erosion from a 30 percent steep ridge sideslope that is about three times the interrill erosion from a flat, level soil surface. Even when land slope is flat, the local ridge sideslope can be very steep, such as 30 percent, and interrill erosion can be very high on the ridge sideslope.

NOTE: ***The only way that ridges exist in RUSLE2 is to create them with a soil disturbing operation.***

Ridge height is used to represent ridge sideslope steepness because ridge height values can be easily visualized and measured for ridge forming operations. Using ridge sideslope steepness in RUSLE2 would require that a value for ridge spacing be entered, which is not always available. Also, more ridges are often present than are usually recognized. For example, the ridge spacing assumed for row crops is often the spacing of the rows, but the planter may leave several small—but very important—ridges besides the ridges associated with row crops. Determining ridge height is much easier for construction machines like scarifiers and bulldozer treads than determining ridge spacing. Figure 6.44 shows RUSLE2 subfactor values as a function of ridge height, when the land slope is less than 6 percent and the ridges are oriented up and down hill.

The effect of ridges on sediment production diminishes in RUSLE2 as land slope steepness increases above 6 percent because the local steepness of the ridges becomes almost equal to the land slope at steepness above 30 percent. For example, the local steepness of the ridge sideslopes is 42 percent when the ridge sideslope is 30 percent and the land slope is 30 percent. Figure 6.45 shows ridge subfactor values as landslope increases above six percent. As illustrated,

Figure 6.44. Ridge subfactor values as a function of ridge height for land slopes less than 6%.



ridge subfactor values converge to 1 at steep land slopes. The values in Figure 6.44 were derived from experimental data while the values in Figure 6.45 were derived from a simple rill-interrill erosion model where rill erosion varies linearly with land slope steepness and interrill erosion with $3(\sin\theta_i)^{0.8}+0.56$.

6.4.2.4.2. Effect of Ridge Orientation on Ridge Subfactor

The ridge subfactor values in Figure 6.45 apply when ridges are oriented up and down slope. When the ridges are oriented on a direction different from up and down slope, ridge subfactor values decrease to one (1) as ridge orientation approaches the contour. The relationship used to adjust ridge subfactor values as a function of ridge orientation (row grade) is shown in Figure 6.46. This relationship is a mirror image of the one used to adjust contouring factor values for ridge orientation, which is discussed in section ?? (This section not available in this draft). The net effect of ridges is a composite of Figure 6.46 and the similar one for contouring.

Figure 6.45. Ridge subfactor values as a function of ridge height and land slope steepness.

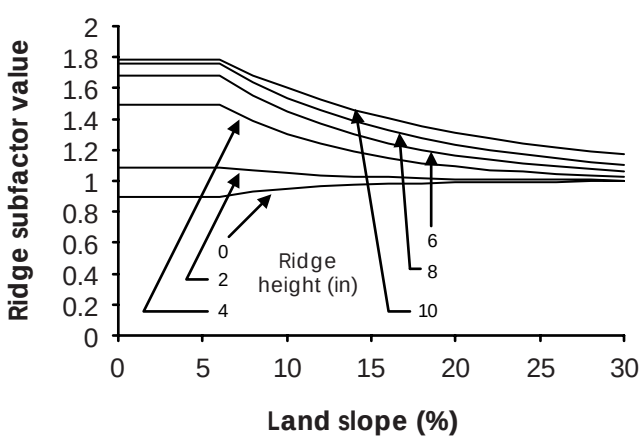
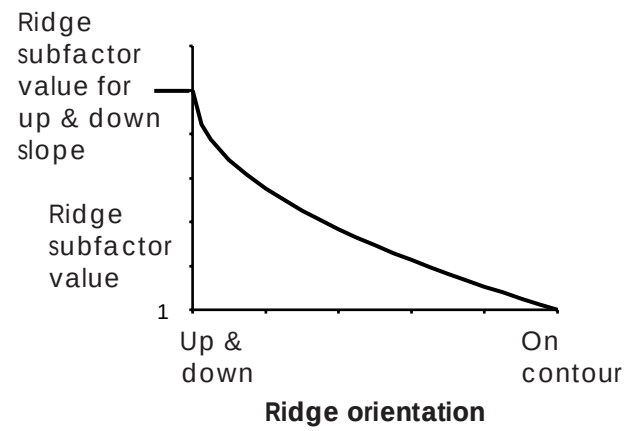


Figure 6.46. Effect of ridge orientation (row grade) on ridge subfactor.



6.4.2.4.3. Ridge Formation and Decay

Ridges are formed by soil disturbing operations. An input ridge height value is entered in the operation component of the RUSLE2 database for each soil disturbing operation. This input value is the "typical" (representative) ridge height created by the operation. A "typical" ridge height is used because ridge height can vary with soil and cover-management conditions, factors not considered in RUSLE2 in contrast to random roughness that RUSLE2 computes as function of soil texture and soil biomass.

Ridge height is assumed to decay as a function of daily rainfall amount and daily interrill erosion. The decay in ridge height by rainfall amount is independent of soil and cover-management conditions, but the decay by interrill erosion depends on rainfall erosivity, canopy cover, and ground cover. A value of 0.025 is used in Equation 6.24 to compute the effect of ground cover on interrill erosion. About 40 percent of the decay in ridge height is from rainfall amount, which represents how the presence of water causes soil settlement, and the remainder is from interrill erosion, which represents the wearing away of the ridge by interrill erosion.

6.4.2.4.4. Assignment of Input Ridge Height Values

RUSLE2 input values for ridge height for an operation should be selected by comparing the characteristic

of the operation with operations having ridge height values assigned in the RUSLE2 "core database" given in Appendix ?? (Not available in this draft). Ridge heights should be selected very carefully where contouring is being analyzed. Ridge height values in the RUSLE2 core database have been selected very carefully to ensure that RUSLE2 computes the proper contouring effect. The tendency is to assign ridge height values that are too low and then be surprised that RUSLE2 computes too little contouring effect.

NOTE: ***Input ridge values should not be based on field measurement at the site where RUSLE2 is being applied.***

6.4.2.5. Soil Biomass

Soil biomass in RUSLE2 includes live and dead roots, buried plant litter and crop residue from vegetation "grown" on-site, and added materials (external residue) that were buried or directly placed in the soil. These materials, including rock added as an "external residue," are assumed to be organic materials that decompose and reduce soil erodibility. An extremely low value is entered for the decomposition coefficient for rock so that essentially no rock mass is lost by decomposition. RUSLE2 assumes buried rock to have the same effect as buried organic material, which may be too much effect for buried rock.[39]

NOTE: ***The effectiveness of contouring in RUSLE2 depends on ridge height. If ridges are not present (no ridge height), there is no contouring effect. To have a contouring effect, ridges must be present.***

6.4.2.5.1. Soil Biomass Effect

Live roots affect soil loss by mechanically holding the soil in place, resisting erosive forces if runoff erodes soil to the depth of roots, and producing exudates that reduce soil erodibility. Also, live roots are a measure of plant transpiration that reduces soil moisture, which in turn increases infiltration and reduces runoff and soil loss.

When vegetation is "killed" in RUSLE2 by an operation that has a "kill" process, live roots becomes dead roots and begin to decompose. The physical presence of dead roots reduces soil loss by reducing the runoff erosivity if the dead roots become exposed, and dead roots also have the appearance of holding the soil in "clumps" when the soil is mechanically disturbed. Also, dead roots decompose and produce organic compounds that reduce soil erodibility and increase infiltration and reduce runoff.

Buried "residue"[40] acts similar to dead roots by physically reducing the erosive forces of runoff if flow erodes to the depth of buried residue, but buried residue does not mechanically hold the soil in the same way that roots hold the soil. Residue decomposes and produces organic compounds that reduce soil erodibility and increase infiltration and decrease runoff and soil loss. Overall, buried residue is less effective than roots on reducing soil loss because the buried residue does not mechanically hold the soil in place, and buried residue is not associated with plant transpiration like roots.

Although residue occurs in a wide range of sizes and types of vegetative material, the effect of all buried residue is treated the same based on experimental research that compared how crop residue, "green" manure, compost, animal manure, hardwood litter, and pine needles affected soil loss.[41] However, preference is given to fine roots instead of coarse roots when root biomass values are entered in the vegetation component of the RUSLE2 database. Fine roots have greater surface area per unit mass than coarse roots and often are very close to the soil surface where they have a greater effect on runoff and soil loss than coarse roots. Fine roots readily slough and become a part of the soil organic matter pool. Coarse roots are assumed to have relatively little effect and not much of the mass of coarse roots is entered for root biomass in the RUSLE2 database to avoid giving too much credit for the root biomass effect.

6.4.2.5.2. Soil Biomass Subfactor

Equation 6.31 is used in RUSLE2 to compute values for the soil biomass subfactor.

$$S_b = c_b \exp[-0.00348 B_{rt} - 0.000433 B_{rs} / S_c^{0.5}] \qquad \textbf{[6.31]}$$

where: $\mathbf{S_b}$ = soil biomass subfactor, $\mathbf{c_b}$ = 0.951,[42] $\mathbf{B_{rt}}$ = the sum of the live and dead root biomass averaged over a 10 inch (250 mm) depth (pounds per acre per inch of depth), $\mathbf{B_{rs}}$ = the amount of buried residue averaged over a depth that linearly ranges from 3 inches (75 mm) if the soil is not consolidated (i.e., C_s = 1) to 1 inch (25 mm) if the soil is fully consolidated (i.e., C_s = 0.45), and C_s = the soil consolidation subfactor (see sections 6.2.8 and 6.4.2.6. for discussion of the soil consolidation subfactor). The coefficients 0.00348 for root biomass B_{rt} and 0.000433 for buried residue B_{rs} are doubled to 0.00696 and 0.000866, respectively, for R_{eq} applications. Soil biomass has a much greater mechanical (physical) effect on rill erosion than on interrill erosion, and thus these coefficients are dou-

bled for R_{eq} applications because most of the erosion is rill erosion caused by surface runoff.

Equation 6.31 was empirically derived by fitting it to soil loss ratio values for the seedbed crop stage period[43] in Table 5 and accompanying tables in AH537.[44] These soil loss ratio values were over a wide range of soil biomass and soil consolidation conditions, including pasture and haylands; no-till and reduced-till forms of conservation tillage for corn grain; and conventional clean-till corn grain, corn silage, soybean and wheat cropping over a range of yields. Also, soil loss data on the effect of incorporation of green manure, animal manure, compost, hardwood litter and pine needles into the soil were analyzed. (See Appendix ?? [Not available in this draft] for additional information on the validation of RUSLE2.)

The 10 inch (250 mm) depth over which root biomass is averaged was the best of several depths analyzed, while a 3 inch (75 mm) depth over which buried residue is averaged also was the best of several depths analyzed. This 3 inch (75 mm) depth is linearly reduced in RUSLE2 to 1 inch (25 mm) as the soil consolidation subfactor C_s decreases from 1 to 0.45, which gives increased credit to buried residue B_{rs} in the upper soil layer. No-till cropping and other cover-management systems leave residue at the soil surface and do not disturb the entire soil surface. A similar feature is the division of the variable buried residue B_{rs} by the square root of the soil consolidation subfactor C_s, which also gives increased credit to buried residue as the soil consolidates. A major advantage of no-till cropping is the accumulation of organic matter in the upper 2 inches (50 mm) of soil. Over time, this layer promotes earthworm burrowing and other processes that decrease runoff and soil erodibility. Tillage and other mechanical soil disturbances disrupt this layer so that its effectiveness for reducing erosion is immediately lost. This zone requires about 5 years to develop in the eastern U.S., which is consistent with using 7 years for the time to soil consolidation to represent this time.

NOTE: ***Soil consolidation refers to lack of soil disturbance and the soil becoming less erodible over time after a soil disturbance rather than the soil necessarily becoming dense.***

Tables 6.17 and 6.18 illustrate values for the soil biomass subfactor for the three corn tillage systems at different yield levels, as well as grass at three production levels. The values for the soil biomass subfactor computed by Equation 6.31 decrease as yield increases because of increased buried residue and live and dead roots. The difference between the clean-till and reduced-till systems is that the reduced-till system leaves additional residue near the soil surface where it has greater effect than residue buried more deeply by the moldboard plow in the clean-till system. The major difference in the no-till system from the other systems is from additional residue near the soil surface and the additional credit given in equation 6.31 for buried residue B_{rs} because of a reduced soil consolidation subfactor C_s. The reduced soil consolidation subfactor has even greater effect in the grass system because of no soil disturbance than in the no-till system because narrow strips are disturbed to plant the seeds. Another factor that reduces the soil biomass subfactor S_b in the grass system is greater live and dead root biomass at the high grass production level than for the high corn yield. More dead root biomass is produced by root sloughing with the grass than is left after the corn harvest.

Table 6.17. Effect of yield and tillage system on the soil biomass subfactor at Columbia, MO.

	SOIL BIOMASS SUBFACTOR		
	TYPE TILLAGE SYSTEM		
YIELD (BU/ACRE)	CLEAN TILL	REDUCED TILL	NO TILL
50	0.78	0.74	0.57
100	0.66	0.60	0.38
200	0.48	0.40	0.16

Table 6.18. Effect of production level of a grass on the soil biomass subfactor

	SOIL BIOMASS SUBFACTOR		
YIELD (BU/ACRE)	ST. PAUL, MN	COLUMBIA, MO	BATON ROUGE, LA
1000	0.47	0.51	0.56
2000	0.22	0.27	0.33
4000	0.05	0.08	0.11

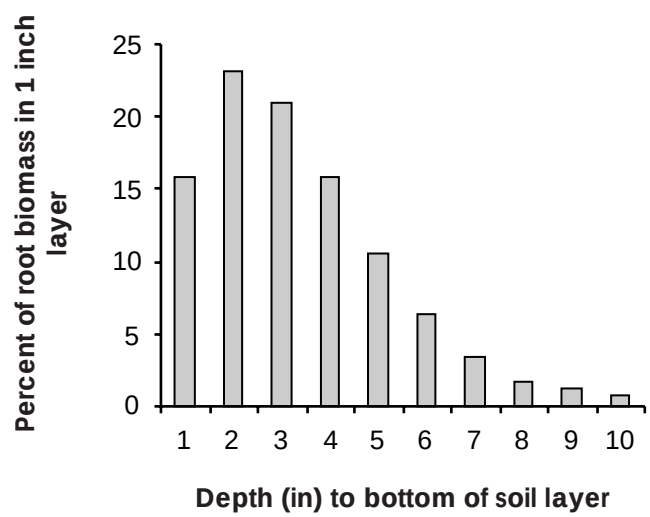
The soil biomass subfactor is a function of location as illustrated in Table 6.18 because decomposition of buried residue and dead roots is related to monthly rainfall and temperature, which varies by location. For example, the soil biomass subfactor for the 2,000

pounds per acre grass production level is 0.22, 0.27 and 0.33 at St. Paul, MN, Columbia, MO, and Baton Rouge, LA, respectively. Decomposition is much higher at Baton Rouge than at St. Paul because of increased temperature and rainfall, especially during winter months in Baton Rouge, where temperatures are sufficiently high for significant decomposition to occur. Given this, the relative effect of location on decomposition increases as production level (i.e., biomass level) increases.

NOTE: ***All features of cover-management systems should be considered rather than focusing on a single variable such as ground cover as a measure of erosion control effectiveness.***

Values for the soil biomass subfactor are significant and comparable in magnitude to values for other subfactors. Although ground cover is frequently considered to be the single most important variable in RUSLE2, the soil biomass subfactor can be equally important. Perhaps most important is the total amount of biomass in a cover-management system and how that biomass is distributed between the biomass pools.

Figure 6.47. **Distribution of live root biomass assumed by RUSLE2.**



6.4.2.5.3. How Biomass Is Added to and Removed from the Soil

RUSLE2 obtains values for live root biomass from data in the vegetation component of the RUSLE2 database for the vegetation currently being "grown." The name of the vegetation associated with each operation having a "begin growth" process is entered in a description of each cover-management system in the management component of the RUSLE2 database. The root biomass values in the RUSLE2 database are for the upper 4 inches (100 mm), whereas equation 6.31 uses biomass values for the upper 10 inches (250 mm). RUSLE2 uses the root distribution illustrated in Figure 6.47 to convert the 4 inch (100 mm) root biomass values to values for a 10 inch (250 mm) depth.[45] The distribution in Figure 6.47 is used for all vegetations[46] and for all time that a particular vegetation is growing. Figure 6.47 shows that most of the live roots are in the upper 4 inches (100 mm) of soil, which is a major reason for the 4 inch (100 mm) depth used for the root biomass input values in the RUSLE2 database.[47]

Other than an operation that includes a "kill" process, nothing affects live root values in RUSLE2 once an operation with a "begin growth" process causes the vegetation to begin to "grow." A "kill" process in an operation transfers the live root biomass at the time of the operation to the dead root biomass pool. (See section 6.4.2.2.3. for a description of how RUSLE2 moves biomass between pools.) Soil disturbing operations redistribute dead roots within the soil but do not bring dead roots to the soil surface. Section 6.4.2.5.4. discusses how a soil disturbance redistributes dead roots in the soil.

NOTE: ***An input for rooting depth is not required by RUSLE2, which does not consider how rooting depth varies with vegetation or plant maturity.***

As plant litter and crop residue decompose on the soil surface, four-tenths of the amount lost by decomposition each day is arbitrarily placed in the buried residue pool in the upper 2 inches (50 mm) of soil so that organic matter can accumulate at the soil surface on pastureland, rangeland, no-till cropland, and other lands not regularly tilled or mechanically disturbed.

Operations with a "disturb soil" process transfer (bury) a portion of the surface (flat) residue to the buried residue pool. The amount of residue that is buried is the product of the surface residue mass and a burial ratio. Values for the burial ratio are entered for each operation with a "disturb soil" process in the operation component of the RUSLE2 database. RUSLE2 distributes the residue that it buries according to one of three mixing distributions illustrated in Figure 6.48. One of the distributions is "inversion with some mixing" for operations like a moldboard plow that invert the soil. Most of the residue is buried in the lower half of the depth of disturbance. The second distribution is

Figure 6.48. The initial distribution when residue is buried by an operation.

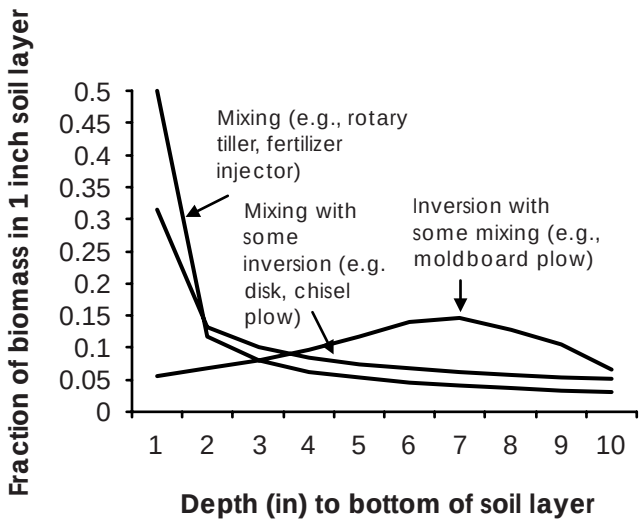
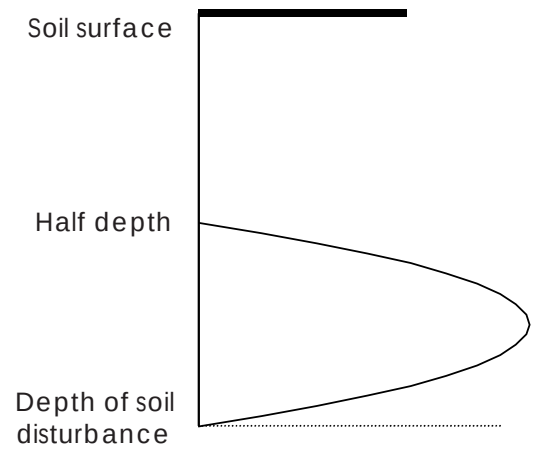


Figure 6.49. Distribution of residue placed by an operation that has an "add residue" process.



"mixing with some inversion" for operations like a tandem disk, chisel plow and field cultivator that leave most of the residue in the upper half of the depth of disturbance. These operations bury residue primarily by mixing but involve some burial by inversion. The third distribution is "mixing only" where almost all of the burial is by mixing with very little by inversion for operations like rotary tillers, subsoilers, and manure and fertilizer injectors that leave most of the residue in the upper one third of the depth of disturbance. One of these three mixing distributions is assigned to each operation with a "disturb soil" process when data for the operation are entered into the RUSLE2 database.

The other way that residue is added to the soil in RUSLE2 is by placing external residue in the soil with an operation that includes an "add residue" process. External residue is placed in the lower half of the disturbance depth, as illustrated in Figure 6.49.

Buried residue is removed from the soil by being resurfaced and transferred to the surface (flat residue) pool by soil disturbing operations. The amount of resurfaced residue is the product of the amount of buried residue in the depth of disturbance at the time of the operation and a resurfacing ratio value assigned to the operation in the RUSLE2 database. The resurfaced residue is extracted layer by layer by first taking out all the buried residue, if necessary, from the top soil layer and then moving to the next and succeeding layers until the total mass of resurfaced residue is obtained. In many cases, only of a portion of the residue in the top 1 inch (25 mm) layer is extracted, and seldom will extraction extend beyond the second layer.

Both buried residue and dead roots are lost by decomposition. The rate that biomass is lost by decomposition depends on the type of residue, which determines the value assigned to the decomposition coefficient for the residue in the residue component of the RUSLE2 database, and on monthly rainfall and temperature (available in the climate RUSLE2 database component) of the site where RUSLE2 is being applied. RUSLE2 maintains biomass pools for buried residue and dead roots, much like a litter layer on the soil surface that is a function of the location. The biomass in these pools is greater at locations where decomposition is less because of reduced temperature and rainfall, such as the northern U.S. in comparison to the southern U.S. The accumulation of biomass in these pools can significantly reduce soil loss as computed by Equation 6.31.

6.4.2.5.4. Redistribution of Dead Roots and Buried Residue in Soil by Operations

Operations with a "disturb soil" process redistribute buried residue and dead roots according to the mixing distribution assigned to that operation. Each day before RUSLE2 buries residue, it redistributes the buried residue and dead roots. Two steps are involved for an operation that has an "inversion with some mixing" distribution. The first step inverts the soil layers with their buried residue and dead roots by layer so that the biomass in the bottom layer becomes the biomass in

the top layer, the biomass in the next to bottom layer becomes the biomass in the next to the top layer, and so forth. The second step transfers biomass between soil layers. A "filtering" concept is used in RUSLE2 where each soil layer is "sifted" so that some of the biomass in each layer is retained in the layer and the remainder of the biomass moves down to the next layer. The amount retained is the product of the biomass in the layer and a retention coefficient having values shown in Table 6.19.[48] The retention values for the "inversion with some mixing" distribution are all equal except for the values for the bottom two layers.

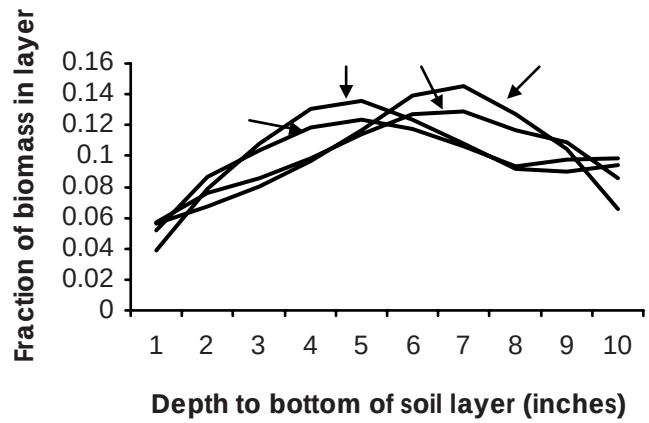
Table 6.19. Retention coefficient values for mixing distribution.

LAYER	INVERSION W/MIXING	MIXING W/INVERSION	MIXING
1(top)	0.40	0.32	0.50
2	0.40	0.39	0.56
3	0.40	0.47	0.61
4	0.40	0.54	0.67
5	0.40	0.62	0.72
6	0.40	0.69	0.78
7	0.40	0.77	0.83
8	0.40	0.84	0.89
9	0.50	0.92	0.94
10	1.00	1.00	1.00

The value for the bottom layer must be 1 so that no biomass passes through the bottom layer and the slightly higher value for the next to bottom layer was empirically determined to determine a good fit between experimental data and computed values. The equal retention values imply that the biomass is equally likely to move downward in the lower part of the disturbance depth as in the upper part. In effect, the soil is uniformly "stirred, mixed and sifted" with disturbance depth.

Only one step is involved in redistributing biomass with the two mixing distributions that primarily do not involve inversion. The retention coefficient for the top layer is assumed to be the same as the fraction of residue placed in the top layer by burial. The values for the retention coefficients for the remaining layers are linearly increased with depth to a value of one (1) as shown in Table 6.19. The value of 1 for the last layer prevents biomass from passing through the bottom layer. The increase in retention values with depth

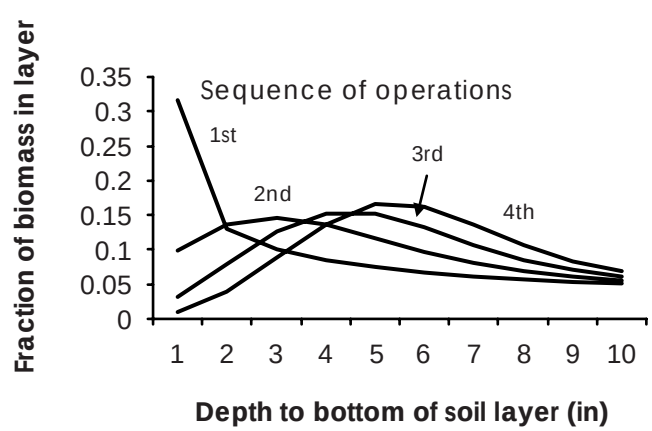
Figure 6.50. Initial burial and redistribution of residue by repeated operations with an inversion mixing distribution (e.g., moldboard plow.)



means that biomass is more likely to move down in the upper part of the disturbance depth than in the bottom part and that stirring and mixing decrease with depth.

Figure 6.50 shows the buried residue distributions after each of four repeated operations for a moldboard plow that has an "inversion with some mixing" mixing distribution where no additional residue is buried after the first operation. The buried residue distribution gradually becomes more uniform with each operation. Figure 6.51 shows buried residue distribution with repeated operations with a tandem disk where residue burial is mainly by mixing. After repeated operations, a bulge of biomass develops that moves downward in the soil. The bulge becomes increasingly concentrated with each operation and moves down-

Figure 6.51. Initial burial and redistribution of residue by repeated operations with a mixing and some inversion mixing distribution (e.g. tandem disk.)



ward less with each operation. Thus rather than the distribution becoming increasingly uniform as assumed in some models, RUSLE2 computes an increasingly non-uniform distribution for the mixing type distributions. Implements like tandem disks and rotary tillers are assumed to bury residue uniformly in the soil, but in fact they only bury residue uniformly under certain conditions, which occurs with about two passes as can be seen from Figure 6.51.

6.4.2.5.5. Additions to the Dead Root Biomass Pool

Biomass is added to the dead root biomass pool when vegetation is "killed" by an operation, such as at harvest, by an operation that kills only a portion of the vegetation, and by root sloughing. An operation that includes a "kill" process transfers all of the live root biomass at the time of the operation to the dead root pool. An example is corn harvest.

A "kill" process is not used in an operation when only a portion of the current plant community is to be "killed" so that only a portion of the live root biomass is to be moved to the dead root pool. (See section 6.4.2.6.3 for information on using "processes" to describe operations.) A "kill" process would transfer the entire live root biomass to the dead root pool. The operation would include a "begin growth" process to instruct RUSLE2 to begin using root biomass values from new vegetation and would include the processes required to handle the above ground biomass associated with the operation. RUSLE2 compares the root biomass value of the previous vegetation on the date of the operation and the first root biomass value for the new vegetation. If the first root biomass value in the new vegetation is less than the root biomass value for the previous vegetation on the date of the operation, RUSLE2 determines the difference and adds the difference to the dead root biomass pool.

NOTE: ***Root biomass and other values used to describe a vegetation can start at any point in time as required to describe the vegetative conditions at any point in time for a cover-management system. The values for day zero and beyond describe conditions on the day that RUSLE2 is to begin using that vegetation.***

An example of a rye cover crop interseeded into silage corn before the corn is harvested illustrates how RUSLE2 handles these root biomass values. Root biomass values for this cover-management system are illustrated in Table 6.20. The rye is seeded and begins to grow before the corn is harvested and continues to grow after the silage corn is harvested to provide vegetative cover through the winter and biomass in the spring when next year's corn crop is planted. Two vegetations are used to describe this cover-management system. The first vegetation is a combination corn-rye, where the first part through day 90 represents only corn growth. After day 90 when the rye is seeded, the values for the root biomass reflect both

Table 6.20. Values for two vegetations: silage corn

DAYS SINCE BEGIN GROWTH	ROOT BIOMASS (LBS/ACRE) PER INCH OVER TOP 4 INCHES)	COMMENT
0	0	Begin growth for corn.
15	40	
30	160	
45	320	
60	480	
75	760	
90	950	Rye begins to develop.
105	980	
120	1080	
135	1280	
150	1380	Silage corn harvested, rye continues to grow.
0	120	Begin growth "calls in" vegetation "interseeded rye after corn silage" that reflects vegetation already growing.
15	300	
30	320	
45	320	
90	320	
105	320	
120	320	
135	340	
150	360	
165	400	
180	400	
195	400	

the corn and rye growing. Had the rye not been interseeded, the root biomass values for the corn would have remained at 950 pounds per acre per inch depth until harvest.

A silage harvest operation on day 150 does not include a "kill" process to kill the corn, even though the corn is actually killed in the field. The silage harvest operation includes processes to properly handle surface biomass and a "begin growth" process that tells RUSLE2 to begin using data from the vegetation interseeded rye after corn silage. The root biomass of 120 pounds per acre per inch depth on day zero represents the state of vegetation when RUSLE2 begins to use data for that vegetation. The root for corn-rye vegetation (the previous vegetation) on the day of the silage harvest was 1,380 pounds per acre per inch depth, while the root biomass for the interseeded rye after corn sillage on day zero was 120 pounds per acre per inch depth. RUSLE2 assumes the difference of 1,260 pounds per acre per inch depth is dead root biomass, which represents the change in live root biomass from "killing" the corn and allowing the rye to continue "growing." RUSLE2 adds this difference to the dead root biomass pool.

Root sloughing, similar to canopy senescence, is an important source of dead root biomass for perennial and similar types of vegetation. The amount of root sloughing in a year ranges from about 25 percent to 40 percent of the root biomass.[49] RUSLE2 represents root sloughing by the decrease in the root biomass during the year, much like RUSLE2 determines senescence by a reduction in canopy. Input values for root biomass should increase when growth occurs and decrease after plant maturity when root biomass is being lost by root sloughing.[50] Roots develop more rapidly than do canopy, and they reach maturity while the canopy is still adding biomass. Root sloughing can be assumed to either precede or parallel canopy senescence. Values for the temporal distribution of root biomass can be manually developed and entered for vegetations in the RUSLE2 database. Also, RUSLE2 includes an easy-to-use procedure that can be used to construct temporally varying root biomass values based on dates of maximum and minimum root biomass and root biomass values at those dates. RUSLE2 also has a procedure that estimates root biomass using built-in values for the ratio of root biomass to above ground biomass production for selected plant communities. See the section 6.4.2.1. that describes the vegetation component of the RUSLE2 database for additional information.

NOTE: ***Using a single root biomass for the entire year for perennial type plants, including hay crops grown for several years, causes RUSLE2 to overestimate soil loss because the dead root biomass pool that accumulates from root sloughing is not represented.***

RUSLE2 determines the amount of root sloughing on each day by comparing the root biomass values on a given day with the root biomass on the previous day. RUSLE2 assumes that a change in root biomass from one day to the next is caused by root sloughing and adds the amount of the decrease to the dead root biomass pool.

6.4.2.5.6. Spatial Non-Uniformity of Soil Biomass

The biomass for live and dead roots and buried residue is spatially non-uniform for row crops, widely dispersed plants like clumps of shrubs and grass on rangelands, and tree seedlings in a forest. However, RUSLE2 assumes that all soil biomass is uniformly distributed, even when the operation only disturbs a portion of the soil surface.

6.4.2.5.7. Assigning Input Values That Determine Soil Biomass

The amount of soil biomass is a critical variable in determining how a cover-management system affects soil loss. The three principal sources of soil biomass are from live root biomass, plant litter and crop residue, and externally added residue. The mass of external residue is based on dry matter and is known. Root biomass values for vegetation should be selected by comparing the vegetation's characteristics with those of vegetations in the RUSLE2 "core database." When selecting root biomass values for a particular vegetation, the role of fine roots versus coarse roots will have to be considered. For example, even though carrots and potatoes make up root biomass, their mass is not considered in assigning root biomass values because those "coarse roots" have little effect on soil loss. In cases where some credit is to be taken for coarse roots, some, but not all, of their biomass is entered along with the biomass of the fine roots.

NOTE: ***A key factor in selecting input root biomass values is to account for the temporal variation in root biomass so that the effect of root sloughing is captured by RUSLE2.***

Do not make field measurements of root biomass values to determine input values for RUSLE2. Measuring

root biomass is very difficult, tedious, and tiresome and should only be done in a research setting. Large errors are common unless extreme care is taken and even then the results may show much variability. The ratio values in the RUSLE2 core database used to determine root biomass values for rangeland plant communities have been chosen based on measured soil loss values obtained during rainfall simulator experiments.[51] Other root biomass values in the RUSLE2 core database have been selected from the research literature, and these values were used when Equation 6.31 was fitted to soil loss data.

NOTE: ***Use of root biomass values that have not been checked for consistency with values in the RUSLE2 "core database" can cause serious errors in RUSLE2.***

The other major source of soil biomass is from decomposition of plant litter and crop residue on the soil surface and from the incorporation of crop residue into the soil. The amount of plant litter is determined by senescence of the plant canopy and the amount of biomass associated with that loss of canopy. The amount of residue produced by a crop is determined by the residue to yield relationships defined for the crop and is entered in the vegetation component of the RUSLE2 database. The other important factor that determines the amount of buried residue is the flattening, burial, and resurfacing ratios used to describe operations in the operation component of the RUSLE2 database.

NOTE: ***Even though a plant community may be a mixture of species, RUSLE2 represents the plant community as a single vegetation where input values are selected to describe the composite effects of the vegetation. RUSLE2 "grows" only one vegetation at a time. RUSLE2 cannot take data from two vegetations, such as corn and rye, and combine them into a single composite vegetation***

6.4.2.6. Soil Consolidation[52]

A mechanical disturbance loosens soil and increases its erodibility, which in turn increases soil loss. After a mechanical soil disturbance, soil erodibility decreases as soil primary particles and aggregates become cemented together by wetting and drying and other soil processes, which is the main soil consolidation effect. A mechanical soil disturbance decreases the bulk density of soil. Increases in soil bulk density do not greatly reduce soil erodibility.

NOTE: ***Soil consolidation in RUSLE2 refers to the decrease in soil erodibility following a mechanical soil disturbance rather than an increase in bulk density.***

6.4.2.6.1. Soil Consolidation Effect

Figure 6.15 is a plot of the soil consolidation subfactor S_c as it decreases with time after a mechanical soil disturbance. The soil is assumed to be 0.45 times as erodible at full consolidation as it is immediately after a disturbance. A soil disturbance resets the soil consolidation subfactor to one (1), and it begins to decrease again with time. Seven (7) years is normally assumed for the time for the soil to become fully consolidated after a mechanical disturbance in the eastern U.S., where rainfall events are sufficiently frequent for the soil to experience repeated wetting and drying cycles required for the cementing process (see section 6.2.8). RUSLE2 will compute times to soil consolidation up to 25 years for areas where average annual precipitation is less than 20 inches (500 mm) to reflect less opportunity for wetting and drying cycles.

The soil consolidation effect is greatest for those soils that have the greatest and most active cementing agents. These agents are most closely related to clay and organic matter particles because of their high specific surface area. Thus, the soil consolidation effect is greatest for soils having high organic matter content, characteristic of cover-management systems involving a high level of soil biomass. The effect of organic matter content as affected by cover-management system is captured in the soil biomass subfactor S_b computed with Equation 6.31.

The soil consolidation effect is also a function of soil texture because of the role of clay in cementing soil particles. The soil consolidation effect is greatest for fine textured soils with high clay content and least for coarse textured soils with low clay content. However, RUSLE2 does not consider the effect of soil texture on the soil consolidation subfactor.[53]

6.4.2.6.2. Importance of Soil Consolidation Factor to Other Variables

The soil consolidation subfactor has indirect effects in RUSLE2 by being a variable in equations used to compute values for other cover-management subfactors. For example, the consolidation subfactor S_c is used in Equation 6.31 to compute values for the soil biomass subfactor S_b. The soil consolidation subfactor is used to compute the rill-to-interrill erosion ratio in Equation 6.10 where soil consolidation is assumed to reduce rill erosion much more than interrill erosion. The ratio of rill-to-

interrill erosion affects the slope length effect and the ground cover subfactor G_c. Mulch is assumed to have reduced effectiveness on steep, cut construction slopes, which are detected in RUSLE2 by a low soil consolidation subfactor and low soil biomass values.

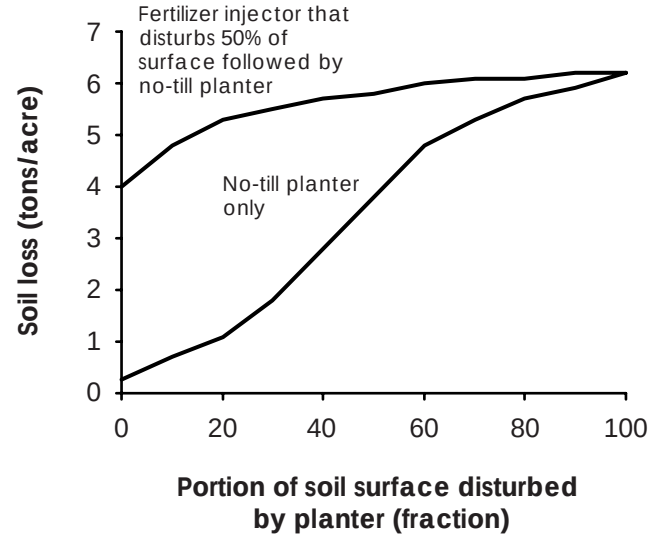
The soil consolidation subfactor is also a variable in RUSLE2 equations used to compute runoff index values (curve numbers) and runoff, which is used to compute how support practices affect soil loss (see section 6.4.2.6.1.). For example, when the soil is consolidated (i.e., S_c values near 0.45), infiltration is assumed to be low and runoff high if no soil biomass is present. A construction site where a surface soil layer was cut away without disturbing the underlying soil represents this condition. However, if the soil is undisturbed, which is indicated by a low S_c value, and contains a high level of soil biomass, infiltration is assumed to be high and runoff low. This condition represents a high production permanent pasture.

An undisturbed soil is required for a layer of high organic matter to develop at the soil surface on range, pasture, and no-till cropland. The soil consolidation subfactor is used as an indicator of the potential for this layer to develop. This effect is captured in Equation 6.31 for the soil biomass subfactor S_b.

The portion of the soil surface that is mechanically disturbed during a cover-management system determines the overall effect of soil consolidation. The effects of the portion of the soil surface disturbed and the soil consolidation subfactor are illustrated in Figure 6.52 for a no-till corn cropping system at Columbia, MO.[54] One of the curves in Figure 6.52 is where the only soil disturbance is by a no-till planter that disturbs the soil in strips for a place to plant the seeds. The portion of the soil surface disturbed by the planter was varied from none to full width disturbance. No other variable such as burial ratio that would normally vary with the portion of the soil surface disturbed was changed. Thus the only effect represented is the effect of soil consolidation as reflected by portion of the soil surface disturbed. The other curve is where a fertilizer injector that disturbs 50 percent of the soil surface precedes the planter. Portions of the soil surface disturbed by the planter were varied, while the 50 percent portion disturbed by the fertilizer injector was fixed.

The ratio of soil loss for the no-till planter with no disturbance and without the fertilizer injector to soil loss with full disturbance in Figure 6.52 is 0.04, which is much more effect than the 0.45 value for the full soil consolidation subfactor for no disturbance. The additional effect beyond the 0.45 is related to the effect of the soil consolidated subfactor on the soil biomass subfactor as computed with Equation 6.31, the reduction in depth over which buried residue mass is averaged for Equation 6.31 as the soil consolidation subfactor decreases, the reduced slope length effect as the soil consolidation subfactor decreases, and decreased ground cover subfactor values as the soil consolidation subfactor decreases.

Figure 6.52. Effect of portion of soil disturbed on soil loss at Columbia, Missouri for no-till corn at 110 bushels/acre. Fertilizer injector does not bury or resurface residue.



The second curve in Figure 6.52 where a fertilizer injector precedes the no-till planter illustrates the importance of considering all soil disturbing operations in a cover-management system instead giving attention solely to a single operation like a planter or drill. Varying the portion of the soil surface disturbed by the planter when it follows the fertilizer injection that disturbs a relatively large portion of the soil surface had relatively little effect on soil loss. The fertilizer injector is the dominant operation in terms of the soil consolidation subfactor effect. Most of the benefits of no-till cropping are lost by the fertilizer injector so adjusting the portion of the soil surface disturbed by the planter had little effect on soil loss.

6.4.2.6.3. Definition of Mechanical Soil Disturbance

Operations that seed crops like corn, soybeans, and wheat in rows, and that inject fertilizer and manure

with thin shanks, disturb only strips of soil and not the entire soil surface. An important input value, as illustrated in Figure 6.49, is the portion of the soil surface disturbed by each operation. The definition of mechanical soil disturbance is required to assign values for the portion of the soil surface that is disturbed by an operation.

NOTE: ***Soil disturbance, as used in RUSLE2, occurs when an operation fractures and loosens the soil, displaces soil, mixes soil and surface residue so that the interface between the residue and the surface soil is no longer distinct, and disrupts a high organic matter layer at the soil surface.***

When an operation displaces soil, the source area of the soil is included in the soil surface disturbed and the receiving area is included under certain conditions. The receiving area **is not** included in the area disturbed if the resulting soil depth from the displaced soil is so thin, less than 0.5 inches (10 mm) as a guide, that it has little effect on detachment by raindrop impact (interrill erosion) or detachment by runoff (rill erosion). The soil surface should be essentially level after an operation to assign a low value to the portion of the soil surface disturbed. The receiving area **is** included in the disturbed area if the surface residue and soil were mixed by the operation or any high organic matter soil layer and the soil surface was disrupted. The receiving area **is** included in the area disturbed, even though the surface residue has not been mixed with soil or high organic matter layer at the soil surface has not been disrupted, if displaced soil is deeper than about 0.5 inches (10 mm) such that significant amounts of interrill and rill erosion occurs because of exposed bare soil. Ridges and furrows are an indication of a high portion of the soil surface disturbed, especially where soil thrown from either side meets to form the ridge. Machines and implements, like scarifiers and hoe drills that involve shanks and shovels, typically disturb a greater portion of the soil surface than implements that involve straight coulters. However, concave coulters and disks can throw large amounts of soil, resulting in almost the entire surface being disturbed.

NOTE: ***A lower limit of 15% for portion of the soil surface disturbed should be used for no-till implements.***

6.4.2.6.4. How RUSLE2 Handles Strips

RUSLE2 does not keep track of individual strips of disturbed areas through time. RUSLE2 maintains only a single composite soil consolidation subfactor value at any time. When an operation occurs that disturbs only a portion of the soil surface, RUSLE2 computes a composite soil consolidation subfactor value based on the portion of the soil surface that is disturbed by using a subfactor value of one (1) for the portion of the soil surface disturbed and the subfactor value at the time for the undisturbed portion at the time of the operation. This composite soil consolidation subfactor value is used in the RUSLE2 soil consolidation subfactor equation, represented by Figure 6.20, to compute an effective time after last soil disturbance. Accounting for time after a soil disturbance starts with this effective time after last disturbance and proceeds.

6.4.2.6.5. Assigning Values for Portion of Soil Disturbed

A value of one (1) is assigned to the portion of the soil surface disturbed for most full width operations like scarifiers, moldboard plows, offset disks, tandem disks, chisel plows, and field cultivators. The portion of the soil surface disturbed for implements like row cultivators, planter, drills, and fertilizer and manure injectors that disturb strips of soil may be, but are not necessarily, less than one (1). Values for the portion of the soil surface disturbed selected for these operations should be consistent with values assigned to comparable operations in the RUSLE "core database," which should be consulted first before values are assigned to new operations being put in the operation component of the RUSLE2 database. However, the portion disturbed can depend on local conditions, specific machines, and individual operators. Thus, input values may need to be adjusted from the "core values" based on the guidelines in section 6.4.2.6.3.

NOTE: ***New input values for portions of soil disturbed by an operation should be carefully examined for consistency, and guidelines should be established so input values are consistently assigned for other new operations.***

Blading and grading used in construction operations must be carefully considered when a value for the portion of the soil disturbed is assigned to these operations. A grading operation for fill material should include a "disturb soil" process that uses a value of one (1) for the portion of the soil surface disturbed, even if the soil has been compacted with a roller or other compaction device. Compacting the soil does not greatly reduce soil erodibility. Repeated wetting and drying and related soil processes must occur to cement the soil particles for the soil to be "consolidated." A zero (0) is assigned to portion of the soil surface disturbed for a grading operation that cuts and removes

NOTE: ***Important RUSLE2 rules:***

- ***Surface material cannot be buried without using an operation with a "disturb soil" process.***
- ***Material cannot be placed in the soil (e.g. manure injection) without an operation with a "disturb soil" process.***
- ***Roughness cannot be created without an operation with a "disturb soil" process.***
- ***Select values for portion of soil surface disturbed based on guidelines in section 6.4.2.6.3.***

NOTE: ***Input values are chosen for RUSLE2 to describe the condition left by an operation, not necessarily the effect on the soil that might have been removed from the local area.***

a soil layer and leaves the lying soil undisturbed. Thus, RUSLE2 assigns a value of one (1) for the soil consolidation subfactor for a fill slope and a value of 0.45 to a cut slope. However, if the cut slope has been ripped with a scarifier, disked for a seed-bed, or mulch crimped in, a value is assigned to the portion of the soil disturbed according to the guidelines in section 6.4.2.6.3.

6.4.2.7. Soil Moisture

The level of soil moisture affects infiltration and runoff to some degree at all locations. However, the effect is least where large amounts of rainfall frequently occur, such as in the southeastern U.S. The effect is more pronounced in the western portion of the Great Plains in the U.S. Soil moisture is removed by growing crops depending on the type of crop and its production level. Soil loss is less following a crop that extracted much of the soil moisture in a low rainfall area. This effect is especially pronounced in the NWRR where rainfall is relatively low and environmental conditions are associated with timing of rainfall and the freezing and thawing of soil under either high or low soil moisture content. A soil moisture subfactor is needed in the NWRR for R_{eq} applications to account for these special effects.

6.4.2.7.1. Soil Moisture Subfactor Effect

Values for the soil moisture subfactor S_m are illustrated in Figure 6.53. Subfactor values are one (1) when the soil profile is "filled" relative to the unit plot and less than one (1) when the soil profile is depleted of moisture relative to the unit plot.

As Figure 6.53 illustrates, the effect is a function of both location and type of crop. Soil moisture subfactor values are lower at Walla Walla than at Pullman because of less precipitation. Also, the values are lower following wheat than following spring peas because of the water usage difference between the two crops. As always, the values for the soil moisture subfactor are one (1) for unit plot conditions.

NOTE: ***The soil moisture subfactor must only be used in the NWRR for R_{eq} applications.***

6.4.2.7.2. Assigning Input Values

An input value is assigned to each type of vegetation. Values are listed in the RUSLE2 core database that can be used as a guide for assigning input values used in the soil moisture subfactor.

The variables in the cover-management component of the RUSLE2 database are listed in Table 6.16.

Figure 6.53. **Soil moisture subfactor values for two locations in Washington for a winter wheat-spring pea rotation. The first peak is the effect of the winter wheat and the second one is the effect of spring peas.**

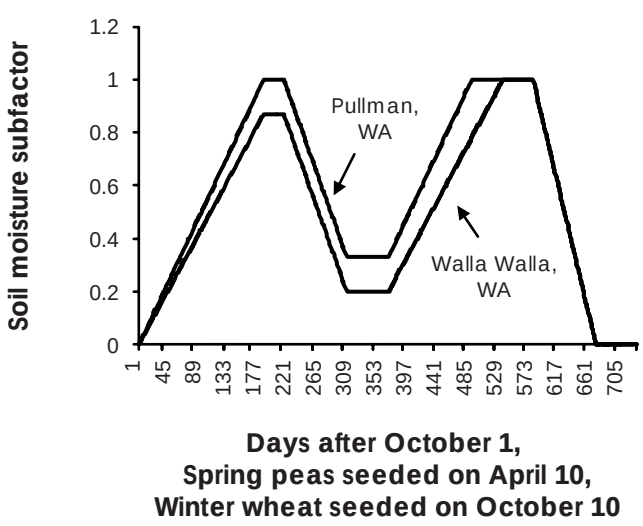


Table 6.16. Variables in the cover-management component of the **RUSLE2** database.

VARIABLE	COMMENTS
List of dates	List of dates for the operations used to create the cover-management condition (practice).
List of operations	Name of operation in operation component from which RUSLE2 pulls information used to describe operation. Operations are events that change vegetation, residue, and/or soil. List of operations used to describe the cover-management condition (practice).
List of vegetations	Name of vegetation in database having the information required by RUSLE2 to represent the effect of vegetation for the period that a particular vegetation is present.
Yield	Identifies production level (yield) in user defined units.
Operation depth	Specifies the depth of operations that disturbs the soil, default value is "recommended".
Operation speed	Specifies the speed of operations that disturbs the soil, default value is "recommended" value in Operation component of database, can enter a different value
External residue	Name of material added to soil surface, uses name to "pull" data from residue component of database. Residue refers to material added to the soil, vegetation produces plant litter and crop residue, external residue is material other than material associated with the vegetations in the management, typical external residue includes manure and mulch (applied erosion control materials).
Residue added/removed	Mass (weight) of material added when external material is applied or the amount of plant material added from the "current" vegetation.
Cover from residue addition	Portion of soil surface covered by the added external or vegetation material, not the actual cover when cover exists at time of application.
Vegetative retardance	Refers to the degree that the vegetation slows surface runoff.

RUSLE2 Appendix I

[1] Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder, coordinators. 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703, 404 pp.

[2] Ellison reference (Citation not available in this draft.)

[3] For discussion of the mathematics related to this approach, see Foster, G.R. 1985. Understanding ephemeral gully erosion (concentrated flow erosion). In: Soil Conservation, Assessing the National Resources Inventory. National Academy Press. Washington, D.C. pp. 90 - 125.

[4] Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall-erosion losses: A guide to conservation planning. U.S. Depatment of Agriculture, Agriculture Handbook # 537.

[5] Equation 6.2 differs from the corresponding equation used in RUSLE1 (AH703). The 0.082 coefficient in equation 6.2 was 0.05 in AH703. For additional discussion, see McGregor, K.C., R.L. Bingner, A.J. Bowie, and G.R. Foster. 1995. Erosivity index values for northern Mississippi. Transactions of the American Society of Agricultural Engineers. 38(4):1039 - 1047.

[6] The USDA-NRCS has a set of climate databases available for erosivity (R), 10 yr EI_{30}, monthly precipitation and monthly temperature that are available from the NRCS state agronomist in your state. The values in this database are on a 1-km by 1-km grid across the U.S. The values have been adjusted with a model known as PRISM for elevation and other spatial factors that affect weather variables. Also, a database is available for the eastern U.S., where the values have been averaged by county. In the western U.S., where counties are large and weather values vary greatly within a county because of elevation changes, take values from the NRCS 1-km by 1km database for your specific location.

[7] The Northwest Wheat and Range Region (NWRR) includes about 10 million acres of non-irrigated cropland in parts of eastern Washington, north central Oregon, northern Idaho, southeastern Idaho, southwestern Montana, western Wyoming, and northwestern Utah. Runoff and erosion processes in this area are dominated by winter events. Many of these events involve rainfall and/or snowmelt on thawing soils. The thawing soils remain quite wet above the frost layer and are highly erodible until the frost layer thaws allowing drainage and consolidation. The transient frost layer near the surface limits infiltration and creates a super-saturated moisture condition such that almost all rainfall and snowmelt runs off.

[8] The R and K factors have units. In this guide R has the units of hundreds of (ft tons in)/(ac yr hr). The corresponding units on K are tons /[ac (hundreds of ft tons in)/(ac hr)]. Metric units in the SI system are (MJ mm)/(ha(h) for erosivity and (t h)/(MJ mm) for erodibility.

[9] The USDA-NRCS has mapped cropland soils in US and soils on many other land uses and has produced maps with map units (names). Properties of each map units are available in published soil surveys by US county. Soils information is available from NRCS in a computer database and in paper form from the local USDA-NRCS office.

[10] Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder. 1997. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Dept. of Agriculture, Agriculture Handbook 703, pp. 404. Much of the information in AH703 on soil erodibility applies to RUSLE2, except for the part on temporal variability of K.

[11] For background information, see Wischmeier, W.H., C.B. Johnson, and B.V. Cross. 1971. A soil erodibility monograph for farmland construction sites. J. Soil Water Conservation. 26:189 - 193. However, information provided in this RUSLE2 User's Guide determines the RUSLE2 application of the nomograph rather than information from other sources.

[12] See the USDA-NRCS soil survey manual for a description of the terms used in the soil erodibility nomograph and for procedures for determining these terms. This manual is available on the NRCS Internet site www.nrcs.usda.gov.

[13] Columbia, MO, is used as a base location in both RUSLE1 and RUSLE2. USLE values for slope length and steepness effect, soil loss ratio, and P factors are assumed to apply at Columbia. RUSLE2 adjusts its values about these base values. The weather at Columbia is near the "middle" of the data for the eastern U.S.

[14] Considering the effect of land use on organic matter in K seems logical because the soil erodibility nomograph includes a variable for organic matter. However, the erodibility nomograph must not be used for that purpose. RUSLE is an empirical equation based on certain definitions rather than being a process-based approach. The variables in RUSLE could have been defined in many different ways, but once defined as in RUSLE, definitions must be carefully followed. Adjusting K to account for the effect of cropping and management on organic matter is inconsistent with RUSLE definitions.

[15] El-Swaify, S.A., E.W. Dangler, and C.L. Armstrong. 1982. Soil Erosion by Water in the Tropics. College of Tropical Agriculture and Human Resources, Univ. of Hawaii, Honolulu, HI. pp. 17.

[16] Soil Survey Manual available on the Internet site www.ftw.nrcs.usda.gov/tech_ref.

[17] The equations used by RUSLE2 are described by Foster, G.R., R.A. Young, and W.H. Neibling. 1985. Sediment composition for nonpoint source pollution analyses. Trans. ASAE 28(1):133 - 139, 146.

[18] A typical procedure used to measure ground cover is lay a line transect, such as a knotted string or measuring tape, across the soil surface diagonal to any cover orientation. An estimate of ground cover is the percentage of knots or markings on a tape that contact ground cover. Another approach is take photographs of the surface, lay a grid over the photograph, and count the intersection points that touch ground cover.

[19] Contact the NRCS Internet site at www.nrcs.usda.gov for additional information.

[20] A definition of soil loss tolerance is intentionally not given here. The many factors that are considered in assigning soil loss tolerance values are discussed by Toy, T.J., G.R. Foster, and K.G. Renard. 2002. Soil Erosion: Processes, Prediction, Measurement, and Control. John Wiley and Son, New York, NY. (in press). The definition for soil loss tolerance given in AH537 implies that erosion can occur indefinitely at T and the soil cannot be degraded even though T values exceed soil formation rates by about a factor of ten. In the context of RUSLE2, a soil loss tolerance value is a target soil loss selected to guide conservation planning in the particular situation where RUSLE2 is being applied.

[21] See AH703 for a discussion of this adjustment, including the mathematics used to make the adjustment.

[22] Equation 6.10 replaces having to select an LS "Table" as required in RUSLE1. RUSLE2, in effect, selects the proper "LS Table" based on cover-management conditions.

[23] The structure of RUSLE2 is that the factors for topography, cover-management, and supporting practices are relative to the unit plot for hydrologic conditions at Columbia, MO. The equations used in RUSLE2 are designed to capture main effects rather than all effects. Therefore, while runoff depth may not capture all effects of runoff rate, it captures the main effects.

[24] Soil consolidation refers to how soil loss decreases with time after a mechanical soil disturbance. Soil consolidation includes how the increase in soil bulk density after a mechanical soil disturbance affects soil loss, but the major effect is how wetting and drying and other processes cement soil particles.

[25] No interaction between canopy cover and ground cover was assumed in RUSLE1. As a result, too much credit was given to effect of canopy at low fall heights. In fact, RUSLE1erroneously computed a zero soil loss for a 100 percent canopy when fall height was zero, rather than soil loss for 100 percent ground cover.

[26] RUSLE2 differs from RUSLE1 in this regard. In RUSLE1, different yields could only be accommodated by creating a vegetation description for each yield. In RUSLE2, a single base vegetation description is created for a particular yield that RUSLE2 uses to adjust values to fit the yield entered for a specific site. However, a vegetation description can be used in RUSLE2 for specific yields just as was required in RUSLE1. See section 6.4.2.1.6. for a description of the procedures RUSLE2 uses to adjust for yield.

[27] RUSLE2 tracks above ground biomass through time, which is different from RUSLE1. In RUSLE1, a biomass value had to be entered that corresponded to the date of an operation that affected above ground biomass. RUSLE2 does not have this requirement. The biomass values are entered at maximum canopy and RUSLE2 tracks biomass through time. An operation can be entered at any time without having to specify biomass on the date of the operation as an input.

[28] "External residue" is nomenclature used in RUSLE2 to refer to any material added to the soil surface or placed in the soil from a source other than vegetation grown on site.

[29] A surface seal is a thin, dense layer of soil particles at the soil surface caused by soil particle dispersion associated with raindrop impact and other processes. This thin layer, which has a reduced permeability, is known as a surface "seal" when wet and a "crust" when dry.

[30] RUSLE2 eliminates the need to choose a b value for the effectiveness of ground cover as was required in RUSLE1.05 or the choice of a land use as was required in RUSLE1.06. RUSLE2 in effect automates a manual selection of b required in RUSLE1, and RUSLE2 computes b values as cover-management conditions vary through time that RUSLE1 did not compute.

[31] An operation is an event that mechanically disturbs the soil, changes the vegetation, or changes the residue.

[32] RUSLE2 assumes that flat residue, buried residue, and dead roots all decompose at the same rate. Standing residue is assumed to decompose at a much slower rate than residue in the other pools. Decomposition rate at the base of standing residue, which determines the rate that standing residue falls, is the same as the decomposition rate for flat residue.

[33] The major reason for having and using a RUSLE2 "core database" is to help ensure consistency in soil loss estimates, especially by cover-management system and by location. Consistency is a major requirement when RUSLE2 is used to implement cost sharing and regulatory type programs, so that all clients can be treated fairly.

[34] Toy, T.J., G.R. Foster, and K.G. Renard. 2002. Soil Erosion: Processes, Prediction, Measurement, and Control. John Wiley and Son, New York, NY. (in press).

[35] See Figure C-10, AH703 for details.

[36] Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall-erosion losses: A guide to conservation planning. U.S. Dept. of Agriculture, Agriculture Handbook # 537.

[37] RUSLE2 differs from RUSLE1 in that RUSLE1 did not use a tillage intensity effect. The roughness that RUSLE1 uses in its computations is completely independent of existing roughness at the time of an operation. That is, the roughness following a spike tooth harrow in RUSLE1 is the same regardless of whether the harrow follows a moldboard plow or a tandem disk. Input roughness values are the same for RUSLE1 and RUSLE2 for operations where the tillage intensity is 1, but roughness values for operations where tillage intensity is less than one (1), will need to be smaller in RUSLE2 than in RUSLE1 to achieve comparable roughness values in both models. However, because of the tillage intensity factor effect, the two models cannot compute the same roughness values for all situations.

[38] Young, R.A. and C. K. Mutchler. 1969. Soil and water movement in small tillage channels. Trans. ASAE. 12(4):543-545. Also, personal communication with K.C. McGregor and C.K. Mutchler, USDA-Agricultural Research Service, National Sedimentation Laboratory, Oxford, MS.

[39] Rock cover entered in the soil component of the RUSLE2 database remains constant and is not subject to burial or decomposition. This rock cover is unaffected by operations in contrast to rock added as an external residue that is manipulated by operations.

[40] Buried residue is RUSLE2 nomenclature for material in the soil that affects soil loss that has been buried or placed in the soil by an operation.

[41] Browning, F.M., R.A. Norton, A.G. McCall, and F.G. Bell. 1948. Investigations in erosion control and reclamation of eroded land at the Missouri Valley Loess Conservation Experiment Station, Clarinda, Iowa, 1931-42. USDA Technical Bulletin 959. (Citation being verified and may not be complete and accurate in this draft.)

Copley, T.L., L.A. Forrest, A.G. McCall, and F.G. Bell. 1944. Investigations in erosion control and reclamation of eroded land at the Central Piedmont Conservation Experiment Station, Statesville, North Carolina, 1930-40. USDA Technical Bulletin 873.

Hays, O.E., A.G. McCall, and F.G. Bell. 1949. Investigations in erosion control and reclamation of eroded land at the Upper Mississippi Valley Conservation Experiment Station near LaCrosse, Wisconsin, 1933-43. USDA-Technical Bulletin 973.

[42] Equation 6.31 also has a second part for very low soil biomass where $c_b = 1$ so that the soil biomass subfactor equals 1 when no soil biomass is present.

[43] Soil loss ratio values in AH537 are the ratio of soil loss with a given cover-management system at a particular crop stage period to soil loss from the unit plot for the same crop stage. The seedbed crop stage period is when the soil has been tilled to prepare a relatively smooth surface for seeding a crop so that the major effect is from soil biomass.

[44] The soil loss ratio values, except for conservation tillage and "undisturbed" land, are a summary of field measured soil loss for more than 10,000 plot years of data. Erosion data are quite variable for unexplained reasons. Also, the length of record often varied between studies and locations, and the number of treatments and replications and other variables differed between locations, which prevents the data from being analyzed by common statistical procedures. Instead, the data must be analyzed and interpreted for main effects, which was expertly done by W.H. Wischmeier and D.D. Smith in AH537. The soil loss ratio values in AH537 are the most comprehensive available by far for calibrating RUSLE2 and are much better for calibrating and validating RUSLE2 than the original soil loss data.

[45] RUSLE2 divides the soil into 1-inch (25 mm) layers to account for soil biomass. Depths of disturbance are rounded to the nearest 1-inch (25 mm) so that the depth of disturbance corresponds with the bottom of a soil layer. The number of layers considered in an operation depends on the number of 1-inch (25 mm) layers in the depth of disturbance. Thus, an operation with a 2 inch disturbance depth only involves two layers. The minimum depth that RUSLE2 recognizes is 1 inch (25 mm).

[46] Data from several literature sources for major agricultural crops of corn, soybeans, wheat, and cotton, several hay and pasture crops, and for selected vegetable crops were reviewed to determine the distribution in Figure 6.47. The relative shape of the root distribution was very nearly the same for all crops and rooting depth for the roots judged to have the most effect on soil loss did not vary among crops, except that the rooting depths for field and pasture crops was about twice that for vegetable crops. However, even though this difference in root depth occurs among these crops and rooting varies with plant development, RUSLE2 captures the main effect of roots on soil loss.

[47] The root distribution differs between RUSLE2 and RUSLE1. RUSLE1 assumed that the root biomass in the second 4 inch (100 mm) soil layer was 75 percent of that in the top 4 inch (100 mm) layer and that no roots were below 8 inches (200 mm). Based on Figure 6.47, RUSLE1 assumed significantly too much root biomass below the 4 inch (100 mm) soil layer below the upper 4 inches (100 mm) of soil.

[48] The development and validation of the RUSLE2 procedure used to distribute buried residue in the soil and to redistribute previously buried residue and dead roots is described in Appendix ?? (Not available in this draft). The RUSLE2 procedure differs from procedures used in other models where material becomes uniformly distributed in the soil after many repeated events of the same operation.

[49] For additional information, see Reeder, J.D., C.D. Franks, and D.G. Michunas. 2001. Root biomass and microbial processes. In: The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. R.K. Follett, J.M. Kimble, and R. Lal (eds). Lewis Publisher, Boca Raton, FL.

[50] The time invariant C factor in RUSLE1 uses a single representative value for root biomass for the entire year and does not consider root sloughing and the accumulation of a dead root biomass pool that can significantly reduce soil loss. Also, the time invariant C factor in RUSLE1 does not consider the accumulation of a buried residue biomass pool that significantly reduces soil loss. Although the time invariant C factor in RUSLE1 was easy to use, it could seriously over estimate soil loss by not considering these important soil biomass pools. Thus, RUSLE2 does not include a time invariant cover-management computation, but it does include many of the easy to use features of the RUSLE1 time invariant C factor so that root sloughing can be easily considered using simple inputs that mimic RUSLE1 inputs. RUSLE1 can consider these soil biomass pools by using its time variant C factor with temporally varying canopy and root biomass values.

[51] The data used to calibrate RUSLE2 to rangelands were collected as a part of the Water Erosion Prediction Project (WEPP) by R. Simantion and others, USDA-ARS, Tucson, AZ. See Table 5-4 in AH703.

[52] A prior land use (PLU) subfactor was used in RUSLE1. This subfactor was the product of the soil consolidation subfactor and the soil biomass subfactor. This same product is used to display RUSLE2 subfactor values in some of the templates.

[53] The soil consolidation subfactor in RUSLE2 is one of the variables least well defined by research. Although its effect varies with soil texture, the research data are not sufficient to derive an empirical equation for the effect of soil texture. Therefore, the soil consolidation effect in RUSLE2 represents an overall effect across all soil textures. Also, the soil consolidation subfactor equation was primarily derived from soil loss measured at Zanesville, OH. However, limited soil loss data from other locations indicate that the equation is valid in general.

[54] The effects computed for the soil consolidation subfactor differ between the non-R_{eq} and R_{eq} applications. The R_{eq} applications give increased credit for soil biomass, which is affected by the soil consolidation subfactor, but the R_{eq} applications do not adjust the soil length and the ground cover subfactor values as a function of the rill-to-interrill ratio that are used in non-R_{eq} applications.