CHAPTER 4. SLOPE LENGTH AND STEEPNESS FACTORS (LS)

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CHAPTER 4. CONTENTS

The effect of topography on erosion in RUSLE is accounted for by the LS factor. Erosion increases as slope length increases, and is considered by the slope length factor (L). Slope length is defined as the horizontal distance from the origin of overland flow to the point where either (1) the slope gradient decreases enough that deposition begins or (2) runoff becomes concentrated in a defined channel (Wischmeier and Smith 1978). Surface runoff will usually concentrate in less than 400 ft, which is a practical slope-length limit in many situations, although longer slope lengths of up to 1,000 ft are occasionally found. Unless the surface has been carefully graded into ridges and furrows that maintain flow for long distances, few slope lengths as long as 1,000 ft should be used in RUSLE. Slope length is best determined by pacing or measuring in the field. For steep slopes, these lengths should be converted to horizontal distance for use in RUSLE. Slope lengths estimated from contour maps are usually too long because most maps do not have the detail to indicate all concentrated flow areas that end RUSLE slope lengths. Figure 4-1 illustrates some typical slope lengths. Hints and guidelines for choosing slope lengths are given in a following section.

The slope steepness factor (S) reflects the influence of slope gradient on erosion. Slope is estimated in the field by use of an inclinometer, Abney level, or similar device. Slope may be estimated from contour maps having 2-ft contour intervals if considerable care is used.

Both slope length and steepness substantially affect sheet and rill erosion estimated by RUSLE. The effects of these factors have been evaluated separately in research using uniform-gradient plots. However, in erosion prediction, the factors L and S are usually evaluated together, and values can be selected from tables 4-1, 4-2, 4-3, or 4-4 for uniform slopes. The following sections give the relationships used to develop these tables. Also, a section explains how to apply RUSLE to nonuniform slopes.

SLOPE LENGTH FACTOR (L)

Plot data used to derive the slope length factor (L) have shown that average erosion for the slope length λ (in ft) varies as

$$L = (\lambda/72.6)^m \qquad [4\text{-}1]$$

where 72.6 = the RUSLE unit plot length in ft and m = a variable slope-length exponent (Wischmeier and Smith 1978). The slope length λ is the horizontal projection, not distance parallel to the soil surface.

The slope-length exponent m is related to the ratio β of rill erosion (caused by flow) to interrill erosion (principally caused by raindrop impact) by the following equation (Foster et al. 1977):

$$m = \beta/(1 + \beta) \qquad [4\text{-}2]$$

Values for the ratio β of rill to interrill erosion for conditions when the soil is moderately susceptible to both rill and interrill erosion were computed from (McCool et al. 1989)

$$\beta = (\sin \theta/0.0896) / \left[3.0(\sin \theta)^{0.8} + 0.56\right] \qquad [4\text{-}3]$$

where θ = slope angle. Given a value for β, a value for the slope-length exponent m is calculated from equation [4-2].

The middle column in table 4-5, calculated from equations [4-3] and [4-2], gives values for m that are typical of agricultural fields in seedbed condition. When runoff, soil, cover, and management conditions indicate that the soil is highly susceptible to rill erosion, the exponent m should be increased as shown in the right column of table 4-5. This condition is most likely to occur on steep, freshly prepared construction slopes. These values for m were determined by doubling the β values from equation [4-3] before applying equation [4-2].

Conversely, when the conditions favor less rill erosion than interrill erosion, m should be decreased as shown in the left column of table 4-5. Values for m and LS for rangelands are usually taken from tables for the low ratio of rill to interrill erosion; those values were computed by halving the β values from equation [4-3] before applying equation [4-2]. Values in table 4-5 are based on an analysis by McCool et al. (1989).

When deposition occurs in furrows between ridges and in depressions, soil loss is independent of slope length; therefore the slope-length exponent is zero. Chapter 6 on the RUSLE P factor describes how to apply RUSLE to these conditions.

The slope-length exponent for the erosion of thawing, cultivated soils by surface flow (common in the Northwestern Wheat and Range Region described in ch. 2) differs from the values given in table 4-5. For the erosion of thawing soil by surface flow alone (McCool et al. 1989, 1993), a constant value of 0.5 should be used for the slope length exponent m, and LS values from table 4-4 should be used. When runoff on thawing soils is accompanied by rainfall sufficient to cause significant interrill erosion, values from table 4-5 for the low ratio of rill to interrill erosion should be used for the slope-length exponent m, and LS values from table 4-1 should be used.

SLOPE STEEPNESS FACTOR (S)

Soil loss increases more rapidly with slope steepness than it does with slope length. The slope steepness factor (S) is evaluated from (McCool et al. 1987)

$$S = 10.8 \sin \theta + 0.03 \qquad s < 9\% \qquad [4\text{-}4]$$

$$S = 16.8 \sin \theta - 0.50 \qquad s \geq 9\% \qquad [4\text{-}5]$$

Equation [4-5] is based on the assumption that runoff is not a function of slope steepness, which is strongly supported by experimental data for steepness greater than about 9%. The extent of the effect of slope on runoff is highly variable on cultivated soils. Runoff is assumed to be unaffected by slope steepness on rangelands not recently treated with mechanical practices such as ripping. The effect of slope on runoff and erosion as a result of mechanical disturbance is considered in the support practices factor (P) (ch. 6).

McIsaac et al. (1987a) examined soil-loss data from several experiments on disturbed lands at slopes of up to 84%. They recommended an equation of a form similar to that of equations [4-4] and [4-5]. Their coefficient of sin θ was a range that encompassed equations [4-4] and [4-5]. Thus these equations should also be valid for disturbed-land applications.

Equations [4-4] and [4-5] are not applicable to slopes shorter than 15 ft. For those slopes, the following equation should be used to evaluate S (McCool et al. 1987):

$$S = 3.0 (\sin \theta)^{0.8} + 0.56 \qquad [4\text{-}6]$$

This equation applies to conditions where water drains freely from the end of the slope.

For the slope steepness factor given by equation [4-6], it is assumed that rill erosion is insignificant on slopes shorter than 15 ft and that interrill erosion is independent of slope length. Therefore, equation [4-6] should not be applied to slopes where rill erosion is expected to occur. Rill erosion is assumed to begin with a slope length of 15 ft, although it will occur on shorter slopes that are especially susceptible. Conversely, rill erosion will not begin until longer slope lengths are reached on soils that are consolidated and resistant to detachment by flow.

When recently tilled soil is thawing, in a weakened state, and subjected primarily to surface flow, the following equations for S of McCool et al. (1987, 1993) should be used:

$$S = 10.8 \sin \theta + 0.03 \qquad s < 9\% \qquad [4\text{-}7]$$

$$S = (\sin \theta \, / \, 0.0896)^{0.6} \qquad s \geq 9\% \qquad [4\text{-}8]$$

Equations [4-7] and [4-8] were used to construct table 4-4.

TOPOGRAPHIC FACTOR (LS)

The combined LS factor in RUSLE represents the ratio of soil loss on a given slope length and steepness to soil loss from a slope that has a length of 72.6 ft and a steepness of 9%, where all other conditions are the same. LS values are not absolute values but are referenced to a value of 1.0 at a 72.6-ft slope length and 9% steepness.

Procedures are developed in this section for predicting soil loss on uniform slopes, where steepness is the same over their entire length; on irregular or nonuniform slopes that may be concave, convex, or complex; and on a particular segment of a slope.

LS Factor Values for Uniform Slopes

Tables 4-1, 4-2, 4-3, and 4-4 give LS values for uniform slopes. These tables should be used for RUSLE-type slopes with a fairly uniform surface. Table 4-1 is used for rangeland and pasture where the ratio of rill to interrill erosion is low. Table 4-2 is used for cropland where the ratio of rill to interrill erosion is moderate. Table 4-3 is used for construction sites where the ratio of rill to interrill erosion is high and the soil has a strong tendency to rill. Table 4-4 is used for thawing soil where most of the erosion is caused by surface flow.

In tables 4-1, 4-2, and 4-3 for slopes longer than 15 ft, S is calculated from equations [4-4] and [4-5]. For slope lengths of 3-15 ft and steepness greater than or equal to 9%, LS values were calculated for the 3-ft slope length using the short-slope equation [4-6] for S and equations [4-3], [4-2], and [4-1] with λ = 15 ft for L. Then for a given slope length of 3-15 ft and a given steepness, a linear relationship (based on the logarithm of length) was used to interpolate between the logarithm of LS at 3 ft and the logarithm of LS at 15 ft to provide intermediate LS values. For slopes of less than 9%, equation [4-4] was used for S, and equations [4-3], [4-2], and [4-1] with λ = 15 ft were used for L. The short-slope equation [4-6] was not used because for very low slopes, the criterion of free draining would not be met. The inapplicability of equation [4-6] is illustrated by the fact that for very low slopes, the use of equation [4-6] indicates a larger LS value at 3 ft than does the use of equation [4-4] at 20 ft.

The range of LS values for slope lengths of 15-1,000 ft is much greater in table 4-3 than in table 4-1, indicating that the range in L is smaller when interrill erosion is dominant than when rill erosion is dominant. Use of the

72.6-ft slope length and 9% steepness as unit conditions in RUSLE leads to the unexpected result that LS values on short slopes for highly erodible conditions (table 4-3) are smaller than those for less erodible conditions (table 4-1). The difference in overall soil loss is accounted for in the K and C factors. Conditions where soil loss varies little with slope length generally have relatively low C-factor values: less than 0.15. Conditions where soil loss varies greatly with slope length typically have high C-factor values. No LS values for slopes shorter than 15 ft are given in table 4-4. At this time, there are no data to use to develop relationships for short slopes under thawing soil conditions.

Irregular and Segmented Slopes

The shape of a slope affects the average soil loss and the soil loss along the slope. For example, the average soil loss from a convex slope can easily be 30% greater than that for a uniform slope with the same steepness as the average steepness of the convex slope. The difference in soil loss is much greater for maximum erosion on the slopes. The average erosion on a concave slope that does not flatten enough to cause deposition is less than that on a uniform slope that is equivalent to the average concave-slope steepness. Maximum erosion along a concave slope, which occurs about one-third of the way along the slope, may nearly equal the maximum erosion on a uniform slope. Therefore, when the slope shape is significantly curved, use of the procedure for an irregularly shaped slope (outlined below) should be considered (Foster and Wischmeier 1974).

If a nonuniform slope of unit width is broken into a number of segments, each with similar characteristics, an equation for sediment yield from the ith segment is (Foster and Wischmeier 1974)

$$E_i = RK_iC_iP_iS_i\left(\lambda_i^{m+1} - \lambda_{i-1}^{m+1}\right) / (72.6)^m \qquad [4\text{-}9]$$

where

E_i = sediment yield from ith segment from top of slope,
R = rainfall and runoff factor,
K_i = soil erodibility for ith segment,
C_i = cover-management factor for ith segment,
P_i = support practice factor for ith segment,
S_i = slope steepness factor for ith segment, and
λ_i = length (ft) from top of slope to lower end of ith segment.

The soil loss per unit area, A_i, for the ith segment is then the sediment yield from that segment divided by the segment length, as follows:

$$A_i = RK_iC_iP_iS_i\left(\lambda_i^{m+1} - \lambda_{i-1}^{m+1}\right) / \left(\lambda_i - \lambda_{i-1}\right)(72.6)^m \qquad [4\text{-}10]$$

The term $S_i\left(\lambda_i^{m+1} - \lambda_{i-1}^{m+1}\right) / \left(\lambda_i - \lambda_{i-1}\right)(72.6)^m$ in equation [4-10] is the effective LS for the segment.

These relationships are applicable to any slope that meets the criteria for the application of RUSLE. The slope segments can be of unequal length. Computations with unequal slope lengths are most easily handled with a digital computer, for example, by use of the RUSLE computer program. However, to illustrate application of the method, slopes of equal segment length will be used. The term for effective segment LS becomes

$$\begin{aligned} LS_i &= S_i\left\{(ix)^{m+1} - [(i-1)x]^{m+1}\right\} / \left[ix - (i-1)x\right](72.6)^m \\ &= S_i x^m\left[i^{m+1} - (i-1)^{m+1}\right] / (72.6)^m \end{aligned} \qquad [4\text{-}11]$$

where

LS_i = effective LS for ith segment, and
x = length in ft of each segment.

An additional relationship that proves useful is the soil loss per unit area, A_i, from any segment of a uniform slope, as follows:

$$A_i = RK_iC_iP_iS_i\left\{(ix)^{m+1} - [(i-1)x]^{m+1}\right\} / (72.6)^m\ x \qquad [4\text{-}12]$$

The total soil loss per unit area from a uniform slope of n segments of length x is

$$A = RKCPS(nx)^m / (72.6)^m \qquad [4\text{-}13]$$

If equal RKCP values along the slope are assumed, the ratio of soil loss from any segment to soil loss from the total slope is

$$A_i/A = \left\{ \left[(ix)^{m+1} - ((i-1)x)^{m+1}\right] / (72.6)^m \, x \right\} \cdot \left\{(72.6)^m/(nx)^m\right\}$$
$$= \left[i^{m+1} - (i-1)^{m+1}\right] / (n)^m \qquad [4\text{-}14]$$

Values of A_i/A for a range of values of m appear in table 4-6.

The simplest irregular-slope case is for soil and cover to be constant along the slope. To apply the irregular-slope procedure, the convex, concave, or complex slope is divided into equal-length segments and the segments are listed in the order in which they occur on the slope, beginning at the upper end (as shown in table 4-7). The number of segments depends on how many are required to treat each segment as uniform for practical purposes. In many situations, three segments are sufficient, and more than five are seldom needed.

The segments and their slopes are listed in order from the top of the slope, columns 1 and 2 of table 4-7. Then the LS values for the entire slope length at the segment slopes are selected from tables 4-1, 4-2, 4-3, or 4-4 and are listed in column 3. In this example, a moderate ratio of rill to interrill erosion is assumed; thus table 4-2 is used. The ratio of soil loss from the segment to total soil loss is selected from table 4-6, based on the m value from table 4-5, and listed in column 4. Interpolation may be required. (If the evaluation is from a thawing soil, an m value of 0.5 is used.) Column 5 is the product of columns 3 and 4 divided by the number of segments. The total of the values in column 5 is the LS value for the entire slope. The segment LS is given in column 6 as the product of columns 3 and 4. This value will predict average soil loss in a given segment.

In this example, the LS value that gives the average soil loss for the convex slope is 3.76 versus a value of 2.84 for a 400-ft-long uniform slope with a gradient of 10%, the average steepness of the convex slope. Average soil loss on the convex slope is about 32% greater than that on the uniform slope.

The maximum erosion in this example occurs at the end of both the uniform and convex slopes. From table 4-7, the maximum segment LS is 7.58 for the convex slope and (2.84 x 1.38 =) 3.92 for the uniform slope (enter table 4-6 with an exponent value of 0.52 for segment 3). That is, soil loss over the lower third of the convex slope is almost double that for the lower third of the uniform slope.

For a concave slope of the same length with the segments in reverse order, the values in column 3 would be listed in reverse order. The data for a concave slope are given in table 4-8. The weighted average LS for the concave slope is about 15% smaller than that for an equivalent uniform slope. The maximum soil loss for a segment, as indicated by the segment LS values in column 6, is greatest from the middle segment of the slope. Maximum erosion on this segment is about 76% of maximum erosion on the lower length of the uniform slope. Average soil loss on the concave slope is about 85% of that on the uniform slope.

CHANGES IN SOIL TYPE OR COVER ALONG THE SLOPE

The procedure for irregular slopes can include the evaluation of changes in soil type along a slope. The values in column 5 of table 4-7 or 4-8 are multiplied by the respective values of the soil erodibility factor (K) before summing. The procedure is illustrated in table 4-9. In the example, by use of the data from table 4-7, the erosion on the last segment is seen to be 14 times that on the first segment, whereas it was only 10 times that when K was uniform along the convex slope. This example illustrates how erosion can be great if an erodible soil occurs on the lower end of a convex slope. Average soil loss for the convex slope, based on the sum of values in column 6, is 45% greater than that estimated for the average K (0.32) on an equivalent uniform slope.

Within limits, the procedure can be further extended to account for changes in the C and P factors along the slope by adding a column of segment C and P values. The procedure applies to the segments experiencing net erosion but not to the segments experiencing net deposition. The amount of deposition cannot be estimated by RUSLE.

The soil loss from any segment of a slope can be estimated by the irregular-slope procedure previously presented (column 6 in tables 4-7 and 4-8 is the segment LS). This value can be used with the pertinent RKCP value for the slope to estimate average soil loss from the particular segment. Similarly, column 7 in table 4-9 is the segment KLS and can be used with the RCP value for the slope to estimate average soil loss from the particular segment.

ALTERNATIVE METHOD FOR ESTIMATING LS FOR A SEGMENT

One application of the irregular-slope procedure is to estimate soil loss on a slope segment and compare that against a soil-loss-tolerance value. The irregular-slope procedure was illustrated previously to show how average erosion for segments along a slope can be computed.

A modification of the procedure can also be used. The slope is divided into equal-length segments like the three segments for the convex slope in table 4-7. Assume that a soil-loss estimate is needed for segment 3. Find the LS value from table 4-2 for a uniform slope having the steepness of the segment and total slope length to the lower end of the segment (400 ft). In this example, this LS value is 5.34. Multiply this value by the soil loss factor, 1.42, in table 4-6 using the value for the third segment in a three-segment slope. The product is 7.58, which is the LS value to use for computing erosion for the segment.

Computation of LS for the second segment requires obtaining the LS value for the uniform slope based on the segment steepness and the length to the lower end of the particular segment (267 ft). The LS value is 2.29 in this example. The third segment has no effect on what happens on the upslope segments; when the user is working on the second segment with this approach, the problem becomes a two-segment slope. Therefore, the factor value, 1.30, chosen from table 4-6 is for the end segment of a two-segment slope. The LS for the second segment is (2.29 x 1.30 =) 2.98, which is the same value obtained earlier in table 4-7.

RELATION OF SOIL-LOSS-TOLERANCE VALUES TO SEGMENT EROSION

Soil-loss-tolerance values given in soil surveys are based on average soil loss along a uniform slope (Schertz 1983). Even on a uniform slope, soil loss on the lowest segment of the slope may be as much as 70% greater than the average value for the slope. Slope-average soil-loss-tolerance values must first be adjusted before soil-loss values for segments along an irregular slope are compared to them. This adjustment takes into account the position on the slope and is made by multiplying the slope-average soil-loss-tolerance value by soil-loss-factor values from table 4-6. The procedure is illustrated for a uniform slope on cropland where RKCP = 1.0 is assumed and the soil-loss- tolerance value, T, is 2.0 ton· $acre^{-1}\cdot yr^{-1}$. The adjusted soil-loss-tolerance values for three segments along a 10% uniform slope of 400-ft length are 2.0 x 0.57 = 1.14 ton · $acre^{-1}\cdot yr^{-1}$ for segment 1, 2.0 x 1.05 = 2.10 ton · $acre^{-1}\cdot yr^{-1}$ for segment 2, and 2.0 x 1.38 = 2.76 ton· $acre^{-1}\cdot yr^{-1}$ for segment 3. The soil-loss-adjustment factor for each segment is determined by entering table 4-5 with the appropriate slope and rill to interrill ratio, obtaining an m value (0.52 for a 10% slope and moderate rill/interrill ratio), and then selecting the appropriate factor for each segment from table 4-5. In this example, interpolation is required. The average soil loss for this slope is the product of (LS)(RKCP) or (2.84)(1.0) = 2.84 ton · $acre^{-1}\cdot yr^{-1}$. Soil-loss values along the slope are found by multiplying this value by the same factor values from table 4-6 that are used to adjust T values for position on the slope. These products give the values of 1.62, 2.98, and 3.92 ton· $acre^{-1}\cdot yr^{-1}$ for segments 1, 2, and 3, respectively. The soil-loss values are now uniform with respect to the adjusted soil-loss-tolerance values along the slope.

For the convex slope in table 4-7, the initial adjusted T values are 1.28, 2.10, and 2.84 ton· $acre^{-1}\cdot yr^{-1}$ for segments 1, 2, and 3, respectively. The mean of these initial segment values is 2.07 ton· $acre^{-1}\cdot yr^{-1}$, greater than the tolerance for a uniform slope of steepness equal to the average of the segment steepness. Therefore, the user should multiply each segment adjusted T value by the ratio of 2.00/2.07 = 0.96 to produce an average slope tolerance of 2.0 ton· $acre^{-1}\cdot yr^{-1}$. The final segment adjusted tolerance values are then 1.23, 2.03, and 2.74 ton· $acre^{-1}\cdot yr^{-1}$ for segments 1, 2, and 3, respectively, whereas the soil-loss values for the segments are 0.72, 2.98, and 7.58 ton· $acre^{-1}\cdot yr^{-1}$. The user should note that soil loss on the upper segment is much less than the adjusted T value;

therefore, erosion on the first segment is considered to be within allowable limits. However, the soil loss on the last segment is much greater than the adjusted T value, so soil loss is judged to be excessive on the last segment of the convex slope.

For the concave slope in table 4-8, the initial adjusted T values are 1.06, 2.10, and 2.60 ton· $acre^{-1}$· yr^{-1} for segments 1, 2, and 3, respectively. The mean of these initial segment values is 1.92 ton· $acre^{-1}$· yr^{-1}, less than the tolerance for a uniform slope of steepness equal to the average of the segment steepness. Therefore, the user should multiply each initial segment adjusted T value by the ratio of 2.00/1.92 = 1.04 to produce an average slope tolerance of 2.00 ton· $acre^{-1}$· yr^{-1}. The final segment adjusted tolerance values are then 1.10, 2.19, and 2.71 ton· $acre^{-1}$· yr^{-1} for segments 1, 2, and 3, respectively, whereas the soil losses along the slope are 2.83, 2.98, and 1.47 ton· $acre^{-1}$· yr^{-1}. The soil-loss values for the upper two segments exceed the adjusted T value, and management practices are chosen to reduce these values to the adjusted T value.

GUIDES FOR CHOOSING SLOPE LENGTHS

In training sessions, more questions are asked about slope length than about any other RUSLE factor. Slope length is the factor that involves the most judgment, and length determinations made by users vary greatly. Figure 4-1 illustrates the major slope-length situations that are found in the field. However, additional guides are useful, especially for rangelands and forest lands.

Actually, an infinite number of slope lengths exist in the field. To apply RUSLE, erosion can be calculated for several of them and the results averaged according to the area represented by each slope length. Sometimes a particular position on the landscape is chosen as the location for a slope length. To establish the ends of the slope length, the user walks upslope from that position, moving perpendicular to the contour, until the origin of overland flow is reached. Often this point is not at the top of the hill but at a divide down the nose of a ridge (illustrated in fig. 4-2).

The lower end of the slope length is located by walking downslope perpendicular to the contour until a broad area of deposition or a natural or constructed waterway is reached. These waterways are not necessarily eroded or incised channels, and this lack of channels can make it difficult to determine the end of slope. One aid is to visualize the locations on the landscape where eroded channels or gullies would naturally form. Figure 4-2 illustrates one area where such waterways are located.

If a slope flattens enough near its end, deposition may occur. When erosion and deposition rates are low and erosion has not recently occurred, deposition begins at the point where slope has decreased to about 5%. Deposition does not necessarily occur everywhere a slope flattens.

Sometimes slope decreases as shown in figure 4-3. On those slopes, deposition can end and erosion can occur on the lower end of the slope. To approximate where deposition ends, the user should do the following: First calculate the ratio of the slope steepness at the end to the slope steepness where deposition begins. Subtract that ratio from 1.0, multiply that difference by the distance from where deposition begins to the end of the slope, and add that product to the distance where deposition begins. To illustrate, assume a 400-ft-long slope with a 2% slope at the end. Assume that deposition begins at 250 ft, where the slope is 5%.

The ratio of the slope steepness is 0.40, and the distance from where deposition begins to the end of the slope is 150 ft. The location where deposition ends is 250+(1.0-0.40)(150) = 340 ft. This procedure, an approximation to results of CREAMS simulations, is for gently curving slopes. When the change of slope is very abrupt, deposition may occur over only a 20- to 40-ft distance.

In the case just described, the water is assumed to flow uniformly as broad sheet flow over the depositional area and onto the downslope eroding area, or from a relatively flat area at the top of the slope onto a steep area. The distance to the origin of flow must be considered in computing soil loss. To compute average erosion for the slope, only the segments experiencing erosion are used in the computations. In this case, RUSLE does not compute sediment yield for the slope. Of course, a diversion ditch across the slope would end the slope length and a new one would begin immediately below the ditch. Also, broad sheet flow does not occur in natural riparian vegetation.

All the situations discussed previously have been simplified. A few specific examples may help the user visualize field slope length. Figure 4-4 is a photo of rill erosion on a steep small-grain field in the Pacific Northwest. Although the small watershed is concave, a relatively straight, closely spaced rill pattern has resulted on most of the slope. The pattern is from the top to the bottom of the slope or to the flow concentration at the bottom of the swale. For these particular conditions alone, slope length can be obtained fairly accurately from U.S. Geological Survey (USGS) 7½-min contour maps with a 20-ft contour interval.

Figure 4-5A shows a row cropped watershed after a series of storms during the early stages of crop growth. The concentrated flow channels are spaced rather closely together, leading to fairly short slope lengths for RUSLE computation. Even with the 1-ft contour interval map in figure 4-5B, realistic slope lengths are difficult to estimate without the aerial photograph for guidance.

The effect of different crop managements on the upper and lower portions of a slope is illustrated in figure 4-6. The boundary between the two managements occurs at about the middle of the slope. Presence of the snow drift on the upper part of the slope causes measured slope length to be a poor predictor of soil loss; the distance to the top of the ridge does not provide a realistic estimate of the length that actually provides the snowmelt. Other than the area where a drill wheel track diverts the runoff and creates a flow concentration, the rill pattern is fairly straight and closely spaced. The bottom of the slope where the runoff collects into a larger channel, or deposits sediment at the toe of the slope, is not shown.

Determination of slope lengths on rangeland and forested watersheds is generally more difficult than determination of slope lengths on cropland because of the permanent vegetation and the frequently irregular topography of the former. Three selected small watersheds from the Lydle Gulch and Blacks Creek drainages east of Boise, Idaho, are shown on a portion of the 7½-min USGS quad sheet for Indian Creek Reservoir in figure 4-7. Figure 4-8 is an example of a steep rangeland watershed with little shrubby permanent vegetation. Because of the steepness of the watershed, there are few depositional areas. However, the hillslopes are rough and the ridgetops rounded, slightly complicating the determination of slope length. Even for this simple case, the determination of slope lengths by inspecting a 7½-min quad sheet with a 20-ft contour interval would lead to slope lengths longer than those determined in the field or from a low-level aerial photograph. The slopes of the transects are irregular, but to conserve space in this publication, LS in figure 4-8 was calculated from the total horizontal slope length and total fall.

Figure 4-9 is a photograph of a more complex rangeland watershed. The slope is flatter than that on the area in figure 4-8, and numerous large mounds make the topography very uneven. The drainage channels are rather broad, vegetated, and poorly defined, and the watershed boundaries are difficult to delineate. The shrubby permanent vegetation is more prevalent than that on figure 4-8, obscuring the flow paths on aerial or oblique photographs. Slope lengths are best determined by field inspection. The use of maps with even a 2-ft contour interval will lead to slope lengths much longer than those determined in the field.

The complex and irregular rangeland watershed that appears on figure 4-10 exemplifies conditions frequently found in the field. The watershed is of low slope, has undulating topography with numerous hummocks or mounds, and has shrubby permanent vegetation that masks the drainages. The determination of slope lengths even by field inspection is difficult, particularly when the grass cover is at its maximum and not yet reduced by grazing.

Figure 4-10 shows a complicated flow system where shrubs, grass clumps, and litter are isolated in hummocks scattered over rangeland, and in effect where water flows down a local slope to a locally concentrated flow area. This flow system may be treated as follows: If flow patterns around and among the hummocks are basically parallel, do not treat the flow concentrations as the end of a short slope length. Choose slope lengths by visualizing the surface as being smooth without the hummocks. If, however, major deposition occurs upstream of the hummocks and/or the flow pattern meanders without a direction, treat the slope lengths as short. Note that on figure 4-10, some of the transects pass through clumps of shrubby vegetation.

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Table 4-1.
Values for topographic factor, LS, for low ratio of rill to interrill erosion.[1]

Slope (%)	Horizontal slope length (ft)																
	<3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.5	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1.0	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.17	0.17
2.0	0.20	0.20	0.20	0.20	0.20	0.21	0.23	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.33	0.34	0.35
3.0	0.26	0.26	0.26	0.26	0.26	0.29	0.33	0.36	0.38	0.40	0.43	0.44	0.46	0.48	0.52	0.55	0.57
4.0	0.33	0.33	0.33	0.33	0.33	0.36	0.43	0.46	0.50	0.54	0.58	0.61	0.63	0.67	0.74	0.78	0.82
5.0	0.38	0.38	0.38	0.38	0.38	0.44	0.52	0.57	0.62	0.68	0.73	0.78	0.81	0.87	0.97	1.04	1.10
6.0	0.44	0.44	0.44	0.44	0.44	0.50	0.61	0.68	0.74	0.83	0.90	0.95	1.00	1.08	1.21	1.31	1.40
8.0	0.54	0.54	0.54	0.54	0.54	0.64	0.79	0.90	0.99	1.12	1.23	1.32	1.40	1.53	1.74	1.91	2.05
10.0	0.60	0.63	0.65	0.66	0.68	0.81	1.03	1.19	1.31	1.51	1.67	1.80	1.92	2.13	2.45	2.71	2.93
12.0	0.61	0.70	0.75	0.80	0.83	1.01	1.31	1.52	1.69	1.97	2.20	2.39	2.56	2.85	3.32	3.70	4.02
14.0	0.63	0.76	0.85	0.92	0.98	1.20	1.58	1.85	2.08	2.44	2.73	2.99	3.21	3.60	4.23	4.74	5.18
16.0	0.65	0.82	0.94	1.04	1.12	1.38	1.85	2.18	2.46	2.91	3.28	3.60	3.88	4.37	5.17	5.82	6.39
20.0	0.68	0.93	1.11	1.26	1.39	1.74	2.37	2.84	3.22	3.85	4.38	4.83	5.24	5.95	7.13	8.10	8.94
25.0	0.73	1.05	1.30	1.51	1.70	2.17	3.00	3.63	4.16	5.03	5.76	6.39	6.96	7.97	9.65	11.04	12.26
30.0	0.77	1.16	1.48	1.75	2.00	2.57	3.60	4.40	5.06	6.18	7.11	7.94	8.68	9.99	12.19	14.04	15.66
40.0	0.85	1.36	1.79	2.17	2.53	3.30	4.73	5.84	6.78	8.37	9.71	10.91	11.99	13.92	17.19	19.96	22.41
50.0	0.91	1.52	2.06	2.54	3.00	3.95	5.74	7.14	8.33	10.37	12.11	13.65	15.06	17.59	21.88	25.55	28.82
60.0	0.97	1.67	2.29	2.86	3.41	4.52	6.63	8.29	9.72	12.16	14.26	16.13	17.84	20.92	26.17	30.68	34.71

[1]Such as for rangeland and other consolidated soil conditions with cover (applicable to thawing soil where both interrill and rill erosion are significant).

Table 4-2.
Values for topographic factor, LS, for moderate ratio of rill to interrill erosion.[1]

Slope (%)	Horizontal slope length (ft) 3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06
0.5	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10
1.0	0.11	0.11	0.11	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.17	0.17	0.18	0.19	0.20	0.20
2.0	0.17	0.17	0.17	0.17	0.17	0.19	0.22	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.41	0.44	0.47
3.0	0.22	0.22	0.22	0.22	0.22	0.25	0.32	0.36	0.39	0.44	0.48	0.52	0.55	0.60	0.68	0.75	0.80
4.0	0.26	0.26	0.26	0.26	0.26	0.31	0.40	0.47	0.52	0.60	0.67	0.72	0.77	0.86	0.99	1.10	1.19
5.0	0.30	0.30	0.30	0.30	0.30	0.37	0.49	0.58	0.65	0.76	0.85	0.93	1.01	1.13	1.33	1.49	1.63
6.0	0.34	0.34	0.34	0.34	0.34	0.43	0.58	0.69	0.78	0.93	1.05	1.16	1.25	1.42	1.69	1.91	2.11
8.0	0.42	0.42	0.42	0.42	0.42	0.53	0.74	0.91	1.04	1.26	1.45	1.62	1.77	2.03	2.47	2.83	3.15
10.0	0.46	0.48	0.50	0.51	0.52	0.67	0.97	1.19	1.38	1.71	1.98	2.22	2.44	2.84	3.50	4.06	4.56
12.0	0.47	0.53	0.58	0.61	0.64	0.84	1.23	1.53	1.79	2.23	2.61	2.95	3.26	3.81	4.75	5.56	6.28
14.0	0.48	0.58	0.65	0.70	0.75	1.00	1.48	1.86	2.19	2.76	3.25	3.69	4.09	4.82	6.07	7.15	8.11
16.0	0.49	0.63	0.72	0.79	0.85	1.15	1.73	2.20	2.60	3.30	3.90	4.45	4.95	5.86	7.43	8.79	10.02
20.0	0.52	0.71	0.85	0.96	1.06	1.45	2.22	2.85	3.40	4.36	5.21	5.97	6.68	7.97	10.23	12.20	13.99
25.0	0.56	0.80	1.00	1.16	1.30	1.81	2.82	3.65	4.39	5.69	6.83	7.88	8.86	10.65	13.80	16.58	19.13
30.0	0.59	0.89	1.13	1.34	1.53	2.15	3.39	4.42	5.34	6.98	8.43	9.76	11.01	13.30	17.37	20.99	24.31
40.0	0.65	1.05	1.38	1.68	1.95	2.77	4.45	5.87	7.14	9.43	11.47	13.37	15.14	18.43	24.32	29.60	34.48
50.0	0.71	1.18	1.59	1.97	2.32	3.32	5.40	7.17	8.78	11.66	14.26	16.67	18.94	23.17	30.78	37.65	44.02
60.0	0.76	1.30	1.78	2.23	2.65	3.81	6.24	8.33	10.23	13.65	16.76	19.64	22.36	27.45	36.63	44.96	52.70

[1]Such as for row-cropped agricultural and other moderately consolidated soil conditions with little-to-moderate cover (not applicable to thawing soil)

Table 4-3.
Values for topographic factor, LS, for high ratio of rill to interrill erosion.[1]

Slope (%)	Horizontal slope length (ft) <3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
0.5	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.09	0.10	0.10	0.10	0.11	0.12	0.12	0.13
1.0	0.09	0.09	0.09	0.09	0.09	0.10	0.13	0.14	0.15	0.17	0.18	0.19	0.20	0.22	0.24	0.26	0.27
2.0	0.13	0.13	0.13	0.13	0.13	0.16	0.21	0.25	0.28	0.33	0.37	0.40	0.43	0.48	0.56	0.63	0.69
3.0	0.17	0.17	0.17	0.17	0.17	0.21	0.30	0.36	0.41	0.50	0.57	0.64	0.69	0.80	0.96	1.10	1.23
4.0	0.20	0.20	0.20	0.20	0.20	0.26	0.38	0.47	0.55	0.68	0.79	0.89	0.98	1.14	1.42	1.65	1.86
5.0	0.23	0.23	0.23	0.23	0.23	0.31	0.46	0.58	0.68	0.86	1.02	1.16	1.28	1.51	1.91	2.25	2.55
6.0	0.26	0.26	0.26	0.26	0.26	0.36	0.54	0.69	0.82	1.05	1.25	1.43	1.60	1.90	2.43	2.89	3.30
8.0	0.32	0.32	0.32	0.32	0.32	0.45	0.70	0.91	1.10	1.43	1.72	1.99	2.24	2.70	3.52	4.24	4.91
10.0	0.35	0.37	0.38	0.39	0.40	0.57	0.91	1.20	1.46	1.92	2.34	2.72	3.09	3.75	4.95	6.03	7.02
12.0	0.36	0.41	0.45	0.47	0.49	0.71	1.15	1.54	1.88	2.51	3.07	3.60	4.09	5.01	6.67	8.17	9.57
14.0	0.38	0.45	0.51	0.55	0.58	0.85	1.40	1.87	2.31	3.09	3.81	4.48	5.11	6.30	8.45	10.40	12.23
16.0	0.39	0.49	0.56	0.62	0.67	0.98	1.64	2.21	2.73	3.68	4.56	5.37	6.15	7.60	10.26	12.69	14.96
20.0	0.41	0.56	0.67	0.76	0.84	1.24	2.10	2.86	3.57	4.85	6.04	7.16	8.23	10.24	13.94	17.35	20.57
25.0	0.45	0.64	0.80	0.93	1.04	1.56	2.67	3.67	4.59	6.30	7.88	9.38	10.81	13.53	18.57	23.24	27.66
30.0	0.48	0.72	0.91	1.08	1.24	1.86	3.22	4.44	5.58	7.70	9.67	11.55	13.35	16.77	23.14	29.07	34.71
40.0	0.53	0.85	1.13	1.37	1.59	2.41	4.24	5.89	7.44	10.35	13.07	15.67	18.17	22.95	31.89	40.29	48.29
50.0	0.58	0.97	1.31	1.62	1.91	2.91	5.16	7.20	9.13	12.75	16.16	19.42	22.57	28.60	39.95	50.63	60.84
60.0	0.63	1.07	1.47	1.84	2.19	3.36	5.97	8.37	10.63	14.89	18.92	22.78	26.51	33.67	47.18	59.93	72.15

[1]Such as for freshly prepared construction and other highly disturbed soil conditions with little or no cover (not applicable to thawing soil)

Table 4-4.
Values for topographic factor, LS, for thawing soils where most of the erosion is caused by surface flow.

Slope (%)	Horizontal slope length (ft)												
	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.10	0.10	0.12	0.15	0.17	0.19
0.5	0.04	0.05	0.07	0.09	0.10	0.12	0.14	0.16	0.17	0.20	0.24	0.28	0.31
1.0	0.06	0.08	0.11	0.14	0.16	0.20	0.23	0.26	0.28	0.32	0.40	0.46	0.51
2.0	0.11	0.14	0.20	0.25	0.29	0.35	0.41	0.46	0.50	0.58	0.71	0.82	0.91
3.0	0.16	0.21	0.29	0.36	0.42	0.51	0.59	0.66	0.72	0.83	1.02	1.17	1.31
4.0	0.21	0.27	0.38	0.47	0.54	0.66	0.77	0.86	0.94	1.08	1.33	1.53	1.71
5.0	0.26	0.33	0.47	0.58	0.67	0.82	0.94	1.06	1.16	1.34	1.64	1.89	2.11
6.0	0.31	0.40	0.56	0.69	0.79	0.97	1.12	1.26	1.38	1.59	1.95	2.25	2.51
8.0	0.41	0.52	0.74	0.91	1.05	1.28	1.48	1.65	1.81	2.09	2.56	2.96	3.31
10.0	0.48	0.62	0.88	1.08	1.25	1.53	1.77	1.98	2.16	2.50	3.06	3.54	3.95
12.0	0.54	0.70	0.98	1.21	1.39	1.71	1.97	2.20	2.41	2.78	3.41	3.94	4.40
14.0	0.59	0.76	1.08	1.32	1.53	1.87	2.16	2.41	2.64	3.05	3.74	4.31	4.82
16.0	0.64	0.82	1.17	1.43	1.65	2.02	2.33	2.61	2.86	3.30	4.04	4.67	5.22
20.0	0.73	0.94	1.33	1.63	1.88	2.30	2.66	2.97	3.25	3.76	4.60	5.31	5.94
25.0	0.83	1.07	1.51	1.85	2.13	2.61	3.02	3.37	3.69	4.27	5.23	6.03	6.75
30.0	0.91	1.18	1.67	2.05	2.36	2.89	3.34	3.73	4.09	4.72	5.78	6.68	7.47
40.0	1.07	1.38	1.95	2.39	2.75	3.37	3.90	4.36	4.77	5.51	6.75	7.79	8.71
50.0	1.19	1.54	2.18	2.67	3.08	3.77	4.35	4.87	5.33	6.16	7.54	8.71	9.74
60.0	1.30	1.67	2.37	2.90	3.35	4.10	4.74	5.30	5.80	6.70	8.20	9.47	10.59

Table 4-5.
Slope-length exponents (m) for a range of slopes and rill/interrill erosion classes[1]

	Rill/interrill ratio		
Slope (%)	Low	Moderate	High
0.2	0.02	0.04	0.07
0.5	0.04	0.08	0.16
1.0	0.08	0.15	0.26
2.0	0.14	0.24	0.39
3.0	0.18	0.31	0.47
4.0	0.22	0.36	0.53
5.0	0.25	0.40	0.57
6.0	0.28	0.43	0.60
8.0	0.32	0.48	0.65
10.0	0.35	0.52	0.68
12.0	0.37	0.55	0.71
14.0	0.40	0.57	0.72
16.0	0.41	0.59	0.74
20.0	0.44	0.61	0.76
25.0	0.47	0.64	0.78
30.0	0.49	0.66	0.79
40.0	0.52	0.68	0.81
50.0	0.54	0.70	0.82
60.0	0.55	0.71	0.83

[1]Not applicable to thawing soils

Source: McCool et al. (1989).

Table 4-6.
Soil loss factor to estimate soil loss on a segment of a uniform slope.

Number of segments	Sequential number of segments	Slope-length exponent (m) .05	.1	.2	.3	.4	.5	.6	.7	.8
2	1	0.97	0.93	0.87	0.81	0.76	0.71	0.66	0.62	0.57
	2	1.03	1.07	1.13	1.19	1.24	1.29	1.34	1.38	1.43
3	1	0.95	0.90	0.80	0.72	0.64	0.58	0.52	0.46	0.42
	2	1.01	1.02	1.04	1.05	1.06	1.05	1.05	1.04	1.03
	3	1.04	1.08	1.16	1.23	1.30	1.37	1.43	1.50	1.55
4	1	0.93	0.87	0.76	0.66	0.57	0.50	0.44	0.38	0.33
	2	1.00	1.00	0.98	0.96	0.94	0.92	0.88	0.85	0.82
	3	1.03	1.05	1.09	1.13	1.16	1.18	1.2	1.22	1.23
	4	1.04	1.08	1.17	1.25	1.33	1.40	1.48	1.55	1.62
5	1	0.92	0.85	0.73	0.62	0.53	0.45	0.38	0.32	0.28
	2	0.99	0.97	0.94	0.90	0.86	0.82	0.77	0.73	0.69
	3	1.01	1.03	1.04	1.05	1.06	1.06	1.06	1.05	1.03
	4	1.03	1.06	1.12	1.17	1.21	1.25	1.29	1.32	1.35
	5	1.05	1.09	1.17	1.26	1.34	1.42	1.50	1.58	1.65

Soil-loss factors = $[i^{m+1} - (i - 1)^{m+1}]/n^m$
where i = sequential number of segment,
m = slope length exponent, and n = number
of segments. Values are forced to give a
factor total equal to number of segments.
Values from RUSLE computer program
may differ slightly due to round-off.

Table 4-7.
Illustration of irregular-slope procedure where only gradient changes along a 400-ft convex slope of n segments on cropland

Column (1)	Column (2)	Column (3)	Column (4)	Column (5)	Column (6)
Segment	Gradient (%)	LS from table 4-2	Soil-loss factor from table 4-6	[1](3)· (4)/n	LS for segment (3)· (4)
1	5	1.13	0.64	0.24	0.72
2	10	2.84	1.05	0.99	2.98
3	15	5.34	1.42	2.53	7.58

[1]Total LS for slope = 3.76.

Table 4-8.
Illustration of irregular slope procedure where only gradient changes along a 400-ft concave slope of n segments on cropland

Column (1)	Column (2)	Column (3)	Column (4)	Column (5)	Column (6)
Segment	Gradient (%)	LS from table 4-2	Soil-loss factor from table 4-6	[1](3)· (4)/n	LS for segment (3)· (4)
1	15	5.34	0.53	0.94	2.83
2	10	2.84	1.05	0.99	2.98
3	5	1.13	1.30	0.49	1.47

[1]Total LS for slope = 2.42.

Table 4-9.
Evaluation of a change in K along a 400-ft convex slope of n segments on cropland

Column (1) Segment	Column (2) Gradient (%)	Column (3) LS from table 4-2	Column (4) Soil-loss factor from table 4-6	Column (5) K	Column (6) [1](3)·(4)·(5)/n	Column (7) KLS for segment (3)·(4)·(5)
1	5	1.13	0.64	0.27	0.065	0.20
2	10	2.84	1.05	0.32	0.318	0.95
3	15	5.34	1.42	0.37	0.935	2.81

[1]Total KLS for slope = 1.32.

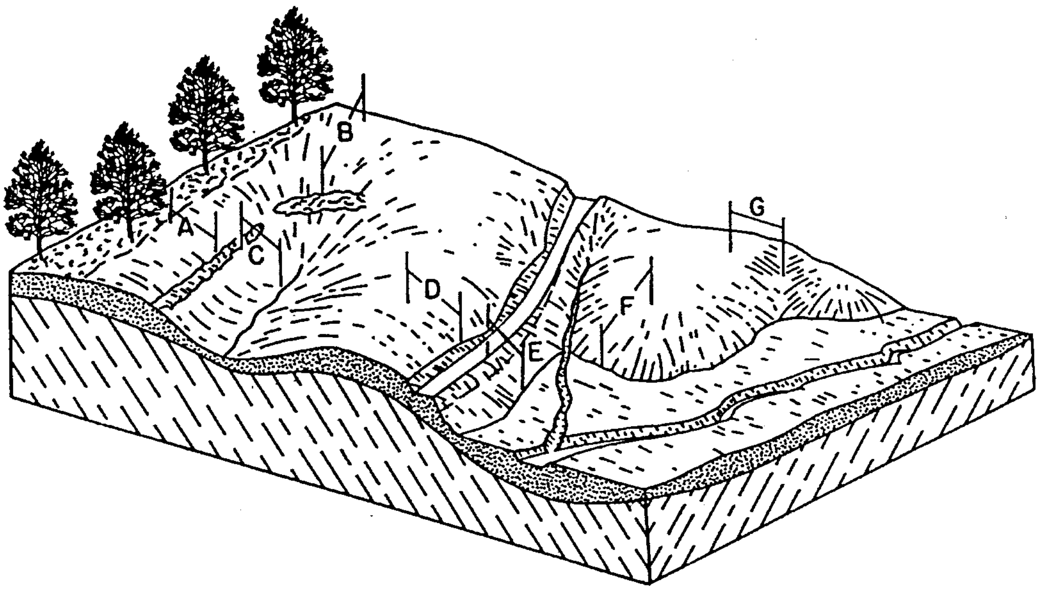


Figure 4-1. Typical slope lengths (Dissmeyer and Foster 1980). Slope A— If undisturbed forest soil above does not yield surface runoff, the top of slope starts with edge of undisturbed forest soil and extends down slope to windrow if runoff is concentrated by windrow. Slope B—Point of origin of runoff to windrow if runoff is concentrated by windrow. Slope C—From windrow to flow concentration point. Slope D—Point of origin of runoff to road that concentrates runoff. Slope E—From road to flood plain where deposition would occur. Slope F—On nose of hill, from point to origin of runoff to flood plain where deposition would occur. Slope G—Point of origin of runoff to slight depression where runoff would concentrate.

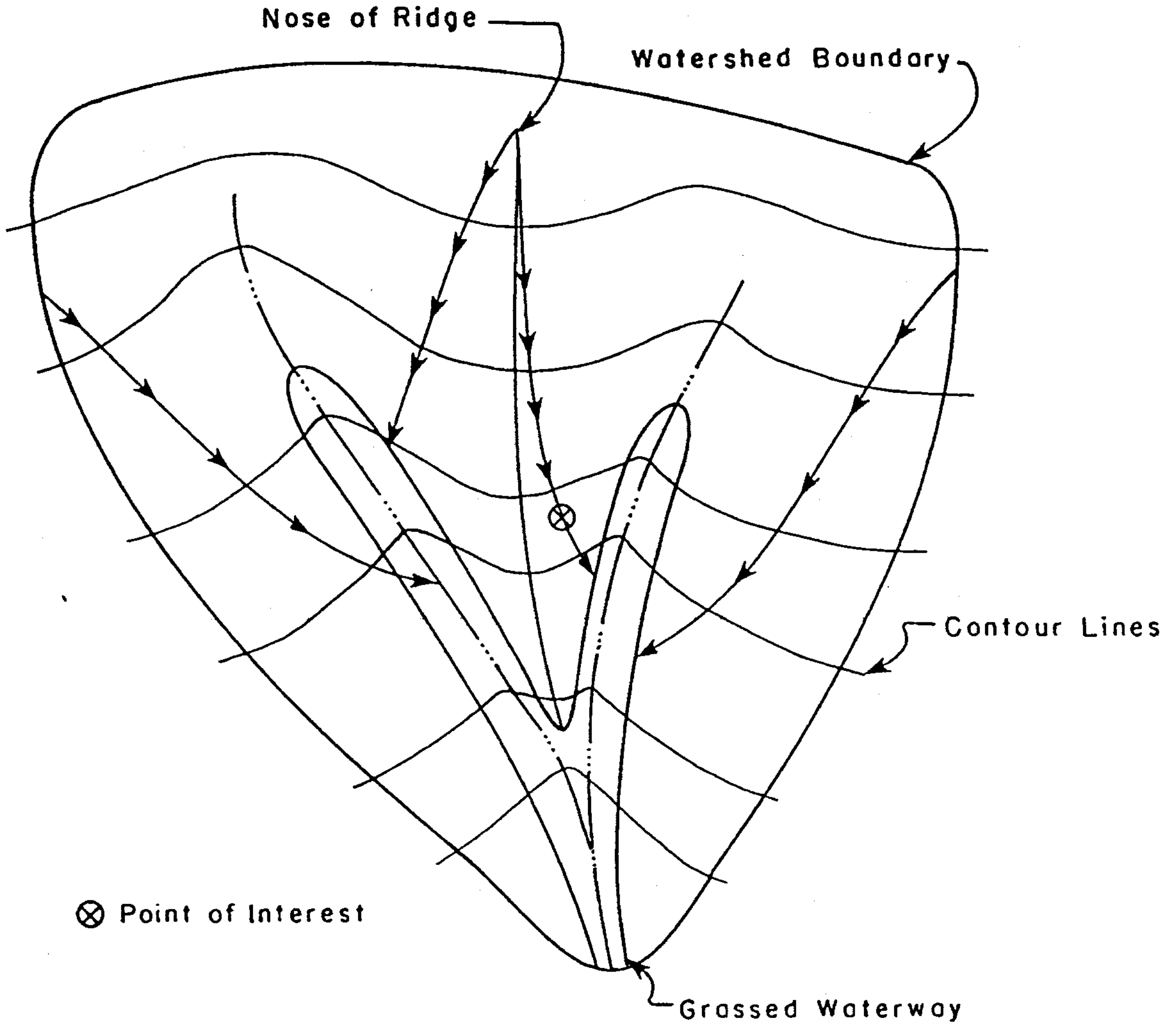


Figure 4-2. Illustration of some RUSLE slope lengths

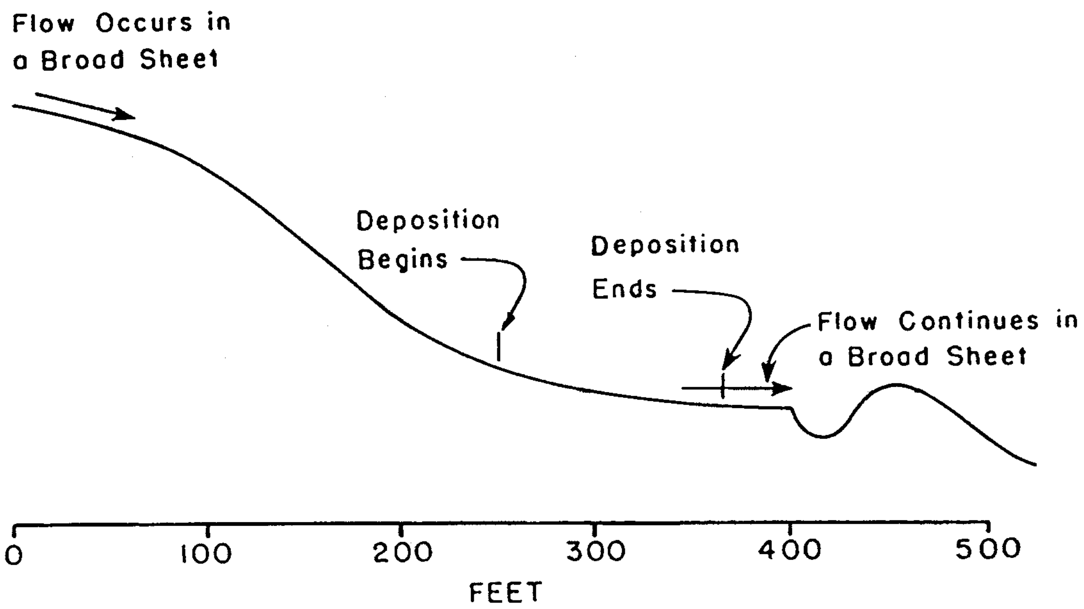


Figure 4-3. Illustration of deposition beginning and ending on a slope

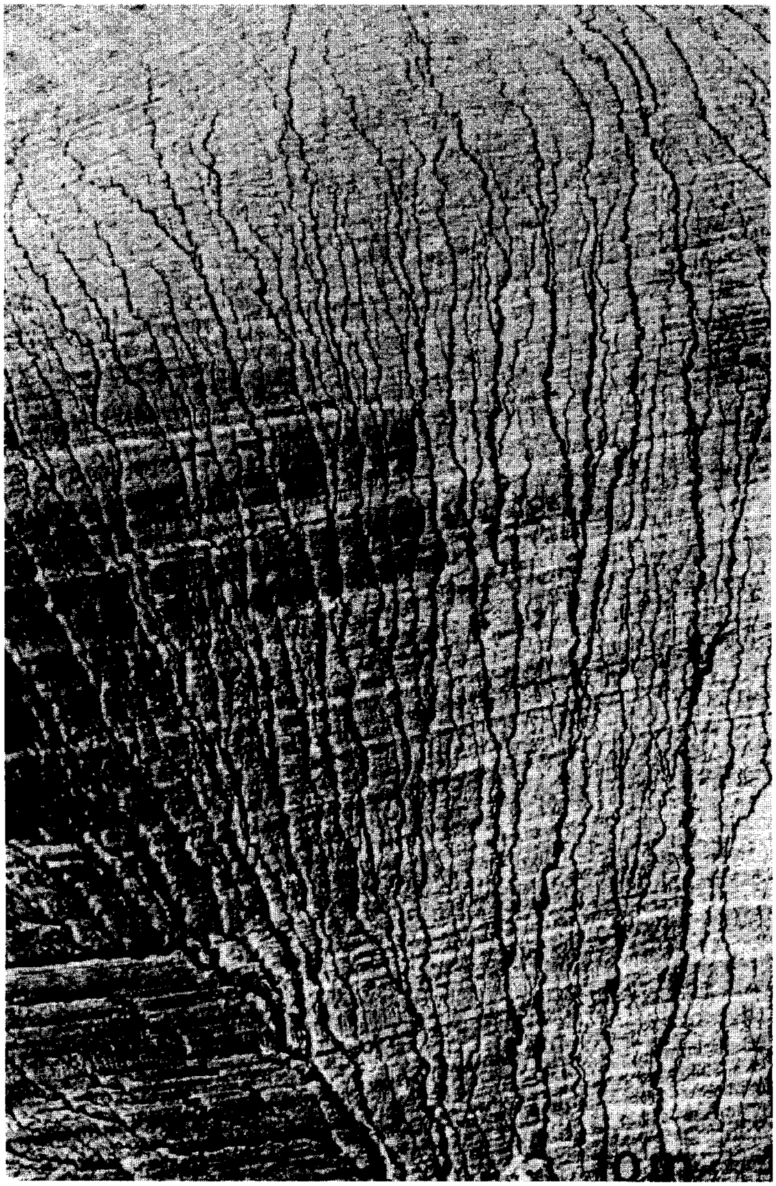
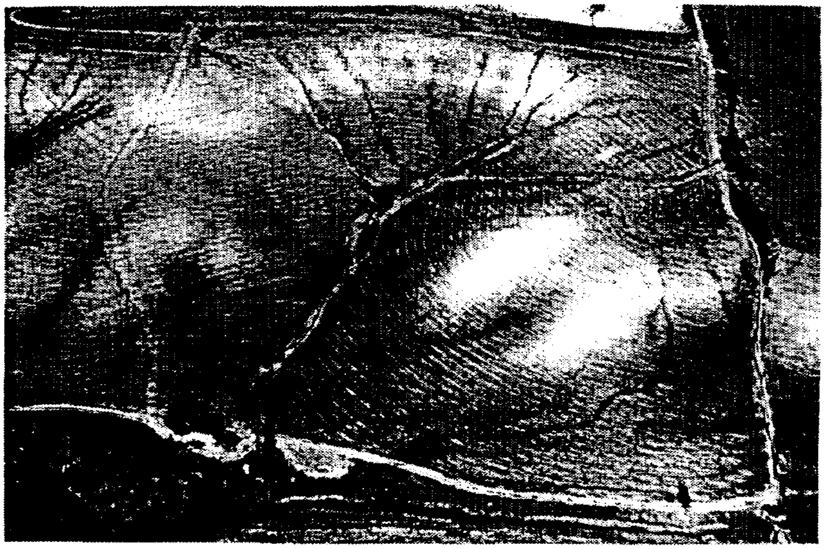


Figure 4-4. Dendritic rill pattern on a concave, north-facing slope. Estimated soil loss was 82 ton · acre^{-1}. From Frazier et al. (1983), reprinted by permission of Soil and Water Conservation Society.



Transect	Slope length (λ) (ft)	Slope steepness (s) (%)	LS
1	280	12	3.14
2	325	13	3.84
3	240	11	2.53
4	205	13	2.97

Figure 4-5A. Erosion resulting from a series of storms on a row crop field during early stages of crop growth

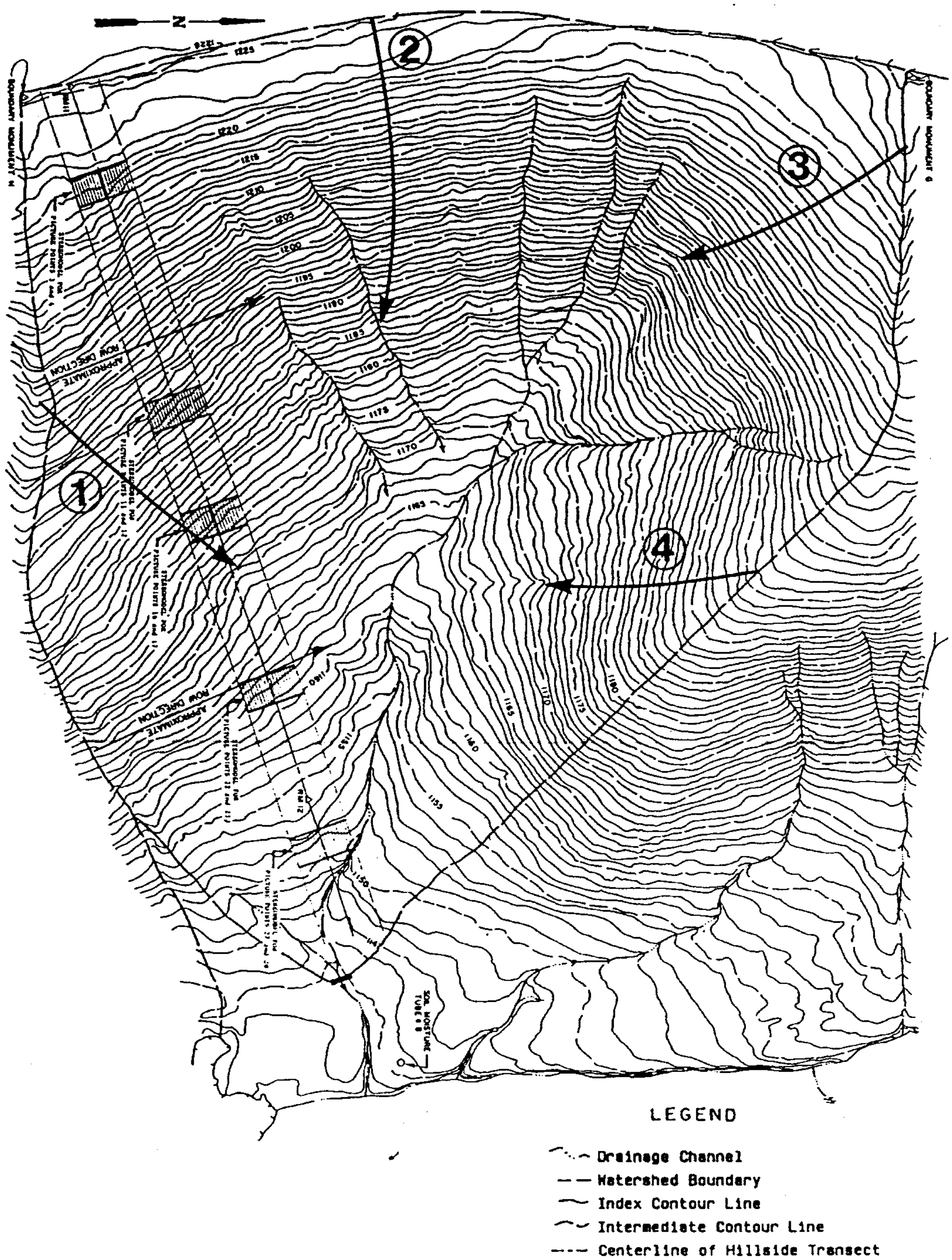


Figure 4-5B. One-ft contour interval map of the row crop field shown in figure 4-5A

Figure 4-6. Erosion from different crop managements on upper and lower halves of a slope. A large snow drift complicated the situation. From Frazier et al. (1983), reprinted by permission of Soil and Water Conservation Society.

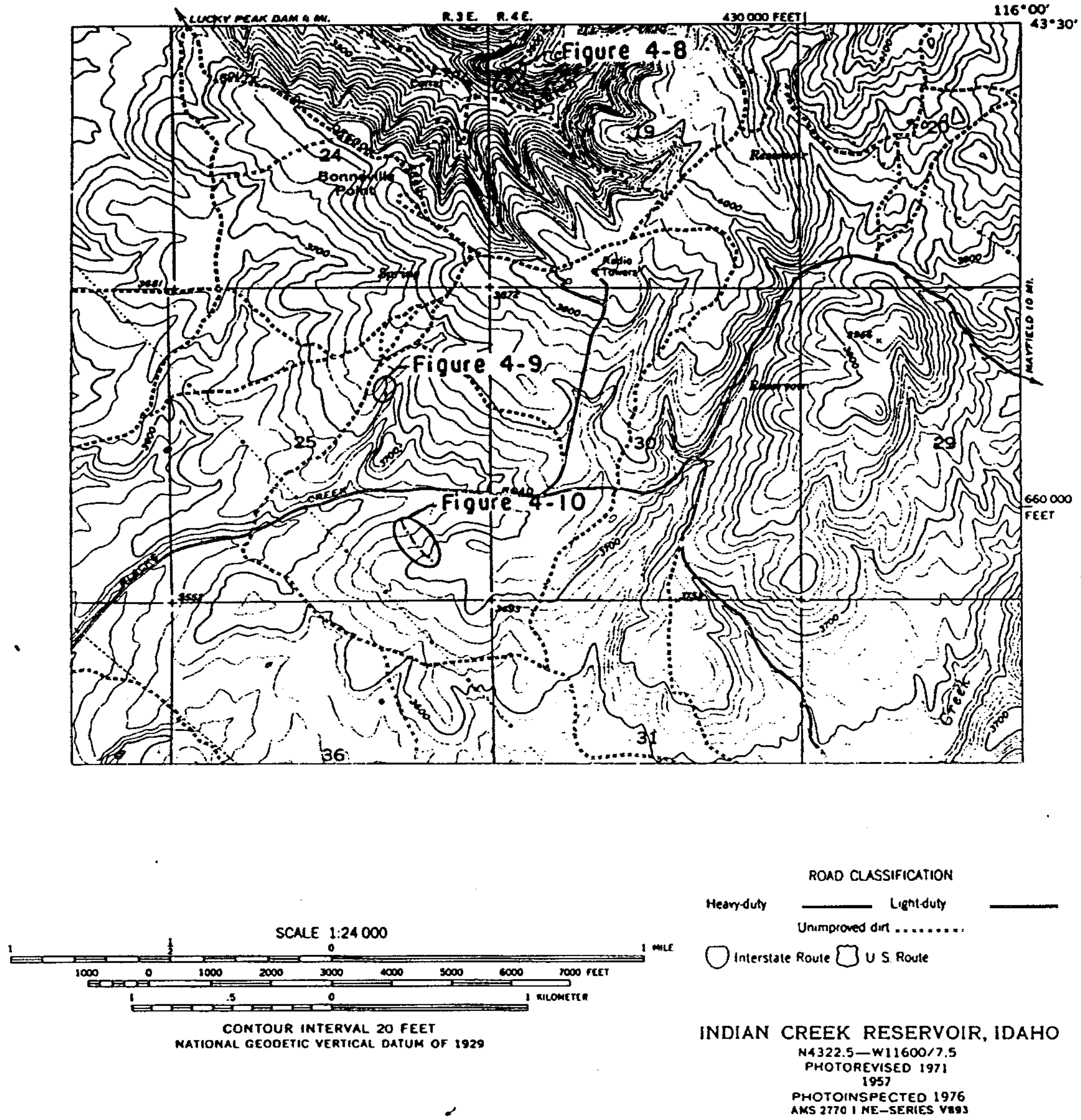
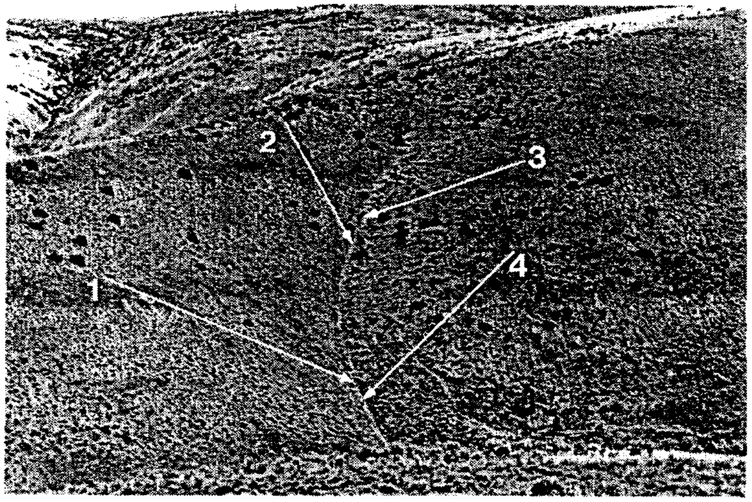
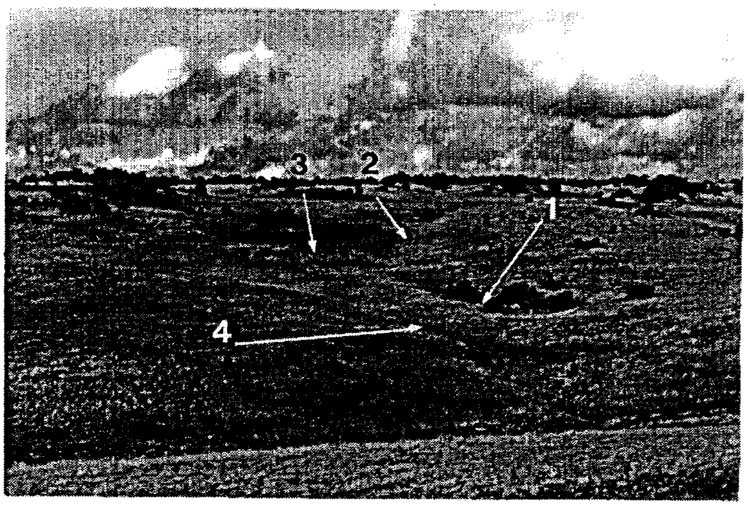


Figure 4-7. Portion of Indian Creek Reservoir USGS 7½-min Quad Sheet showing an area east of Boise, Idaho



Transect	Slope length (λ) (ft)	Slope steepness (s) (%)	LS
1	225	61	15.44
2	135	53	10.32
3	150	45	9.39
4	375	60	20.18

Figure 4-8. Small rangeland watershed on Lydle Creek east of Boise, Idaho



Transect	Slope length (λ) (ft)	Slope steepness (s) (%)	LS
1	165	14	2.53
2	30	6	0.53
3	50	16	1.85
4	60	14	1.70

Figure 4-9. Small rangeland watershed on Blacks Creek east of Boise, Idaho

Transect	Slope length (λ) (ft)	Slope steepness (s) (%)	LS
1	135	10	1.46
2	45	14	1.51
3	65	21	2.81
4	100	11	1.50
5	40	10	0.95

Figure 4-10. Small rangeland watershed on Blacks Creek east of Boise, Idaho