CHAPTER FOUR

LS factor: Hillslope Length and Gradient

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The effect of topography on erosion is accounted for by the LS factor in RUSLE, which combines the effects of a hillslope-length factor, L, and a hillslope-gradient factor, S. Generally speaking, as hillslope length and/or hillslope gradient increase, soil loss increases. As hillslope length increases, total soil loss and soil loss per unit area increase due to the progressive accumulation of runoff in the downslope direction . As the hillslope gradient increases, the velocity and erosivity of runoff increases. The following sections of this chapter describe the effects of L and S on soil-loss rates, the interactions between L and S, and their combined effects on soil loss, and the ability of RUSLE to estimate soil loss from non-uniform, complex, hillslopes.

A RUSLE screen showing the LS estimate for a hillslope composed of two distinct profile segments is shown in **Figure 4-1**. The first segment at the top of the hillslope is 250 feet in length with a gradient of 3%, while the lower segment is 50 feet in length with a gradient of 33%. The first entry shows that this hillslope is composed of two segments. The next entry to the right shows that the lengths of the segments are measured horizontally rather than along the hillslope surface (in which case a 1 would have been the correct input). The second entry in the left column indicates that the segment lengths are not equal (versus an entry of 2 for segments of equal lengths). The third entry in this column indicates that the texture of the hillslope soil is "silt loam." The last entry in this column indicates that the soil surface is made of disturbed topsoil fill without a rock cover.

The use of soil texture and general land use in the computation of the LS value is a major change and improvement in RUSLE version 1.06 as compared with earlier versions. The effect of hillslope length on soil loss depends on the ratio of rill to interrill erosion on the hillslope. This ratio is a function of soil texture and general land use. Soils with a high percentage of silt (>85%) are assumed to have a high rill to interrill erosion ratio. Soils with a textural classification of silt loam are assumed to have a high to moderate rill to interrill erosion ratio. Soils with a high percentage of sand are assumed to have a moderate to low rill to interrill erosion ratio. Soils with a high percentage of clay (>35%) are assumed to have a low rill to interrill erosion ratio.

The general land use also is used to estimate the ratio of rill to interrill erosion Recently disturbed mine or construction lands are assumed to have a high rill to interrill erosion ratio. Croplands and disturbed forests are assumed to have a moderate rill to interrill erosion ratio. Land uses such as no-till cropland, pasture land, and range land that

have not been recently disturbed by mechanical operations usually have a low rill to interrill erosion ratio because the soil exists in a consolidated condition, and consolidation is assumed to have a greater effect on rill erosion than interrill erosion.

Once the user has entered the information on the screen and pressed the *F3* key, RUSLE estimates the LS value. Thus, not only are the LS estimates for the two individual hillslope segments calculated, but a LS value for the entire hillslope is estimated for use in other parts of RUSLE. An equivalent hillslope gradient (that would result in the same LS estimate if the gradient was uniform for the entire 300 feet) is also estimated.

```
       File        Exit        Help        Screen
+-----------------------------< LS Factor 1.06 >-------------------------------+
|                                                                               |
|    number of segments: 2          segment lengths are measured: 2             |
|          segments are: 1                                                      |
|          soil texture: silt loam                                              |
|      general land use: 8                                                      |
| ------------------------------------------------------------------------------
|                               1        2                                      |
|  Gradient (%) of Segment      3       33                                      |
|  Length of Segment (ft)     250       50                                      |
|  Segment LS                0.59    22.95                                      |
| ----+-------------------------------------------------------------------+-------
|     | overall LS = 4.32; equiv. slope = 14.2 %; horiz. length = 300 ft |      |
|     +-------------------------------------------------------------------+      |
|                                                                               |
|                                                                               |
|                                                                               |
|                                                                               |
|                                                                               |
|                                                                               |
+---------------------------------< Esc exits >-------------------------------+
Tab  Esc F1   F3   F9
FUNC esc help cont info
```

Figure 4-1. LS-factor screen from the RUSLE program.

Hillslope-Length Factor (L)

The hillslope length factor, L, reflects the effect of hillslope length on soil loss. The L factor has a value of 1 for a unit plot 72.6 feet in length with a gradient of 9 percent. However, the L value is less than 1 for hillslope lengths less than 72.6 feet and greater than 1 for lengths greater than 72.6 feet.

If soil loss is entirely generated by interrill erosion, which is nearly always uniform along a hillslope, the L value will be 1 for all lengths. However, if the soil loss is generated entirely by rill erosion, the L value will increase linearly with length because rill erosion increases in the downslope direction as runoff accumulates. Soil loss is usually a combination of both interrill and rill erosion; L values remain nearly constant as hillslope

lengths increase when interrill erosion predominates along hillslopes, or increase when rill erosion predominates.

When soil loss estimates are used for conservation planning and the protection of a soil resource, hillslope length is defined as the distance from the origin of the overland flow to a point along the hillslope profile where either the gradient decreases to the extent that soil deposition occurs, or where the overland flow becomes concentrated in a well-defined channel (AH-703, Renard et al., 1997). However, in the field this distance can be difficult to determine due to insufficient evidence to identify the place where overland flow begins upslope and insufficient evidence of the place where deposition begins downslope. Deposition occurring in micro-topographic depressions as a result of tillage or animal traffic along a hillslope is not the same as sedimentation in hillslope-ending depositional areas, and would not be considered in measuring the downslope terminus of the hillslope length.

The main areas of deposition that terminate hillslope length for RUSLE occur on concave hillslopes. This depositional area can be estimated from the following "rule of thumb": if no signs of deposition are present on a concave hillslope profile, it can be assumed that deposition begins where the gradient is one-half of the average gradient for the concave profile (Soil and Water Conservation Society, 1993).

For example, assume a concave hillslope decreases from 18 percent gradient at the upper end to a 2 percent gradient at the lower end. The average gradient is 10 percent, and one-half of the average gradient is 5 percent. Thus, deposition is assumed to begin at the location where the hillslope has flattened to a gradient of 5 percent, and this would mark the endpoint for this particular length segment. On the other hand, consider a concave hillslope that decreases from a gradient of 4 percent on the upper hillslope to a gradient of 2 percent on the lower end. In this case the average gradient is 3 percent and one-half of that is 1.5 percent. Because the gradient at the lower end of the hillslope profile (2 percent) is greater than the gradient where deposition would occur (1.5 percent), no deposition is assumed to take place on this hillslope. This latter example reinforces the fact the deposition does not always occur as a hillslope flattens.

When the RUSLE soil-loss values are used to estimate off-site sediment delivery, the hillslope length is measured from the origin of overland flow through the depositional area. The P factor, to be discussed in Chapter 6, is used to compute the amount of deposition and sediment from the hillslope.

Fortunately, however, estimated soil-loss values from RUSLE are not as sensitive to inaccurate estimates of hillslope length as they are to inaccurate estimates of hillslope gradient. In fact, differences in lengths of ±10 percent are not important for most hillslopes, especially flat gradients.

Diversion channels installed as part of a conservation-system design on mined lands or construction sites conduct water to an outlet for controlled drainage from the landscape. These diversions reduce hillslope length, thereby reducing soil loss, because hillslope length is measured from the place where overland flow begins to the beginning of the diversion on the hillside. However, if contouring alone is employed on the mined lands or construction sites, hillslope length is measured as though the contours do not exist. Contouring effects on soil loss are taken into account by the Support Practice, P factor, discussed in Chapter 6.

Terraces also reduce the influence of hillslope length on soil loss. **Figure 4-2** shows three possible terrace configurations. Outward-sloping terrace benches, such as that illustrated in **Figure 4-2A**, are constructed to increase hillslope stability. If the edge of the bench is very close to the contour, so that the overland flow continues across the bench without concentrating, the hillslope length extends from the place near the top of the hillslope where overland flow originates, across the bench, to the hillslope below. In this case, the hillslope consists of three segments included in the estimation of the LS value.

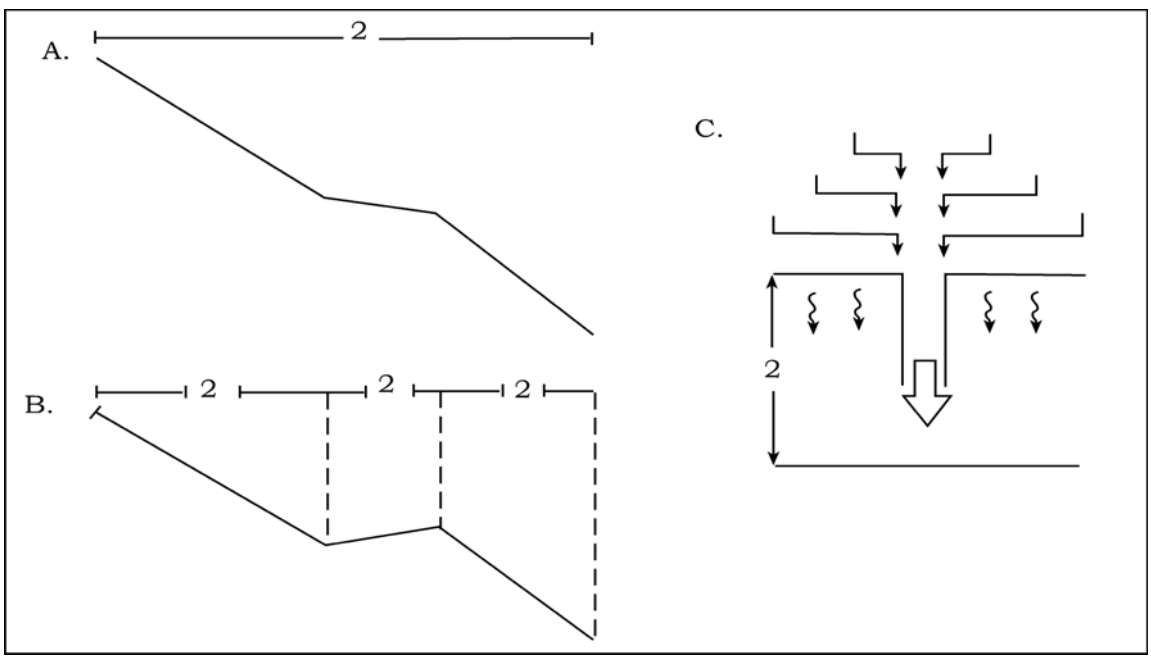


Figure 4-2. Effect of terraces on hillslope length

Back-sloping benches, such as that illustrated in **Figure 4-2B**, function as diversions, ending the hillslope length as described above. Three separate RUSLE analyses should be used to estimate soil loss from the hillslope depicted in **Figure 4-2B**.

Sometimes the berm along the front edge of a bench is uneven in height. The runoff collected behind the berm may be directed to several "breakovers" locations along the

berm, concentrating the flow at these locations. In those areas of the hillslope where runoff is diverted, a new hillslope length begins below the diversion and extends to the bottom of the hillslope, as depicted in Figure **4-2C**.

The accuracy of estimates for the L value is the highest for hillslope lengths of 35 to 300 feet because most experimental-plot lengths occurred within these limits. However, the L value estimates for lengths from 20 to 50 and 300 to 600 feet are moderately accurate. Because the relationships for longer lengths have been extrapolated from shorter experimental-plot lengths, the accuracy of L values is probably poorest for lengths from 600 to 1000 feet. RUSLE should not be used to estimate soil loss from hillslope longer than 1000 feet.

Hillslope lengths usually do not exceed 400 feet under natural conditions. Overland flow usually becomes concentrated into concentrated flow paths or rills in less than 400 feet. Although natural hillslopes can occur that are longer than 1,000 feet under certain environmental conditions, RUSLE should not be used to estimate soil loss from hillslopes longer than 1000 feet, and indeed, the RUSLE program will not accept values for lengths that total more than 1000 feet.

The hillslope-length values used in RUSLE can be either horizontal measurements or measurements along the hillslope. In the field, it is easier and more accurate to measure length along the hillslope rather than horizontally, especially for longer hillslopes. Hillslope-segment data are entered into the RUSLE program from the top to the bottom of the hillslope profile as shown in the earlier example. For gradients of less than 20 percent (5:1), the difference between the calculated L value for lengths measured along the hillslope or measured horizontally is small. **Figure 4-3** illustrates some typical lengths in the field (AH-703).

Horizontal hillslope-length measurements can, in some cases, be obtained from topographic maps. However, because accuracy decreases as scale decreases, great care should be employed when taking length data from topographic maps with contour intervals greater than 2 feet. Usually, length is overestimated when topographic maps, such as USGS 7½ minute quadrangle maps (20-foot intervals), are used because the origin of the overland flow where the length should begin and especially concentrated flow areas or deposition area where length should be terminated are difficult to ascertain from such maps. One example where the USGS 7½-minute quadrangle maps with 20-foot contour intervals can be used with fair accuracy is a small concave watershed with a relatively straight, closely-spaced rill pattern on most of the hillslope profile and a flow pattern from the top to the bottom of the hillslope or to a flow concentration at the bottom of a swale (AH-703). Likewise, fair accuracy could be expected for similar topographic situations based on maps with 5 to 10-foot contour intervals.

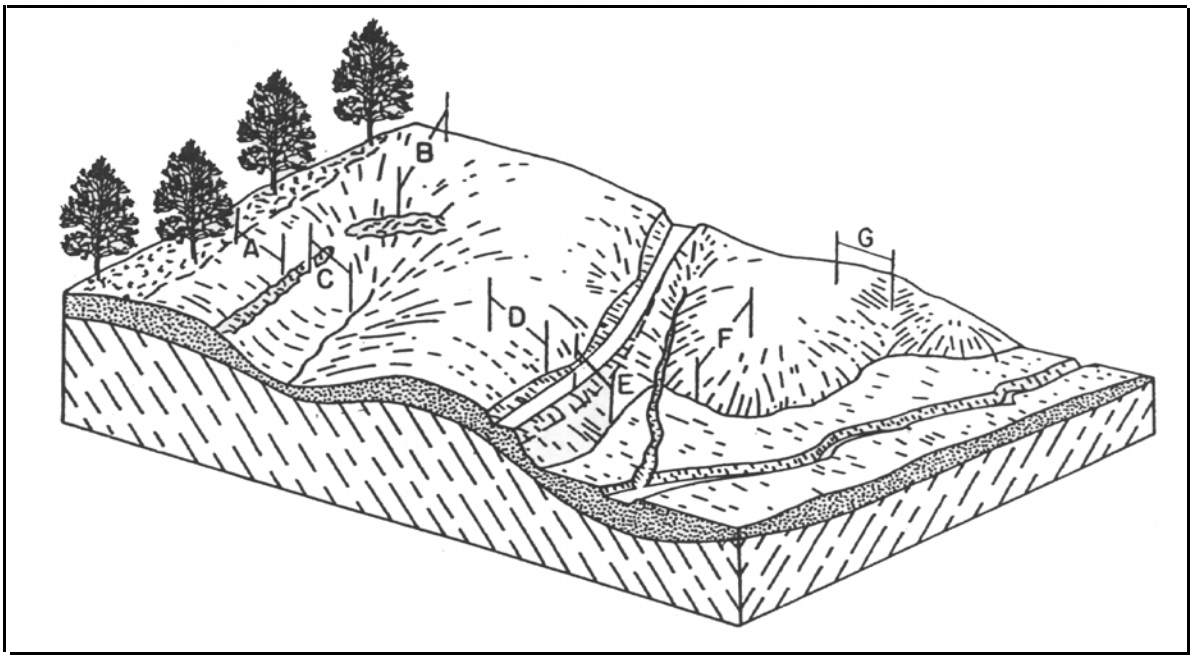


Figure 4-3. Typical hillslope lengths (Dissmeyer and Foster 1980). Hillslope A -- If undisturbed forest soil above does not yield surface runoff, the top of hillslope starts with edge of undisturbed forest soil and extends downslope to windrow if runoff is concentrated by windrow. Hillslope B -- Point of origin of runoff to windrow if runoff is concentrated by windrows. Hillslope C -- From windrow to flow concentration point. Hillslope D -- Point of origin of runoff to road that concentrates runoff. Hillslope E -- From road to flood plain where deposition would occur. Hillslope F -- On nose of hill, from point to origin of runoff to flood plain where deposition would occur. Hillslope G -- Point of origin of runoff to slight depression where runoff would concentrate

Hillslope-Gradient Factor (S)

The hillslope-gradient factor, S, reflects the effect of hillslope-profile gradient on soil loss. For a unit plot, with a 9 percent gradient as described earlier, the S value is equal to 1. The S values vary from above to below 1, depending on whether the gradient is greater than or less than that of the unit plot. Soil losses increase more rapidly as gradient increases than as length increases. Also, rill erosion is affected more by hillslope gradient than is interrill erosion.

The gradient of a hillslope profile is defined as the change in elevation per change in horizontal distance, expressed in percent. The gradient of a particular hillslope can be measured in the field using a rod and Abney or hand level, electronic survey level, or a GPS unit, at the same time that length is measured. Hillslope gradients may also be

estimated from digital aerial surveys or specific site maps but, again, accuracy decreases as the map scale decreases.

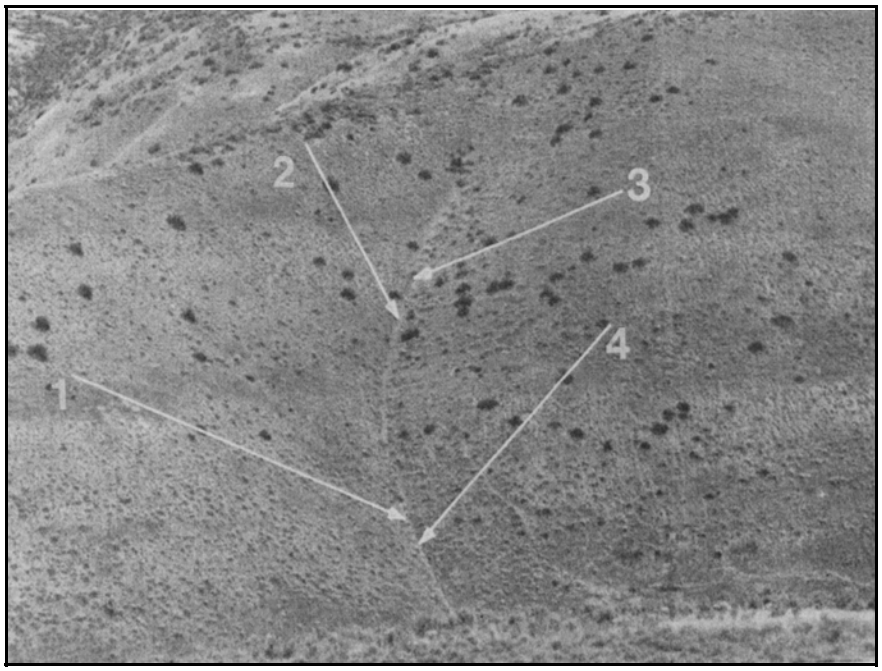
Accuracy of estimates for the S value is the highest for hillslope gradients from 3 to 20 percent. The accuracy is moderate for gradients of 1 to 3 and 20 to 35 percent. The accuracy of S is less for gradients exceeding 35 percent. Gravitational soil movement (such as slumps and slides) may be the dominant mode of soil loss when gradients exceed 50 percent (2:1).

Usually, the area of the field having the greatest potential erosion is where the hillslope gradient and S value are the greatest. This area is used to compute soil loss in order to estimate the highest probable rate. If an average soil-loss value is desired, soil loss should be estimated for several sites with varying lengths and gradients and a weighted average used to represent the soil loss from the area.

Interaction of Hillslope Length and Gradient

Within RUSLE, the hillslope length (L) and gradient (S) terms are combined into a single topographic factor (LS) representing the ratio of soil loss from a given hillslope length and gradient to soil loss from the unit plot (72.6 ft in length and 9 percent in gradient). Thus, LS values are not absolute values but are based upon a value of 1 for unit plot conditions (AH-703).

Individual values describing the hillslope length and gradient are entered into RUSLE, as shown earlier in **Figure 4-1**, and a single LS value is estimated for the hillslope profile. Examples of the LS calculations for hillslope segments of various lengths and gradients on small hillslopes in a rangeland watershed are shown in **Figure 4-4.**



Transect	Hillslope length (ft)	Hillslope steepness(s) (%)	LS
1	225	61	13.27
2	135	53	9.34
3	150	45	8.58
4	375	60	16.82

Figure 4-4. Examples of LS calculations hillslopes in a rangeland watershed.

It should be noted that an estimated LS value is used to describe a single hillslope profile within a landscape and does not apply to an entire watershed. Three-dimensional effects of hollows that concentrate overland flow, and spur-ends which disperse overland flow, require special consideration within RUSLE. If the average watershed soil loss is required, several representative combinations of RUSLE factors (including LS) should be used to estimate soil loss. Then, an areally-weighted average soil loss should be calculated outside of RUSLE based on the proportion of the watershed that each factor combination represents.

When entering the data for hillslope length and gradient, RUSLE requires the user to select one of several general land uses . The choices for disturbed lands assume that rill erosion is greater than interrill erosion for the surface and soil conditions. Hillslope length, therefore, is assumed to have a greater effect on soil loss than for undisturbed conditions where the topsoil is fully consolidated. Also, for disturbed sites, the effect of hillslope length on soil loss is influenced by the "cut" or "fill" nature of the surface material. A

topsoil surface is assumed to be less susceptible to rill erosion than a subsoil of the same soil texture. Once the time since material placement and reclamation extends beyond the "years to consolidation" given in the estimation of the K-factor, discussed in Chapter 3, the land use should be considered as cropland, pastureland, or rangeland.

The proper choice of general land use is very important in the computation of accurate LS values by the RUSLE program. Research has shown that some graded spoil materials are highly erodible due to high bulk densities, crusting, and low porosities, resulting in low permeabilities and infiltration capacities (Gilley et al., 1977; Schroeder, 1987). **Table 4-1** illustrates the influences of land use and hillslope gradient on LS values for hillslopes of 100 and 600 ft lengths. As expected, LS values increase with increasing hillslope length and gradient. For short hillslopes (100 ft. or less), the LS values are similar for the three land uses, especially when the hillslope gradients are small. For long hillslopes (600 ft or more) of the sort often created by land-disturbing activities or included in reclamation plans, the differences in the LS values for the three land uses increase as the hillslope gradient increases. For a hillslope that is 600 ft in length and 20% in gradient, the LS value of disturbed land with subsoil fill is 14.1, while the LS value of pastureland is 6.23. Other factors being equal, the soil loss from the disturbed land would be more than twice (2.26 times) that of the pastureland. The influence of land use on LS values is greater for long hillslopes than for short hillslopes because of the greater downslope accumulation of runoff on long hillslopes than on short hillslopes.

Care must be taken in determining not only the most appropriate values entered for hillslope length and gradient, but also the appropriate land use. This is especially critical as hillslope lengths and gradients increase, as shown in Table 4-1.

Table 4-1. Hillslope length-gradient (LS) values for hillslopes of 100 and 600 ft lengths with various gradients and land uses.

Hillslope Length = 100 ft, silt loam soil	**Land Use**		
Slope Gradient (%)	**Disturbed Land, Subsoil Fill**	**Regularly Tilled Cropland**	**Pastureland**
0.5	0.088	0.086	0.085
1	0.15	0.14	0.14
3	0.41	.039	0.37
6	0.82	0.77	0.73
10	1.46	1.38	1.29

Slope Gradient (%)	Disturbed Land, Subsoil Fill	Regularly Tilled Cropland	Pastureland
15	2.25	2.38	2.22
20	3.57	3.39	3.16
30	5.59	5.32	4.96
50	9.15	8.74	8.16

Hillslope Length = 600 ft, silt loam soil	Land Use		
Slope Gradient (%)	**Disturbed Land, Subsoil Fill**	**Regularly Tilled Cropland**	**Pastureland**
0.5	0.12	0.099	0.090
1	0.24	0.19	0.16
3	0.98	0.66	0.48
6	2.47	1.64	1.09
10	5.04	3.38	2.17
15	9.49	6.53	4.12
20	14.1	9.91	6.23
30	23.4	16.9	10.6
50	40.4	29.9	19.1

Non-Uniform Hillslope Profiles

In many cases, hillslope profiles are complex, consisting of several segments of differing lengths, gradients, and shapes which necessitate special handling in the RUSLE program. RUSLE computes an LS value for non-uniform hillslope profiles by estimating an "effective LS value". The hillslope profile is divided into segments of uniform length and gradient characteristics and each segment is entered into the program individually. Five segments often define the hillslope profile, although RUSLE will allow up to 10 segments.

The shape of the hillslope profile affects soil loss rates due to the changes in the length and gradient characteristics along the hillslope. This effect on soil loss, however, is not related to the proximity of the sediment-receiving channel. These various hillslope-profile forms are characterized as uniform, concave, convex, and complex (convex -

concave). Meyer and Romkens (1976) described the soil loss tendencies on these hillslope-profile forms in the following manner:

> "A convex slope is more erodible than a uniform slope, because it is steepest near the toe where runoff is greatest. A uniform slope will yield more sediment than a concave one, because the concave slope is steepest where the flow is least and because some of the sediment eroded from the upper portions of the concave slope may deposit as it flattens near the toe …. A complex slope that is convex along its upper portion and concave along its lower portion will generally yield less sediment than a uniform slope. A flat section at the toe of a slope will also reduce sediment yield."

The segment data are entered sequentially from the top to the bottom of the hillslope profile. As stated earlier, the total length of all the segments must not exceed 1000 feet.

Examples of LS-factor screens for uniform, convex, concave, and complex hillslope profiles are shown in **Figures 4-5 through 4-8**. All characteristics, with the exception of the gradients for the various segments, are the same for all profiles. The difference between hillslope-profile forms can be seen in the gradients entered for the 10 segments that define the particular hillslope-profile shape. As can be seen from the estimates of the LS values for these examples, all other factors being equal, the order of soil loss (from least to greatest) for these hillslope profiles is: complex < concave < uniform < convex. Although the construction of complex or concave hillslope profiles may offer grading challenges, these shapes can substantially reduce soil-loss rates.

These LS values emphasize the importance of correctly identifying the configuration of the hillslope profile in question. Accurate measurements of the field characteristics will produce the most accurate estimates of the LS value, especially for non-uniform hillslope profiles consisting of more than one segment.

```
      File        Exit        Help        Screen
+----------------------------< LS Factor 1.06 >-----------------------------+
|
|   number of segments: 10         segment lengths are measured:  2
|         segments are: 2          uniform segment length (ft) : 30
|         soil texture: silt loam
|     general land use: 6
|-----------------------------------------------------------------------------
|                            1         2         3         4         5
| Gradient (%) of Segment   11        11        11        11        11
| Length of Segment (ft)    30        30        30        30        30
| Segment LS               1.021     1.502     1.759     1.95      2.106
|-----+-----------------------------------------------------------------+--------
|     | overall LS = 2.06; equiv. slope = 11 %; horiz. length = 300 ft |
|-----+-----------------------------------------------------------------+--------
|                            6         7         8         9        10
| Gradient (%) of Segment   11        11        11        11        11
| Length of Segment (ft)    30        30        30        30        30
| Segment LS               2.239     2.357     2.462     2.558     2.646
|-----------------------------------------------------------------------------
|
+--------------------------------< Esc exits >--------------------------------+
Tab  Esc F1   F3   F9
FUNC esc help cont info
```

Figure 4-5. LS values for a uniform hillslope profile.

```
      File        Exit        Help        Screen
+----------------------------< LS Factor 1.06 >-----------------------------+
|
|   number of segments: 10         segment lengths are measured:  2
|         segments are: 2          uniform segment length (ft) : 30
|         soil texture: silt loam
|     general land use: 6
|-----------------------------------------------------------------------------
|                            1         2         3         4         5
| Gradient (%) of Segment   11        11        11        11        11
| Length of Segment (ft)    30        30        30        30        30
| Segment LS               1.021     1.502     1.759     1.95      2.106
|-----+-----------------------------------------------------------------+--------
|     | overall LS = 2.06; equiv. slope = 11 %; horiz. length = 300 ft |
|-----+-----------------------------------------------------------------+--------
|                            6         7         8         9        10
| Gradient (%) of Segment   11        11        11        11        11
| Length of Segment (ft)    30        30        30        30        30
| Segment LS               2.239     2.357     2.462     2.558     2.646
|
+---------------------------------< Esc exits >-------------------------------+
Tab  Esc F1   F3   F9
FUNC esc help cont info
```

Figure 4-6. LS values for a convex hillslope profile.

```
      File        Exit        Help        Screen
+----------------------------< LS Factor 1.06 >-------------------------------+
|                                                                              |
|   number of segments: 10         segment lengths are measured:  2            |
|         segments are: 2          uniform segment length (ft) : 30            |
|         soil texture: silt loam                                              |
|     general land use: 6                                                      |
|------------------------------------------------------------------------------|
|                            1         2         3         4         5         |
| Gradient (%) of Segment   20        18        16        14        12         |
| Length of Segment (ft)    30        30        30        30        30         |
| Segment LS               1.998     2.827     2.943     2.763     2.403       |
|----+-------------------------------------------------------------------+-------|
|    |                                                                   |       |
|    | overall LS = 1.84; equiv. slope = 10.1 %; horiz. length = 300 ft  |       |
|----+-------------------------------------------------------------------+-------|
|                            6         7         8         9        10         |
| Gradient (%) of Segment   10         8         6         4         2         |
| Length of Segment (ft)    30        30        30        30        30         |
| Segment LS               1.924     1.461     1.073     0.681     0.318       |
|------------------------------------------------------------------------------|
|                                                                              |
+--------------------------------< Esc exits >-------------------------------+
Tab  Esc F1   F3   F9
FUNC esc help cont info
```

Figure 4-7. LS values for a concave hillslope profile.

```
      File        Exit        Help        Screen
+----------------------------< LS Factor 1.06 >-------------------------------+
|                                                                              |
|   number of segments: 10         segment lengths are measured: 2             |
|         segments are: 2          uniform segment length (ft) : 3             |
|         soil texture: silt loam                                              |
|     general land use: 6                                                      |
|------------------------------------------------------------------------------|
|                           1         2         3         4         5         |
| Gradient (%) of Segment   2         6        12        12        12         |
| Length of Segment (ft)    30        30        30        30        30         |
| Segment LS               0.223     0.743     1.994     2.219     2.403       |
|----+-------------------------------------------------------------------+-------|
|    | overall LS = 1.3; equiv. slope = 8.17 %; horiz. length = 300 ft  |       |
|----+-------------------------------------------------------------------+-------|
|                            6         7         8         9        10         |
| Gradient (%) of Segment   10         8         6         4         2         |
| Length of Segment (ft)    30        30        30        30        30         |
| Segment LS               1.924     1.461     1.073     0.681     0.318       |
|------------------------------------------------------------------------------|
|                                                                              |
+--------------------------------< Esc exits >-------------------------------+
Tab  Esc F1   F3   F9
FUNC esc help cont info
```

Figure 4-8. LS values for a complex hillslope profile.