A Guide For Predicting Sheet and Rill Erosion On Forest Land

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PURPOSE OF HANDBOOK

Managing forest soils require knowledge of factors that cause and reduce soil losses. Forests are often managed to produce multiple goods and services; most of these products are dependent upon the basic resource—soil. How the forester manages a site influences the productivity of the soil and the amount of goods and services produced on that site. Forest management practices vary in impact upon sheet and rill erosion. The soil loss prediction procedure presented in this handbook provides a method for estimating sheet and rill erosion for various practices. The same procedure is useful for planning forestry practices that will minimize erosion, and for understanding the cause and effect relationships between management practices and erosion.

The procedure presented is based upon an empirical equation, the Universal Soil Loss Equation (USLE) (7). The USLE was developed for agriculture with increasing use on forest land. The USLE has been modified to better predict sheet and rill erosion on forest land *(1)*. The cover-management factor C was modified; and it is now possible to assign an approximate C value for most forest conditions. The procedure was validated using research plots and watersheds.

The C-Factor procedure for forests is an adaptation of a system developed by Wischmeier *(5, 6)* and Wischmeier and Smith *(7)* for agricultural land where the component subfactors affecting C are evaluated to assign a composite C value. Nine subfactors have been identified and this approach provides great flexibility in assigning a C value. However, the use of nine subfactors presents problems of consistency in application and in interpretation of the subfactors.

This handbook's goal is to provide consistent application and interpretation of subfactors in the field. Words alone will not suffice; therefore, the text is accompanied by illustrations. Where appropriate, these illustrations are given numerical values to provide consistent rating of field conditions.

It is beyond the purpose of this handbook to discuss the origin of the USLE and its application to agriculture and construction sites. These subjects are covered in Agriculture Handbook 537 *(7)*.

The USLE estimates sheet and rill erosion where forest management activities and other causes expose soil to the erosive energy of rainfall and runoff. Erosion is defined as the amount of soil delivered to the toe of the slope where either deposition begins or where runoff becomes concentrated. The USLE does not estimate gully, landslide, soil creep or stream channel erosion. Nor does it estimate deposition at the toe of the slope, sediment yield, or erosion from a single storm. Finally, the USLE should not be applied to mechanical site prepared areas treated by bedding.

UNIVERSAL SOIL LOSS EQUATION

The erosion rate of a given site expresses the influence of numerous physical and management factors. Over the years, several soil loss equations have been developed to estimate erosion for various agriculture conservation planning programs. These equations were attempts to extrapolate limited research data to the wide variety of conditions found in the field. The USLE has evolved to become the best available model to predict erosion for a large portion of the United States; its application is being expanded to other regions and countries *(7)*.

The USLE was developed to predict long term, average soil losses in runoff from specific field areas in specified cropping and management systems in agriculture *(7)*. This means if the site and cover conditions remain fixed, the average erosion for 20 or more years could be estimated by the USLE. Obviously, site, rainfall and cover factors vary by season of year and over time. How to develop a weighted erosion rate for these changing conditions is discussed later.

With appropriate selection of its factor values, the USLE estimates the average soil losses for rotation of timber, recovery period of a disturbance, a particular year within the recovery period, or a season within a particular year of a recovery period. It predicts the soil loss for a given site as a product of six major factors whose values at a particular location can be expressed numerically. Erosion variables reflected by these factors vary considerably about their means from storm to storm, but the effects of these fluctuations average out over the long run. Because of these unpredictable short-term variations, the USLE is substantially less accurate in predicting specific events and short periods, than for predicting long term averages.

The soil loss equation is: A = RKLSCP

Where: A is the computed soil loss per unit area, expressed in the units selected for K and for the period selected for R. In practice, these are usually so selected that they compute A in tons per acre per year, but other units can be selected.

R, the rainfall and runoff factor, is the number of rainfall erosion index units, plus a factor for runoff from snowmelt or applied water where such runoff is significant.

K, the soil erodibility factor, is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, which is defined as a 72.6-foot length of uniform 9-percent slope continuously in clean-tilled fallow.

L, the slope-length factor, is the ratio of soil loss from the field slope length to that from a 72.6-foot length under identical conditions.

S, the slope-steepness factor, is the ratio of soil loss from the field slope gradient to that from a 9-percent slope under otherwise identical conditions.

C, the cover and management factor, is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled, continuous fallow.

P, the support practice factor, is the ratio of soil loss with a support practice like contour disking to that with straight-row farming up and down the slope.

Applying the USLE

The USLE is used to estimate sheet and rill erosion from rainfall and runoff. The erosion estimate is made by multiplying the values for the six factors (RKLSCP). Values for these factors are derived from figures, tables, published information, and field observations.

The rainfall and runoff factor R is read from figure 1. To make an erosion estimate, locate the

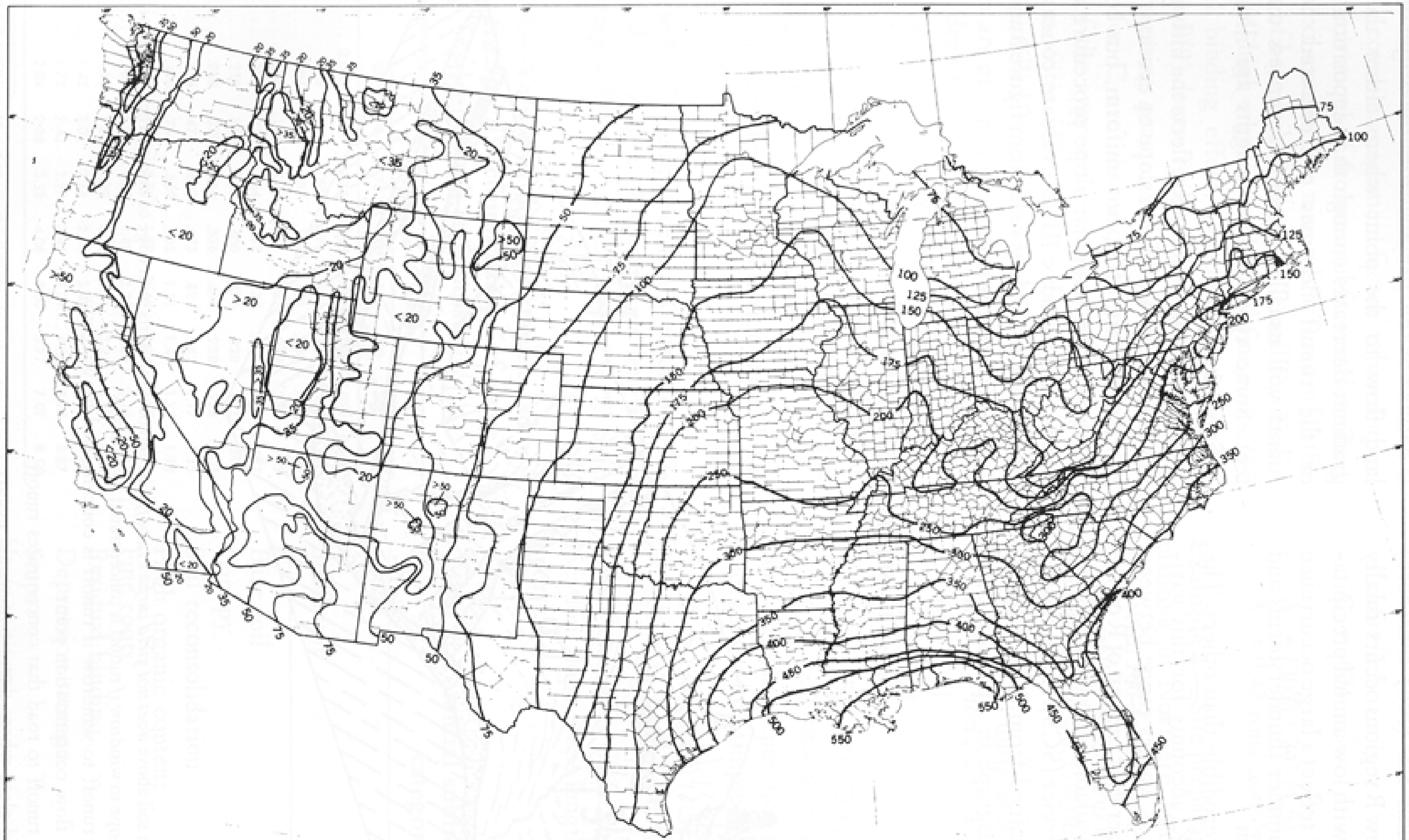


Figure 1.—Average annual values of the rainfall index.[1]

[1]Measured in EI units—(100 foot tons/acre) (inches/hour). Wischmeier and Smith *(7)*.

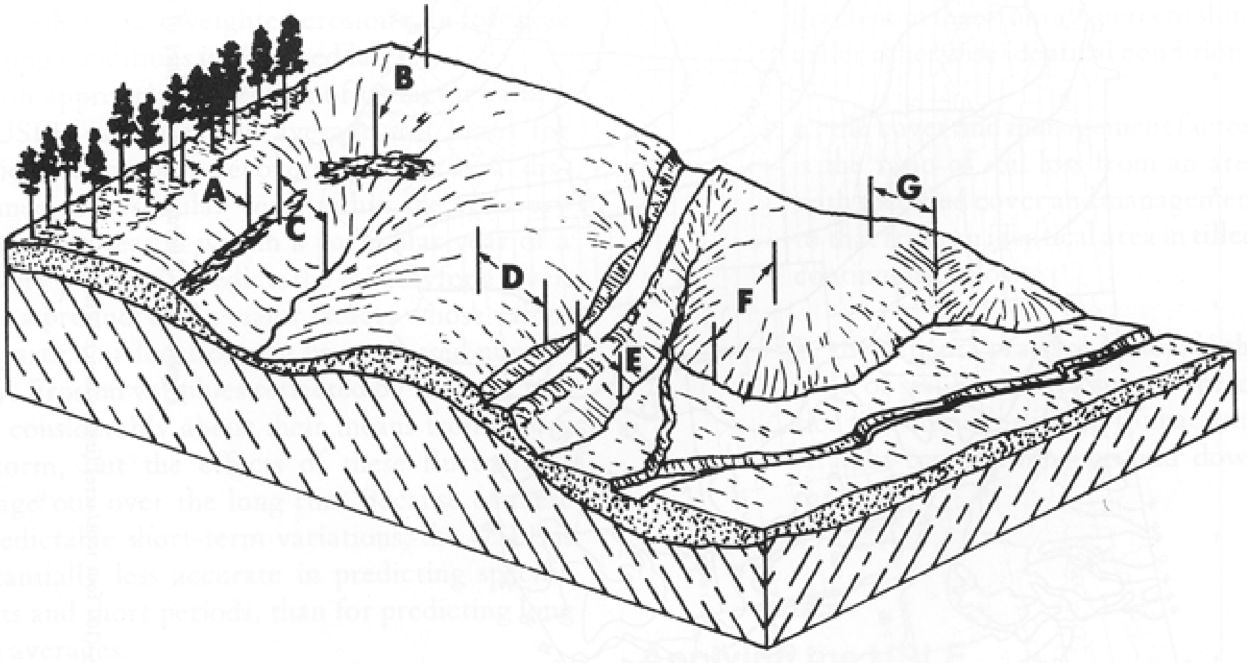
area on the map and note the R value shown there. R values can be interpolated between isoerodent lines. R values range from less than 50 to 550 EI units. One EI unit equals 100 (foot tons/acre) (inches/hour). Rain in low R regions occurs usually as low intensity storms, with low annual precipitation. High R's generally reflect a large occurrence of intense spring and summer thunderstorms and high annual precipitation.

Some soils are more erodible than others. The soil erodibility factor K accounts for this variability in soils. Usually, K values range between 0.1 and 0.5 tons per acre per year per unit of R on the unit plot. K values are available for most soils from the Soil Conservation Service (SCS). If the desired K values cannot be obtained from SCS, refer to the soil erodibility nomograph in Appendix II.

Erosion increases as slope length increases. However, there is a practical limit to the maximum length to be found in the field. Slope length is defined as the distance from the origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the runoff becomes concentrated. Surface runoff will usually concentrate in less than 400 feet. Some typical slope lengths are illustrated in figure 2.

Slope-steepness factor S reflects the influence of the gradient of a uniform slope on erosion. However, slopes are often not uniform, but concave or convex. An irregular slope procedure is presented in Appendix III to evaluate concave and convex slopes. Values read from figure 3 and table 1 are for uniform slopes.

Figure 2.—Slope length examples.



Legend:

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 of origin of runoff to flood plain where deposition would occur.
Slope *G*. Point of origin of runoff to slight depression where runoff would concentrate.

L and S are evaluated together from table 1 or figure 3. Slope is read in percent using a clinometer, Abney level or similar device. Slope length is paced, measured, or estimated in the field.

C, the cover-management factor, is based upon field observations of the nine subfactors described in the next section. The nine subfactors are (1) the amount of bare soil, (2) canopy, (3) soil reconsolidation, (4) high organic content, (5) fine roots, (6) residual binding effect, (7) onsite storage, (8) steps, and (9) contour tillage. The ninth is part of the supporting practices P factor of the USLE. Values for C are obtained by multiplying the values of the appropriate subfactors for a given condition. Sites fall into two disturbance categories (untilled or tilled) and the subfactors to consider are grouped by category in table 2. Disking and deep root raking break up or till the soil, and make it more susceptible to erosion. The observer must inspect each site to determine which subfactors are operating and derive subfactor values from figures and tables presented in the following section.

A couple of examples will show the use of the USLE in estimating erosion:

Example 1.—Logging in central Georgia on a 10-percent slope with a 120-foot slope length on a soil having a K value of 0.24 tons/acre/EI unit.

Table 1.—Values of the topographic factor, LS, for specific combinations of slope length and steepness.[1]

Percent slope	Slope length (feet)							
	25	50	75	100	150	200	300	400
0.2	0.060	0.069	0.075	0.080	0.086	0.092	0.099	0.105
0.5	.073	.083	.090	.096	.104	.110	.119	.126
0.8	.086	.098	.107	.113	.123	.130	.141	.149
2	.133	.163	.185	.201	.227	.248	.280	.305
3	.190	.233	.264	.287	.325	.354	.400	.437
4	.230	.303	.357	.400	.471	.528	.621	.697
5	.268	.379	.464	.536	.656	.758	.928	1.07
6	.336	.476	.583	.673	.824	.952	1.17	1.35
8	.496	.701	.859	.992	1.21	1.41	1.72	1.98
10	.685	.968	1.19	1.37	1.68	1.94	2.37	2.74
12	.903	1.28	1.56	1.80	2.21	2.55	3.13	3.61
14	1.15	1.62	1.99	2.30	2.81	3.25	3.98	4.59
16	1.42	2.01	2.46	2.84	3.48	4.01	4.92	5.68
18	1.72	2.43	2.97	3.43	4.21	4.86	5.95	6.87
20	2.04	2.88	3.53	4.08	5.00	5.77	7.07	8.16

[1] $LS = (\lambda/72.6)^m (65.41 \sin^2\theta + 4.65 \sin\theta + 0.065)$ where λ = slope length in feet; θ = angle of slope in degrees; and m = 0.2 for gradients less than 1 percent, 0.3 for 1 to 3 percent slopes, 0.4 for 3.5 to 4.5 percent slopes, and 0.5 for slopes of 5 percent or greater (7).

C for logging equals 0.004 (the derivation is described later).

R = 300 EI units/year (figure 1)
K = .24 tons/acre/EI unit
LS = 1.5 (figure 3)
C = .004

A = (300) (.24) (1.5) (.004)
A = 0.43 tons/acre/year

Example 2.—Site preparation by disking for tree planting in Northern Michigan on a 2-percent slope with 100-foot slope length and a soil having a K value of 0.17 tons/acre/EI unit. The cover-management factor is 0.118(the derivation is described later).

R = 75 EI units/year (figure 1)
K = .17 tons/acre/EI unit
LS = .201 (table 1)
C = .118

A = (75) (.17) (.201) (.118)
A = 0.30 tons/acre/year

The same site preparation treatment in the central Georgia site in example 1 would have produced:

A = (300) (.24) (1.5) (.118)
A = 12.7 tons/acre/year

These examples illustrate the importance of location, slope, slope length, soil and management upon erosion.

Table 2. Potential subfactors by disturbance category

Subfactor	Disturbance category	
	Tilled	Untilled
Bare soil	X	X
Canopy	X	X
Soil reconsolidation	X	X
High organic content		X
Fine roots	X	X
Residual binding	X	
Depression storage	X	X
Steps	X	X
Contour tillage	X	

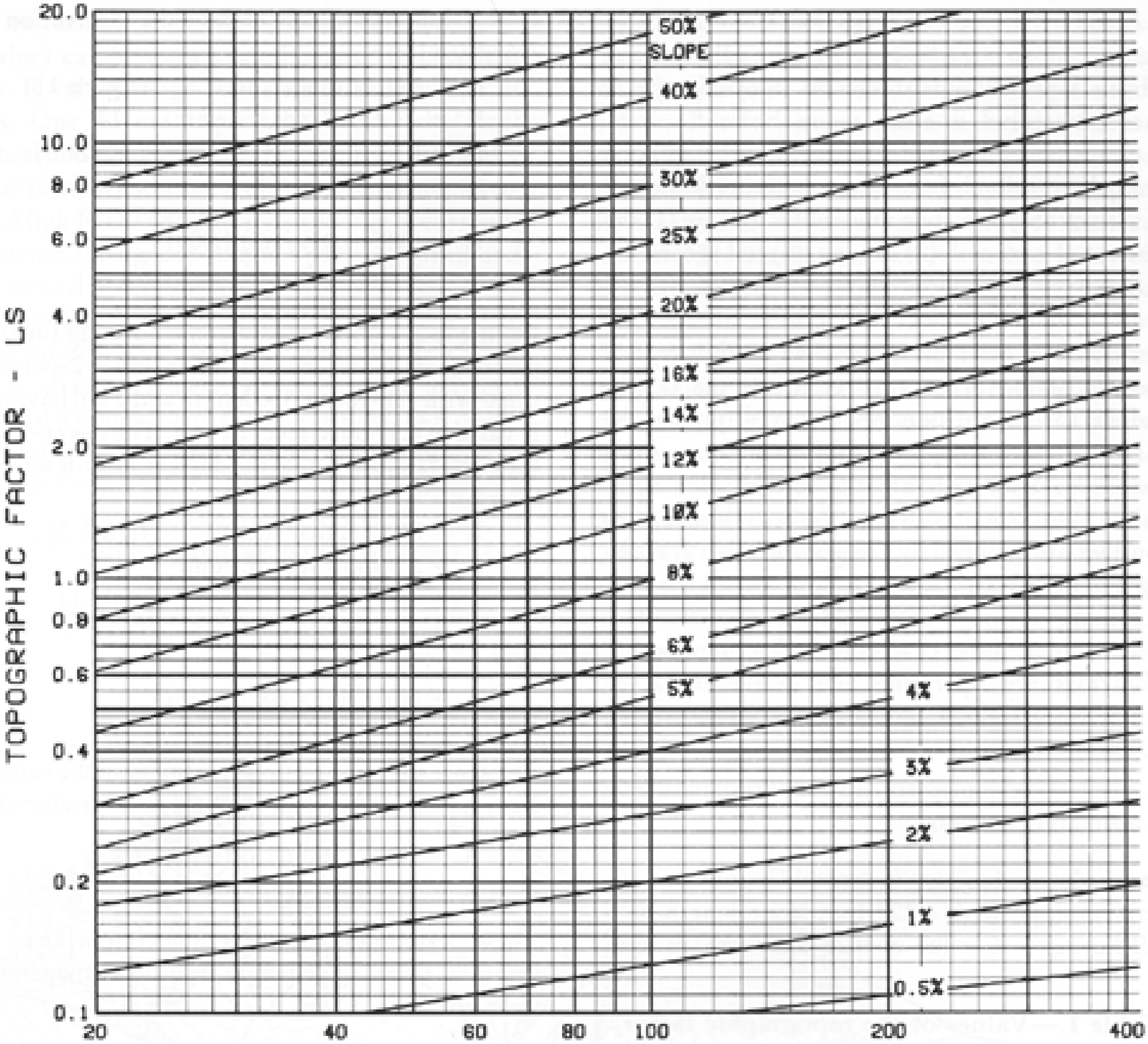


Figure 3.—Slope effect chart.[1]

[1]Topographic factor, LS. $LS = (\lambda/72.6)^m\ (65.41 \sin^2\theta + 4.65 \sin\theta + 0.065)$ where λ slope length in feet; θ = angle of slope in degrees and m = 0.2 for gradients less than 1 percent, 0.3 for 1 to 3 percent slopes, 0.4 for 3.5 to 4.5 percent slopes, and 0.5 for slopes of 5 percent or greater (7).

COVER-MANAGEMENT FACTOR (C) FOR FORESTS

Logging, fire, grazing, mechanical site preparation, wildlife and other activities disturb and destroy cover, exposing soil to the erosive energy of rainfall and runoff. An undisturbed and totally covered forest soil usually yields no surface runoff; thus, it has no sheet and rill erosion *(4)*. Although these activities and their end results vary, C factor values can be assigned to express these conditions. P is included as a subfactor for our purposes. Experimental data are not available for this wide range of condition on forest land. Consequently, we adapted a system developed by Wischmeier *(5, 6)* and Wischmeier and Smith *(7)* where the component subfactors affecting C are evaluated and used to develop a composite C.

Wischmeier *(6)* identified three major subfactors: (I) canopy, (II) surface cover, and (III) below surface effects. The Type III subfactor can be further broken into effects for soil detachability, roughness, land use residual, and incorporation of crop residue *(5)*. This procedure for subfactoring C was further validated for cropland in Agriculture Handbook 537 *(7)*. It is this basic procedure that we used with appropriate additions and modifications, to develop a procedure for evaluating C factors for forest conditions. The cover-management factor C procedure presented here should be used instead of tables 11 and 12 in Agriculture Handbook 537 *(7)*.

Forest Subfactors

Major subfactors operating in the forest environment are:
(1) amount of bare soil, or conversely, ground cover, (2) canopy, (3) soil reconsolidation, (4) high organic content, (5) fine roots, (6) residual binding effect, (7) onsite storage, (8) steps, and (9) contour tillage. Subfactors 1,2,3,5,6 and 7 have direct counterparts in agricultural practices, especially conservation tillage. The eighth does not occur in most agricultural situations. The ninth is part of the supporting practices P factor of the USLE. A value for the composite C factor is a product of values for each of the subfactors operating in a given forest situation.

Bare Soil Subfactor

Erosion is a function of the amount of exposed soil. Cover such as litter, slash, logs, and surface rock protects the soil from the erosive forces of raindrop impact and runoff (figure 4). Protected and undisturbed forest soils have infiltration rates that usually exceed rainfall intensity *(4)*. Exposed forest soils are subject to soil detachment by raindrop impact. Also, they yield surface runoff, which potentially erodes soil and transports detached soil from the slope. The observer estimates the percent of the area in bare soil. Figure 5 is a guide for estimating the area occupied by bare soil.

Figure 4.—Litter, slash and rock protects soil from rainfall and runoff.

The relationship for the bare soil subfactor is an adaptation of Wischmeier's *(6)* curve for the effect of surface cover. His curve was adjusted for ground cover greater than 80 percent to give no erosion at 0 percent bare soil. In the forest, a 0 percent bare soil is generally a healed or an undisturbed condition (figure 6). Generally, no runoff occurs, thus no erosion. In contrast, agricultural soils are regularly tilled and, even with zero bare soil, runoff and slight erosion can occur, which is reflected by the 0.04 value from Wischmeier's curve at zero bare ground.

Bare soil in forests tends to be in patches randomly distributed over the area (figure 7). These patches are usually much larger and much fewer than the numerous small bare spots in agricultural situations that are typically uniformly distributed. Runoff generally occurs uniformly from both bare and mulch covered areas of agricultural soils. In contrast, covered patches in forests often yield no runoff or sediment. Runoff and sediment from bare patches reaching the toe of the slope in forest situations depends on the interconnection of bare areas. Runoff from a bare area onto a covered area may be completely absorbed. This further warrants the modification of Wischmeier's curve *(6)* below 20 percent bare soil.

A patch of ground cover in a largely exposed area usually has a very high ground cover percentage within its boundaries; this area is not eroding. Surface runoff is usually directed around such patches.

If forest, brushland or desert situations are encountered that are similar to agriculture conditions, where bare soil is uniformly distributed in small patches (on the order of 4 square inches), runoff occurs uniformly from both bare and covered areas, and some runoff occurs when the soil is completely covered; Wischmeier's *(6)* mulch effect curve may be used instead of the procedure described in this handbook.

Canopy Subfactor

Vegetal canopy intercepts rainfall and collects water on its foliage. Water drops form and fall to the ground. Drops falling from the canopy may be larger than the original raindrops, but they fall from a low canopy; the energy of the drops reaching the soil surface is less than that of rainfall in open areas. Some of the intercepted rainfall never reaches the ground, but is evaporated during and after the storm. Some of the intercepted rainfall reaches the ground as stemflow and may contribute to runoff. Wischmeier *(6)* developed values for the canopy subfactor that depend on foliage density and average drop height. Figure 8 illustrates the average drop height, which is approximately the midpoint for several types of canopies.

This subfactor applies only to the canopy above bare soil (figure 9). Canopy over litter is not included because the surface cover is the controlling factor here (figure 6). Canopy is evaluated by estimating the percentage of bare soil having canopy over it (figure 8), and the average drop height of the canopy. The open area within the canopy where rain can pass is not counted as part of the canopy.

Evaluation of canopy in most forestry situations is different than for agriculture *(6)*. In forests, canopy often is not uniformly distributed, nor is the bare soil. Areas of forest soil with undisturbed litter cover usually yield no surface

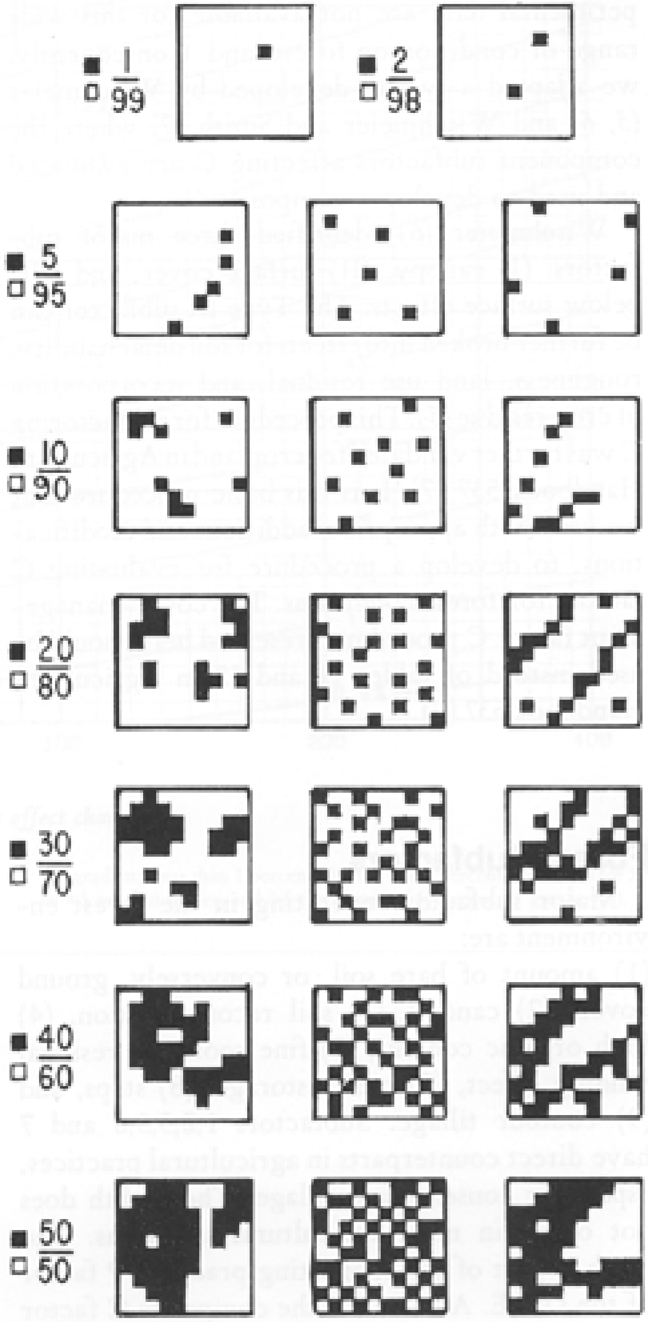


Figure 5.—Guide for estimating density of bare soil, canopy, fine roots and steps.

Figure 6.—A totally protected forest soil.

runoff, whereas covered agricultural soil often does. Wischmeier's *(6)* reduction of the canopy factor assumes uniform conditions and some surface runoff even from areas of covered soil. Forest canopy over bare soil reduces erosion from rainfall detachment erosion; because no surface runoff occurs from protected soil, canopy is given full credit.

If forests, brushland and desert conditions are encountered where canopy and bare soil are uniformly distributed as in agricultural situations, and the observer has difficulty estimating the canopy cover over bare soil; Wischmeier *(6)* provides a procedure for reducing canopy effect for this situation. Both the above and Wischsmeier's procedures produce the same answer.

Soil Reconsolidation Subfactor

Soil reconsolidates and becomes less erodible over time after land is retired from tillage. After 7 years, erosion on plots at Zanesville, Ohio, reduced to 45 percent of the erosion while maintained in tilled, continuous fallow *(5)*. The 0.45 value corresponds to the C factor for undisturbed land with no cover *(7)*. This soil-type subfactor is necessary because the soil erodibility factor K is derived from tilled soils in continuous fallow; that is, continuously void of vegetative cover. The relationship for decrease in erosion over time as soil reconsolidates is shown in figure 10.

For untilled forest soils, the soil reconsolidation subfactor is 0.45 (figure 7). However, if the soil is tilled by disking, or rootraking 2 inches or more deep, this subfactor begins at 1.0 and decreases with time after tillage (figure 11). To evaluate soil reconsolidation, the observer determines whether the soil has been tilled or not, and if tilled, how long ago.

High Organic Content Subfactor

Under permanent forest, topsoil accumulates a high organic matter content that is not considered in the USLE soil erodibility nomograph *(7)* which only goes as high as 4 percent organic matter. With good management, organic matter content can

Figure 7.—Nonuniform distribution of bare soil.

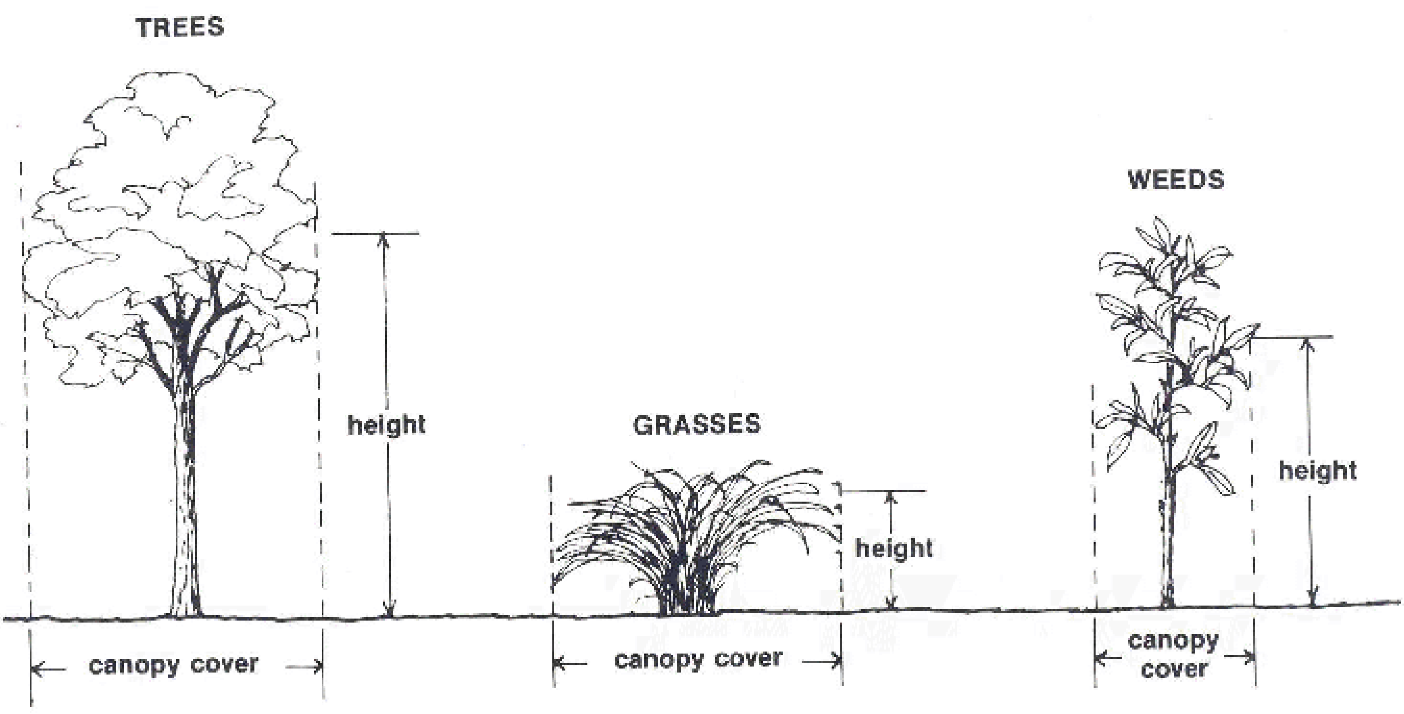


Figure 8.—Canopy effect and typical drop heights for three types of vegetation.

Figure 9.—Canopy over bare soil.

be maintained in agricultural soils, but seldom will it be as high as that under permanent forests. This higher organic content results in permanent forest soils being less erodible (figure 12). Wischmeier and Smith *(7)* recommend multiplying by a subfactor of 0.7 to account for the high organic content of permanent forest soils. Topsoil should exceed 4 percent organic matter and be more than 1 inch thick to qualify.

However, forests on recently abandoned farms have not had time for a high organic content to accumulate in the topsoil; thus, no adjustment is made (figure 13). This latter situation is common in the Piedmont and Coastal Plain regions in the South. The observer will need to dig a few shallow holes around the site to determine if 1 inch of topsoil is present or not.

Fine Root Subfactor

A dense mat of fine roots is usually present in the top 2 inches of forest soils (figure 14). Even after the trees are removed, the residual root mat will partly protect soil from erosive forces of rainfall and runoff by holding soil in place. Little data are available for this effect. Thus, we used Wischmeier's *(6)* curve for the effect of a grass root network to describe the protective effect of the roots. His curve was used after the reconsolidation effect was removed, since he had combined both into a single curve. The fine root mat effect of trees is described by the curve in figure 15.

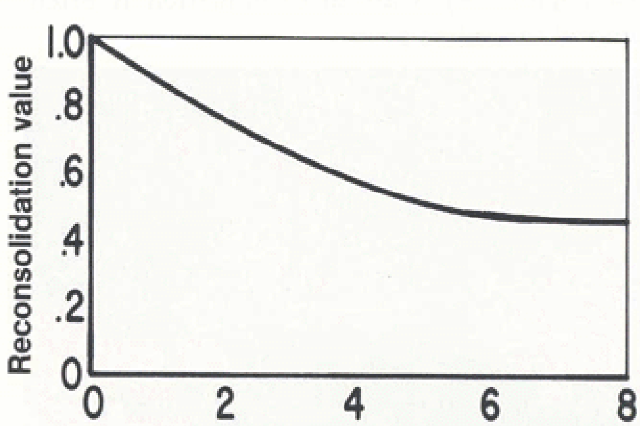


Figure 10.—The subfactor for soil reconsolidation after land was last tilled.

Figure 11.—Mechanical site preparation by disking.

Sometimes the site is exposed by removal of the surface organic material, while the topsoil with its fine root mat is left in place. Where equipment has removed the topsoil, the fine root mat is usually eliminated. The observer estimates the percentage of bare soil having this effective root mat in place (figure 5). To qualify as an effective root mat, a fine root should be present in each 1/4-inch square area (figure 14). Careful examination is often required to see fine roots.

Sometimes roots extend laterally, radiating out from invading vegetation, often far beyond the crown. Other vegetation extend their roots straight down under the root collar with no fine roots in the soil surface (figure 16). Therefore, when evaluating this subfactor, the observer must estimate the percentage of the disturbed bare soil now occupied by roots of invading plants (figure 5).

Figure 12.—Highly organic topsoil.

Figure 13.—Soil lacking highly organic topsoil.

Figure 14.—Dense, fine root mat of trees.

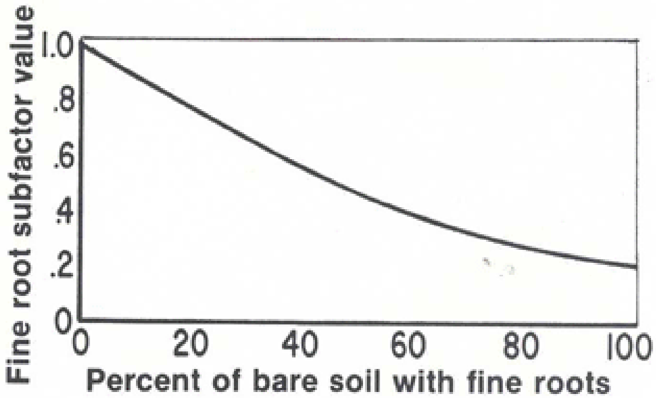


Figure 15.—The subfactor for fine roots in the top 1 to 2 inches of soil.

If forest, brushland or desert situations are encountered that are similar to agricultural conditions, where bare soil is uniformly distributed in small patches (on the order of 4-square inches), runoff occurs uniformly on both bare and covered areas, and where covered areas do not divert runoff; use the percent of the total area rather than the percent of bare soil. This adjusted procedure must be used with Wischmeier's *(6)* mulch-effect curve.

Residual Binding Effect Subfactor

The erosion response of a soil depends on the soil's recent history. That is, there is a residual or carryover effect when the land use or condition changes. When a soil that has not been tilled for some time is cultivated, erosion immediately after it is first tilled may be much less than it will be 2 to 3 years later. At first the soil has a fairly good structure: fine roots and organic matter bind soil into more stable aggregates (figure 17). With time, this effect decays and the soil becomes more erodible.

The magnitude of the effect, and its duration, is a function of the amount of roots and organic matter in the soil at the time of tillage, plus structure and permeability of the subsoil. Four residual conditions have been identified:

1. Topsoil has good initial fine root mat; and subsoil has good structure and permeability (figure 17).
2. Topsoil has poor initial fine root mat; subsoil has good structure and permeability.
3. Topsoil is absent with poor initial root mat; subsoil has good structure and permeability (figure 18).
4. Topsoil is absent with poor initial fine root mat; subsoil has poor structure and permeability.

The four residual conditions were adopted from USLE data for residual effect of turned sod *(7)*.

This subfactor is evaluated by inspecting the site for the presence or absence of topsoil, a good fine root mat in the topsoil, and by determining the structure and permeability of the subsoil. The subsoil can be inspected in nearby road cuts.

Onsite Depression Storage Subfactor

Not all detached soil may be delivered to the toe of the slope; a portion may be stored locally in depressions. Onsite storage opportunities in-

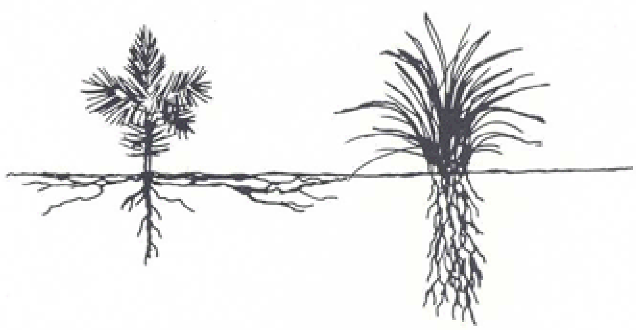


Figure 16.—Area of bare soil influenced by fine roots of invading vegetation.

Figure 17.—Condition 1 residual binding effect.

Figure 18.—Condition 3 residual binding effect.

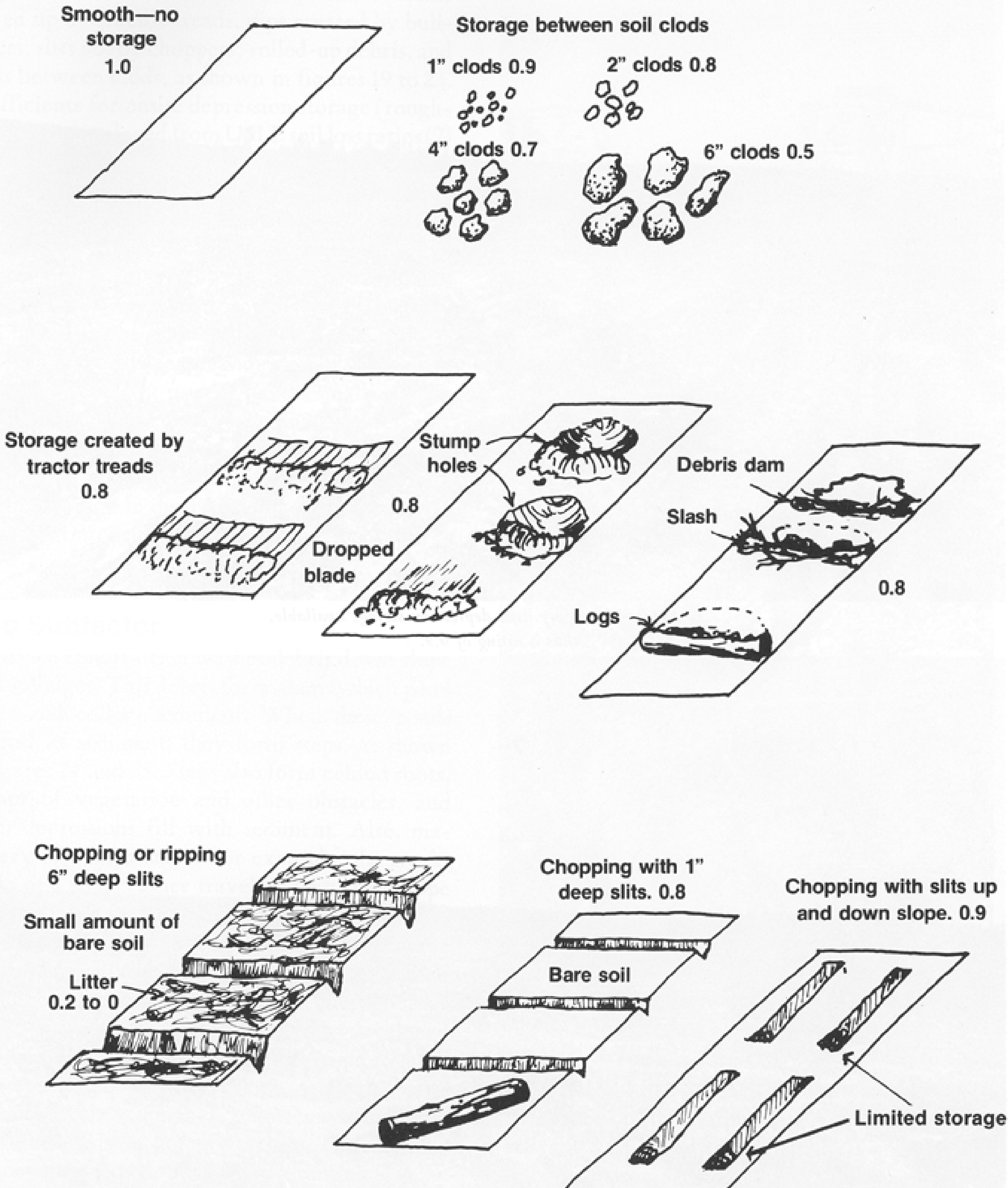


Figure 19.—Subfactor for onsite depression storage

Figure 20.—Very little depression storage available, thus a rating of 0.9.

Figure 21.—Depression storage in tracks and behind berms, with a rating of 0.7.

clude depressions such as stump holes, berms turned up by tractor treads, dips created by bulldozers, slits cut by choppers, rolled-up debris, and voids between clods, as shown in figures 19 to 23. Coefficients for onsite depression storage (roughness) were developed from USLE soil loss ratios *(7)* and from Wischmeier's *(5)* analysis of conservation tillage systems. Values range from 0 to 1 for forest conditions. A "0" means that all detached soil is stored on site, and a "1" means no storage.

The observer evaluates onsite depression storage by estimating the proportion of the existing onsite erosion that will be trapped in these depressions. To get a depression storage value close to 0.0, the site must usually have a small amount of exposed soil and erosion adjacent to depressions that can trap and hold most eroded soil.

The observer must be careful not to count depression storage in disked areas as it is accounted for in the contouring subfactor.

Step Subfactor

Surface runoff often washes debris down slope until it lodges. This debris forms dams which pond water and collect sediment. When these ponds are full of sediment, they form steps, as shown in figures 24 and 25. Steps also form behind roots, clumps of vegetation and other obstacles, and when depressions fill with sediment. Also, machinery can form steps. For example, the tracks marks of a tree crusher traveling up a steep slope have the configuration of steps.

Steps reduce slope steepness on the area occupied by steps. Approximately 100 steps were measured throughout the Southeast, with the average slope being 3 percent. The step subfactor was developed by assuming that the portion of the slope covered by steps acted as short slope segments of 3 percent steepness. Further, runoff was assumed to flow uninterrupted across the steps. The relationship for steps was developed by assuming that the steps were small and randomly distributed, and by applying Foster and Wischmeier's *(3)* irregular slope procedure. The step subfactor is evaluated by estimating the percentage of the slope occupied by steps (figure 5) and measuring the slope gradient.

Figure 22.—Chopper slits trapping most of the erosion, with a rating of 0.1.

Contour Tillage Subfactor

Disking on the contour generally reduces sheet and rill erosion by reducing runoff amount and velocity in comparison with tillage up and down slope, which is the standard or base condition assigned 1.0 in the P factor of the USLE *(5, 7)*. Site preparation by disking is similar to agricultural tillage. However, disking on the contour in forests is usually judged less effective than contouring

Figure 23.—Very little erosion with large depression storage, with rating of 0.0.

Figure 24.—Steps formed behind debris dams.

from row ridges in farm fields. Therefore, we modified the USLE P factor values (7) for disking.

Disking equipment should be operated on the contour (figure 11), but this is not always practical, resulting in ridges and furrows being oriented at an angle to the contour. As furrows and ridges increasingly deviate from the contour, their effectiveness decreases (figure 26). As the grade along the furrow increases, transport capacity of runoff in the furrows increases and the amount of material deposited in furrows quickly decreases. The value for this subfactor is a function of degrees off contour by the furrows and land slope.

At this time, the use of the USLE contour subfactor or even the USLE to mechanically site prepared areas that have been bedded is not recommended. Additional research is needed for this special situation.

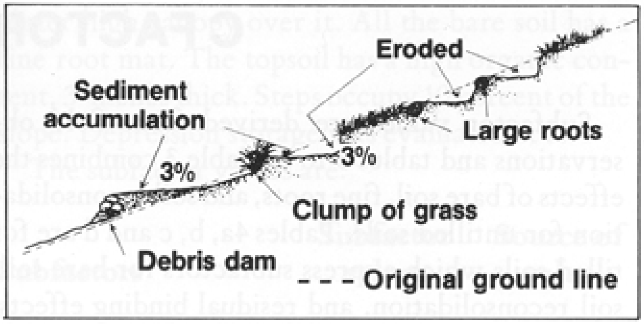


Figure 25.—Step formation.

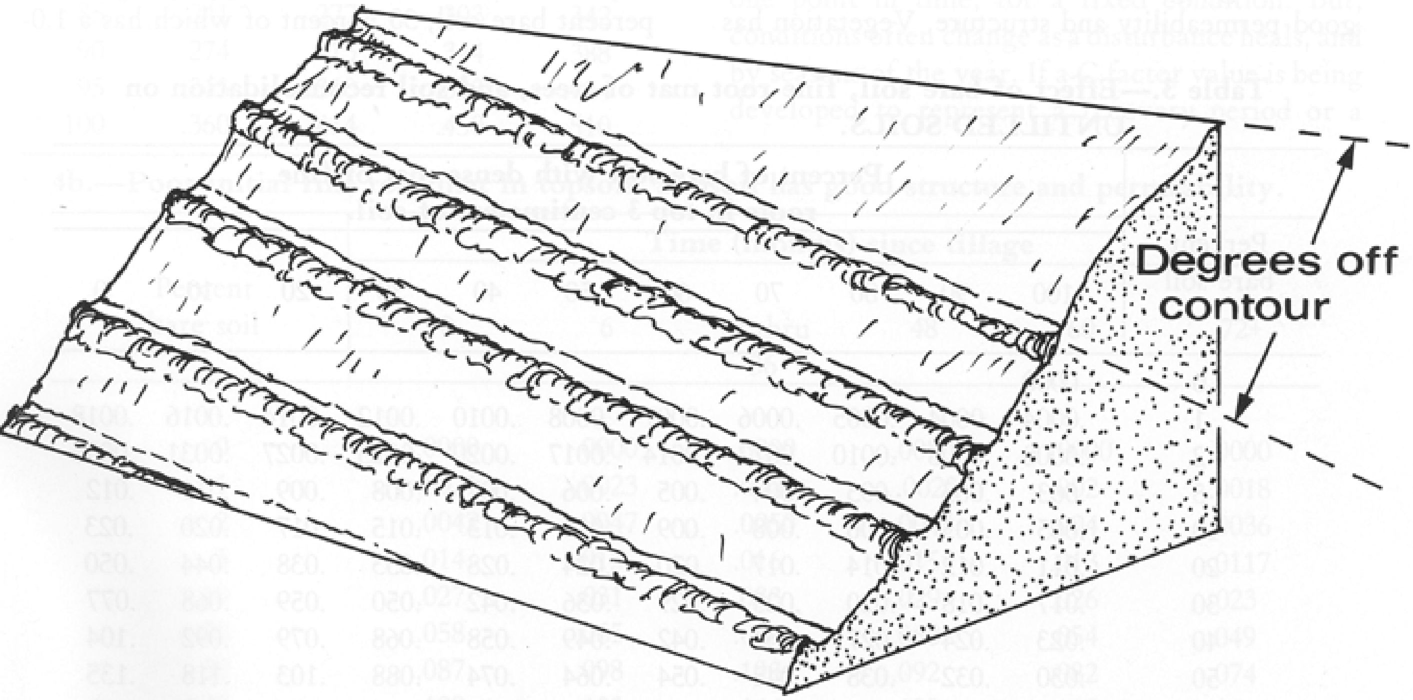


Figure 26.—Contour tillage subfactor.

C FACTOR EVALUATION

Subfactor values are derived from field observations and tables 3 to 8. Table 3 combines the effects of bare soil, fine roots, and soil reconsolidation for untilled soils. Tables 4a, b, c and d are for tilled soils which express subfactors for bare soil, soil reconsolidation, and residual binding effects. Values for the remaining subfactors are given in other tables and figures.

Most forest management practices or disturbances do not normally till the soil; that is, logging, burning, grazing, chopping, chopping and burning, and shearing and windrowing. Disking and root raking till the soil.

The following examples illustrate the use of the procedure and subfactor tables. The first situation is a disked site that is 6-months old on a 10-percent slope. The site has 70 percent bare soil, with a canopy over 20 percent of the bare soil. The canopy height is 0.5 meters. Topsoil is present, containing a good, fine root mat. The subsoil has good permeability and structure. Vegetation has invaded, with new, fine roots occupying 25 percent of the bare soil. Half the new roots are lateral. The disk furrows are 20 degrees off the contour. The subfactor values are:

Subfactors	Subfactor value	Source of value
Bare soil, residual binding, and soil reconsolidation	.194	Table 4a
Canopy	.83	Table 5
Invading vegetation	.82	Table 6
Contour tillage	.89	Table 8

The cover-management factor (C) for this disked site becomes:

$$C = (.194)\ (.83)\ (.82)\ (.89)$$

$$C = 0.118$$

The second example, logging on a 10-percent slope, is an untilled situation: Logging exposed 15 percent bare soil, 30 percent of which has a 1.0-

Table 3.—Effect of bare soil, fine root mat of trees, and soil reconsolidation on UNTILLED SOILS.

Percent bare soil	Percent of bare soil with dense mat of fine roots in top 3 centimeters of soil.										
	100	90	80	70	60	50	40	30	20	10	0
0	.0000										
1	.0004	.0004	.0005	.0006	.0007	.0008	.0010	.0012	.0014	.0016	.0018
2	.0008	.0008	.0010	.0012	.0014	.0017	.0020	.0023	.0027	.0031	.0036
5	.003	.003	.003	.004	.005	.006	.007	.008	.009	.011	.012
10	.005	.005	.006	.008	.009	.011	.013	.015	.017	.020	.023
20	.011	.012	.014	.017	.020	.024	.028	.033	.038	.044	.050
30	.017	.018	.020	.025	.029	.036	.042	.050	.059	.068	.077
40	.023	.024	.027	.034	.042	.049	.058	.068	.079	.092	.104
50	.030	.032	.038	.045	.054	.064	.074	.088	.103	.118	.135
60	.037	.038	.043	.055	.067	.079	.092	.109	.127	.147	.167
70	.047	.049	.054	.068	.083	.098	.117	.138	.161	.187	.212
80	.055	.058	.066	.081	.098	.118	.141	.164	.192	.221	.252
85	.066	.069	.078	.095	.115	.138	.165	.195	.228	.264	.300
90	.075	.080	.089	.111	.133	.157	.187	.222	.260	.301	.342
95	.086	.090	.102	.125	.155	.182	.217	.255	.298	.345	.392
100	.099	.104	.117	.144	.180	.207	.248	.293	.342	.396	.450

Table 4.—Effect of bare soil, soil reconsolidation and residual binding on TILLED SOILS.

4a.—Good initial fine root mat in *topsoil* and subsoil has good structure and permeability.

Percent bare soil	Time (months) since tillage			
	0	6	12 and 72 +	24 + thru 60
0	.0000	.0000	.0000	.0000
1	.0014	.0017	.0018	.0020
2	.0029	.0033	.0036	.0041
5	.009	.011	.012	.013
10	.019	.022	.023	.026
20	.037	.045	.049	.056
30	.059	.068	.074	.084
40	083	.095	.104	.117
50	.108	.124	.136	.153
60	.137	.157	.172	.194
70	.169	.194	.212	.240
80	.212	.244	.267	.301
85	.241	.277	.303	.342
90	.274	.315	.344	.388
95	.313	.360	.393	.444
100	.360	.414	.450	.510

4b.—Poor initial fine root mat in topsoil. Subsoil has good structure and permeability.

Percent bare soil	Time (months) since tillage					
	0	6	12 thru 36	48	60	72+
0	.0000	.0000	.0000	.0000	.0000	.0000
1	.0021	.0023	.0025	..0022	.002	.0018
2	.0042	.0047	.0050	.0045	.004	.0036
5	.014	.015	.016	.015	.013	.0117
10	.027	.031	.033	.029	.026	.023
20	.058	.065	.069	.060	.054	.049
30	.087	.098	.103	.092	.082	.074
40	.122	.135	.144	.129	.115	.104
50	.159	.176	.188	.167	.150	.135
60	.201	.224	.239	.213	.190	.171
70	.249	.277	.296	.263	.235	.212
80	.313	.348	.352	.330	.295	.266
90	.403	.448	.479	.426	.380	.342
95	.461	.513	.548	.487	.435	.392
100	.530	.590	.630	.560	.500	.450

meter high canopy over it. All the bare soil has a fine root mat. The topsoil has a high organic content, 3-inches thick. Steps occupy 10 percent of the slope. Depression storage was evaluated at 0.9.

The subfactor values are:

Subfactors	Subfactor values	Source of value
Bare soil and fine roots	0.008	Table 3
Canopy	0.79	Table 5
Steps	0.94	Table 7
Depression storage	0.90	Figure 19
High organic content	0.70	Discussed in text

Logging with these conditions produces the following C factor value:

$$C = (.008)\ (.79)\ (.94)\ (.90)\ (.70)$$
$$C = 0.004$$

The C factor values just determined are for one point in time, for a fixed condition. But, conditions often change as a disturbance heals, and by seasons of the year. If a C factor value is being developed to represent a recovery period or a

4c.—Poor initial fine root mat with *topsoil absent*. Subsoil has good structure and permeability.

Percent bare soil	Time (months) since tillage							
	0	6	12	24	36	48	60	72+
0	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
1	.0028	.0029	.0030	.0029	.0026	.0022	.0020	.0018
2	.0056	.0058	.0059	.0057	.0052	.0045	.0040	.0036
5	.018	.019	.019	.018	.017	.015	.013	.012
10	.036	.038	.038	.037	.034	.029	.026	.023
20	.076	.079	.080	.077	.070	.060	.054	.049
30	.115	.120	.121	.116	.107	.092	.086	.074
40	.161	.169	..170	.163	.150	.129	.115	.104
50	.210	.220	.222	.213	.195	.168	.150	.135
60	.266	.279	.281	.270	.247	.213	.190	.171
70	.329	.345	.347	.334	.306	.263	.235	.212
80	.413	.432	.436	.419	.384	.330	.295	.266
85	.469	.491	.495	.476	.436	.375	.335	.302
90	.532	.557	.562	.540	.494	.426	.380	.342
95	.609	.638	.643	.618	.566	.487	.435	.392
100	.700	.733	.739	.710	.650	.560	.500	.450

4d.—Poor initial fine root mat with *topsoil absent*. Subsoil has poor structure and permeability.

Percent bare soil	Time (months) since tillage							
	0	6	12	24	36	48	60	72+
0	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
1	.0032	.0033	.0033	.0030	.0026	.0022	.0020	.0018
2	.0064	.0066	.0065	.0059	.0052	.0045	.0040	.0036
5	.021	.022	.021	.019	.017	.015	.013	.012
10	.042	.043	.043	.038	.034	.029	.026	.023
20	.086	.089	.088	.080	.070	.060	.054	.049
30	.131	.136	.134	.122	.107	.092	.084	.074
40	.184	.190	.188	.170	.150	.129	.115	.104
50	.240	.248	.245	.222	.195	.168	.150	.135
60	.304	.314	.311	.281	.247	.213	.190	.171
70	.376	.389	.384	.348	.306	.263	.235	.212
80	.472	.488	.483	.437	.384	.330	.295	.266
85	.536	.554	.548	.496	.436	.375	.335	.302
90	.608	.629	.622	.562	.494	.426	.380	.342
95	.696	.719	.712	.644	.566	.487	.435	.392
100	.800	.827	.818	.740	.650	.560	.500	.450

year, a weighted C factor value must be approximated that reflects changes in subfactors with time. Changes in subfactors can be documented by field observations throughout either the year or the various stages of recovery.

Rainfall erosivity (R) often varies by season of year and should be recognized in developing a weighted C factor value. Distributions for R are given by Wischmeier and Smith (7); see Appendix I. For a year, a weighted C factor value can be approximated by multiplying the seasonal C factor values times the seasonal R values, summing the products (CR) and dividing by the annual R. This procedure is the same as computing a C factor value for a crop rotation on agricultural land described in Agriculture Handbook 537 *(7)*.

Table 5.—Canopy Subfactor

Canopy height *meters (feet)*	Percent of bare soil with canopy cover 0	10	20	30	40	50	60	70	80	90	100
0.5-(1.5)	1.00	.91	.83	.74	.66	.58	.49	.41	.32	.24	.16
1.0-(3.2)	1.00	.93	.86	.79	.72	.65	.58	.51	.44	.37	.30
2.0-(6.5)	1.00	.95	.90	.85	.80	.75	.70	.65	.60	.55	.50
4.0-(13.0)	1.00	.97	.95	.92	.90	.87	.84	.82	.79	.76	.74
6.0-(19.5)	1.00	.98	.97	.96	.94	.93	.92	.90	.89	.87	.85
8.0-(26.0)	1.00	.99	.98	.97	.96	.95	.95	.94	.93	.93	.92
16.0-(52.0)	1.00	1.00	.99	.99	.98	.98	.98	.97	.97	.96	.96
20.0-(65.0)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 6.—Fine roots of invading plants on TILLED SOIL.

Percent bare soil with fine roots	Fine root subfactor
0	1.00
10	.87
20	.76
30	.65
40	.56
50	.47
60	.40
70	.34
80	.28
90	.24
100	.22

Table 7.—Step effect on slope.

Percent slope	Percent of total slope in steps										
	0	10	20	30	40	50	60	70	80	90	100
5	1.00	.99	.99	.98	.97	.96	.95	.94	.94	.93	.92
6	1.00	.97	.94	.92	.89	.86	.84	.81	.78	.76	.73
7	1.00	.96	.92	.88	.84	.80	.75	.71	.67	.63	.59
8	1.00	.95	.90	.85	.80	.75	.69	.64	.59	.54	.49
9	1.00	.94	.89	.83	.77	.71	.65	.60	.54	.48	.42
10	1.00	.94	.87	.81	.75	.68	.62	.56	.49	.43	.36
12	1.00	.93	.85	.78	.71	.63	.56	.49	.42	.34	.27
15	1.00	.92	.84	.75	.67	.59	.51	.43	.34	.26	.18
20	1.00	.91	.82	.74	.65	.56	.47	.38	.29	.20	.11
30+	1.00	.91	.81	.72	.63	.53	.44	.35	.25	.15	.06

Table 8.—Contour tillage subfactors.

Percent slope	On contour	Degrees off contour				
		15	30	45	60	90
0-2	0.80	.88	.91	.94	.96	1.00
3-7	0.70	.82	.87	.91	.94	1.00
8-12	0.80	.88	.91	.94	.96	1.00
13-18	0.90	.94	.96	.97	.98	1.00
19+	1.00	1.00	1.00	1.00	1.00	1.00

VALIDATION

This procedure was tested using data from forest research watersheds in northern Mississippi, western Tennessee, and North Carolina, and research plots in South Carolina. The four plots and 35 watersheds were located in the Southern Coastal Plain, Mississippi Valley Silty Uplands, and Southern Piedmont. The plots were about 0.09 to 0.13 ha and the watersheds ranged between 0.2 and 1.0 ha, averaging 0.5 ha. The forest management conditions covered a wide range: undisturbed, clearcut, strip cut forest, and a variety of site preparation treatments including bedding, chopping, disking, shearing and windrowing, and shearing, windrowing and seeding with grass.

Observed data included sediment yield, recording raingage charts, soils maps of the watersheds, periodic ground cover surveys, and descriptions of conditions from onsite inspections. Sediment yield (SY) at the plot or watershed outlet is given by:

$$SY = RKLSCP + \text{Channel Erosion} - \text{Deposition}$$

Variables R,K,L,S,C and P are the USLE factors. Their product gives the USLE estimate of soil loss to the end of the slope as defined for the USLE. The USLE does not estimate deposition by overland flow or channel flow, nor gully, or stream channel erosion. Gully and stream channel erosion and deposition were estimated from field observations.

Standard procedures *(7)* were used to estimate R from EI (storm energy times maximum 30-minute intensity), computed from raingage charts for each storm that occurred over a 9- to 12-month period. The value used for R was the sum of the EI's for the study period rather than the average annual R value normally used in the USLE when the equation is used in planning.

The LS factor was approximated using the Foster and Wischmeier *(3)* procedure for estimating soil loss from irregular slopes. Soil erodibility factor values for K were obtained from the SCS, and were assigned to the sites based upon soil maps and field inspection. Values for factors C and P were estimated by the procedures described above.

We estimated sediment yield for each treatment using the sediment yield equation before the measured sediment yield data were supplied to us, to avoid biasing the computations. The calculated sediment yield estimates were sent to Stanley J. Ursic and James E. Douglass, USDA Forest Service researchers at the Southern and Southeastern Forest Experiment Stations, respectively, where the watershed data originated. The plot data were supplied by forest industry researchers in South Carolina. The measured values are plotted against the estimated values in figure 27. The points are about equally distributed around the line of perfect fit. The regression line for the validation data is close to the line of perfect fit, and has an R^2 of 0.90. The standard error of the estimate is 1.43 metric tons per hectare, which is 71 percent of the mean, measured, sediment yield.

Estimates of soil loss are most accurate for high erosion rates, 1.0 metric tons per hectare and greater. The percentage error in soil loss estimates, with the USLE, seemed to increase as the estimate decreases. As bare soil decreases to less than 10 percent in forests; its nonuniform distribution is such that the probability of eroded soil reaching the toe of the slope was highly variable. Intervening litter, storage opportunities, presence or absence of runoff paths, and continuity of bare soil are variable factors contributing to the error of estimates at low values.

The field data for this validation are subject to error. Errors could be large in the estimates of deposition and channel erosion from field observations. Also, the time period only included 9 to 12 months of precipitation. At least 10 years of data is preferable for good estimates of the average, annual soil loss. However, forest disturbances heal too rapidly to provide opportunities to study the same condition year after year on the same plot. There are also errors in the estimates of the soil erodibility factor K. However, these are the best data available, to our knowledge. Good quality data to develop and validate the USLE for forestry conditions remains an important need.

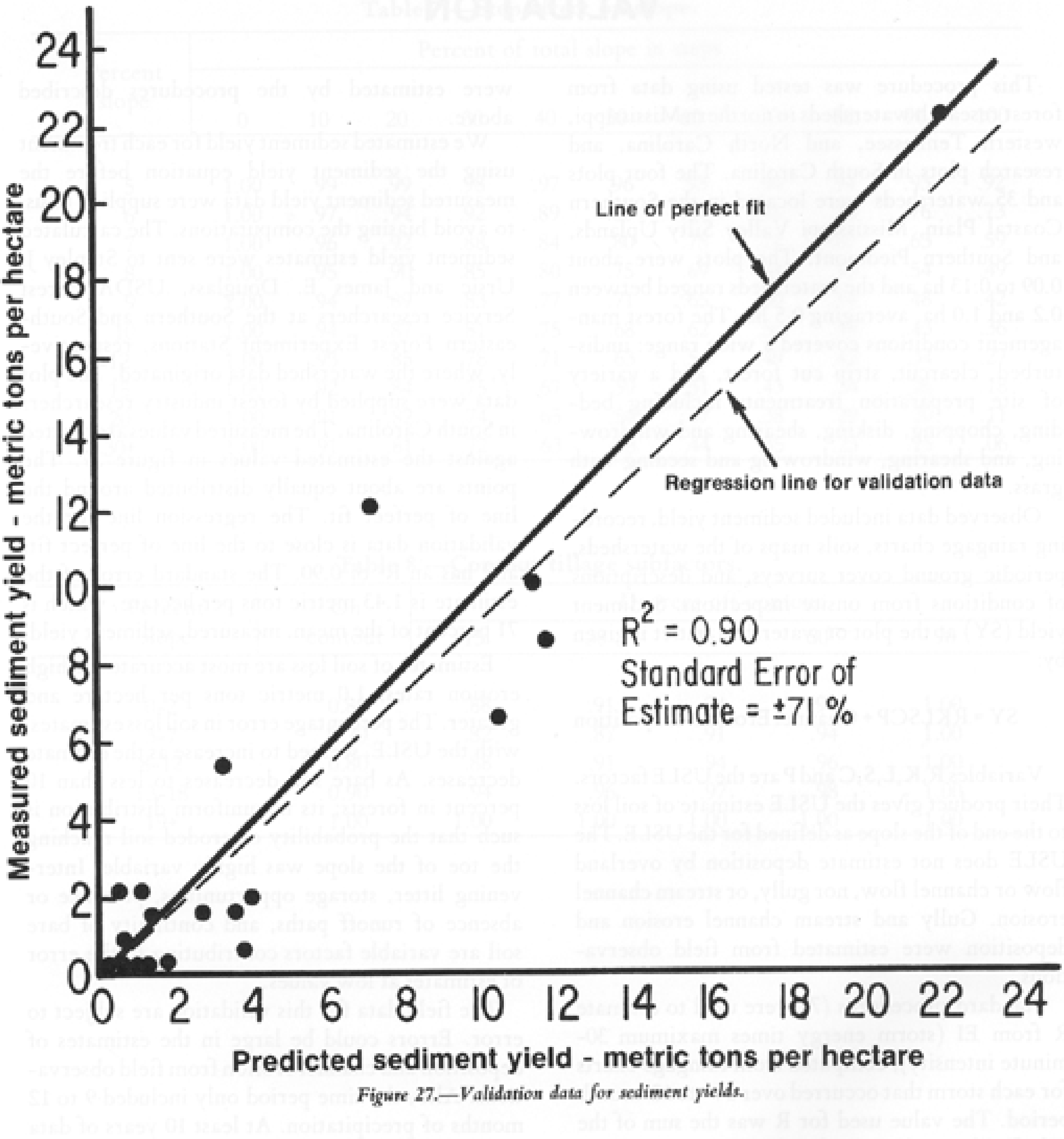


Figure 27.—Validation data for sediment yields.

CONCLUSIONS

Results of the validation suggests that the procedure gives reasonable values for the USLE cover-management factor C for forest conditions. This procedure incorporates many factors that affect sheet and rill erosion on forest land, and properly reflects their influences. The procedure provides a means for evaluating C factors for a broad range of conditions that could not be appraised with a tabular classification system. Furthermore, the results of the validation demonstrate that the USLE can be used to estimate sheet and rill erosion for forest conditions where the equation appropriately applies. The procedure for estimating factor C values is recommended as a replacement for tables 11 and 12 in Agricultural Handbook 537 *(7)*.

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APPENDICES

The following appendix material provides the necessary information and evaluation data for the R,K,L and S factors of the USLE. The appendix is divided into sub-appendices for factors R,K,L and S. Appropriate sections of Agriculture Handbook 537 *(7)* are reproduced in these appendices so that all the necessary material is under one cover. The numbers for tables presented in this handbook do not correspond to figure and table numbers in Agriculture Handbook 537. The figure and table numbers referred to in the following excerpts from Agricultural handbook 537 are enclosed in brackets indicating that the figure or table was used but the number was changed. Material shown in indented paragraphs is from Agriculture Handbook 537. Additional comments are presented to help apply the USLE factors to forest land.

APPENDIX I: RAINFALL EROSION INDEX (R)

The research data indicate that when factors other than rainfall are held constant, storm soil losses from cultivated fields are directly proportional to a rainstorm parameter identified as the EI (defined below). The relation of soil loss to this parameter is linear, and its individual storm values are directly additive. The sum of the storm EI values for a given period is a numerical measure of the erosive potential of the rainfall within that period. The average annual total of the storm EI values in a particular locality is the rainfall erosion index for that locality. Because of apparent cyclical patterns in rainfall data, the published rainfall erosion index values were based on 22-year station rainfall records.

Rain showers of less than 0.5 inch and separated from other rain periods by more than 6 hours were omitted from the erosion index computations, unless as much as 0.25 inch of rain fell in 15 minutes. Exploratory analyses showed that the EI values for such rains are usually too small for practical significance and that, collectively, they have little effect on monthly percentage of EI. The cost of abstracting and analyzing 4,000 location-years of rainfall-intensity data was greatly reduced by adopting the 0.5-inch threshold value.

EI Parameter

By definition, the value of EI for a given rainstorm equals the product, total storm energy (E) times the maximum 30-min intensity (I_{30} is in inches per hour).

EI is an abbreviation for energy times-intensity, and the term should not be considered simply an energy parameter. The data show that rainfall energy, itself, is not a good indicator of erosive potential. The storm energy indicates the volume of rainfall and runoff, but a long, slow rain may have the same E value as a shorter rain at much higher intensity. Raindrop erosion increases with intensity. The I_{30} component indicates the prolonged-peak rates of detachment and runoff. The product term, EI, is a statistical interaction term that reflects how total energy and peak intensity are combined in each particular storm.

The energy of a rainstorm is a function of the amount of rain and of all the storm's component intensities. Median raindrop size increases with rain intensity and terminal velocities of free-falling waterdrops increase with increased dropsize. Since the energy of a given mass in motion is proportional to velocity-squared, rainfall energy is directly related to rain intensity. The relationship is expressed by the equation:

$$e = 916 + 331 \log_{10} i$$

where e is kinetic energy in foot-tons per acre-inch and i is intensity in inches per hour. A limit of 3 inches/hour is imposed on i by the finding that median dropsize does not continue to increase when intensities exceed 3 inches/hour. The energy of a rainstorm is computed from recording rain gage data [table 9]. The storm is divided into successive increments of essentially uniform intensity, and a rainfall energy-intensity table derived from the above formula [table 10] is used to compute the energy for each increment. (Because the energy equation and energy-intensity table have been frequently published with energy expressed in foot-tons per acre-inch, this unit was retained in [table 10]. However, for computation of EI values, storm energy is expressed in hundreds of foot-tons per acre. Therefore, energies computed by the published formula or [table 10] must be divided by 100 before multiplying by I_{30} to compute EI.)

Isoerodent Map

Local value of the rainfall erosion index may be taken directly from the isoerodent map [figure 1]. The plotted lines on the maps are

Table 9.—Example EI computation.[1]

Chart readings: Time	Chart readings: Depth (inch)	For each increment: Duration (minutes)	For each increment: Amount (inch)	For each increment: Intensity (in/hr)	Energy: Per inch	Energy: Total
4:00	0					
:20	0.05	20	0.05	0.15	643	32
:27	.12	7	.07	.60	843	59
:36	.35	9	.23	1.53	977	225
:50	1.05	14	.70	3.00	1074	752
:57	1.20	7	.15	1.29	953	143
5:05	1.25	8	.05	.38	777	39
:15	1.25	10	0	0	0	0
:30	1.30	15	.05	.20	685	34
Totals		90	1.30			1,284

[1] Kinetic energy of the storm = 1,284 (10^{-2}) = 12.84 hundreds of foot-tons/acre.

Table 10.—Kinetic energy of rainfall expressed in foot tons per acre per inch of rain.[1]

Intensity inch per hour	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	—	254	354	412	453	485	512	534	553	570
0.1	585	599	611	623	633	643	653	661	669	677
.2	685	692	698	705	711	717	722	728	733	738
.3	743	748	752	757	761	765	769	773	777	781
.4	784	788	791	795	798	801	804	807	810	814
.5	816	819	822	825	827	830	833	835	838	840
.6	843	845	847	850	852	854	856	858	861	863
.7	865	867	869	871	873	875	877	878	880	882
.8	884	886	887	889	891	893	894	896	898	899
.9	901	902	904	906	907	909	910	912	913	915
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	916	930	942	954	964	974	984	992	1000	1008
2	1016	1023	1029	1036	1042	1048	1053	1059	1064	1069
3	[2]1074									

[1]Computed by the equation, $e = 916 + 331 \log_{10} i$, where e = Kinetic energy in foot tons per acre inch of rain, and i = rainfall intensity in inches per hour.

[2]The 1074 foot tons per acre value also applied for all intensities greater than 3 inches per hour.

called isoerodents because they connect points of equal rainfall erosivity. Erosion index values for locations between the lines are obtained by linear interpolation.

The isoerodent map in the original version of this handbook was developed from 22-year station rainfall records by computing the EI value for each storm that met the previously defined threshold criteria. Isoerodents were then located between these point values with the help of published rainfall intensity-frequency data and topographic maps. The 11 Western States were omitted from the initial map because the rainfall patterns in this mountainous region are sporadic and not enough long-term, recording-rain gage records were available to establish paths of equal erosion index values.

The isoerodent map was extended to the Pacific Coast in 1976, by use of an estimating procedure. Results of investigations at the Runoff and Soil Loss Data Center at Purdue University showed that the known erosion index values in the Western Plains and North Central States could be approximated with reasonable accuracy by the quantity $27.38\ P^{2.17}$, where P is the 2-year, 6-hour rainfall amount. This relationship was used with National Weather Service isopluvial maps to approximate erosion index values for the Western States. The resulting isoerodents are compatible with the few point values that had been established within the 11 Western States and can provide helpful guides for conservation planning on a site basis. However, they are less precise than those computed for the 37-State area, where more data were available and rainfall patterns are less erratic. Also, linear interpolations between the lines will not always be accurate in mountain regions because values of the erosion index may change rather abruptly with elevation changes. The point values that were computed directly from long-term station rainfall records in the Western States are included in [table 11] as reference points.

[Figure 1] shows that local, average-annual values of the erosion index in the 48 conterminous States range from less than 50 to more than 500 EI units. The erosion index measures the combined effect of rainfall and its associated runoff. If the soil and topography were exactly the same everywhere, average annual soil losses from plots maintained in continuous fallow would differ in direct proportion to the erosion index values. However, this potential difference is partially offset by differences in soil, topography, vegetative cover, and residues.

If fairly accurate estimates are needed for a site in a mountainous region and recording raingage data are available, a better estimate of R can be obtained by computing R from several years, preferably 22, of record. This procedure is discussed later in this appendix.

Seasonal Distribution of R

Average annual rainfall erosivity (R) does not completely describe the effects of local differences in rainfall pattern on soil erosion. Rainfall erosivity varies from month to month, and from season to season of the year.

The distribution of R throughout the year is important in planning erosion control strategies in forestry. Figure 28 shows three typical EI distribution curves. To minimize erosion, the critical erosion stage of a forestry practice should be planned to avoid the period of highest EI, if practical.

The distribution of EI can vary within short distances in mountainous regions as illustrated in table 11. Thus, figure 29 was not extended into mountainous areas by Wischmeier and Smith *(7)*. However, EI distribution curves were developed for homogenous EI areas for the East (figure 29 and table 12).

Table 11.—Monthly distribution of EI at selected raingage locations.

Location[1]	2/1	3/1	4/1	5/1	6/1	7/1	8/1	9/1	10/1	11/1	12/1	12/31
	Average percentage of annual EI occurring from 1/1 to:											
California												
Red Bluff (69)	18	36	47	55	62	64	65	65	67	72	82	100
San Luis Obispo (51)	19	39	54	63	65	65	65	65	65	67	83	100
Colorado												
Akron (91)	0	0	0	1	18	33	72	87	98	99	100	100
Pueblo (68)	0	0	0	5	14	23	40	82	84	100	100	100
Springfield (98)	0	0	1	4	26	36	60	94	96	99	100	100
Hawaii												
Hilo (770)	9	23	34	44	49	51	55	60	65	72	87	100
Honolulu (189)	19	33	43	51	54	55	56	57	58	62	81	100
Kahului (107)	14	32	49	62	67	68	69	70	71	76	86	100
Lihue (385)	19	29	36	41	44	45	48	51	56	64	80	100
Montana												
Billings (18)	0	0	1	6	22	49	86	88	96	100	100	100
Great Falls (17)	1	1	2	6	20	56	74	93	98	99	100	100
Miles City (28)	0	0	0	1	10	32	65	93	98	100	100	100
New Mexico												
Albuquerque (15)	1	1	2	4	10	21	52	67	89	98	99	100
Roswell (52)	0	0	2	7	20	34	55	71	92	99	99	100
Oregon												
Pendleton (6)	8	12	15	22	56	64	67	67	74	87	96	100
Portland (43)	15	27	35	37	40	45	46	47	54	65	81	100
Puerto Rico												
Mayaguez (600)	1	2	3	6	15	31	47	63	80	91	99	100
San Juan (345)	5	8	11	17	33	43	53	66	75	84	93	100
Washington												
Spokane (8)	5	9	11	15	25	56	61	76	84	90	94	100
Wyoming												
Casper (11)	0	0	1	6	32	44	70	90	96	100	100	100
Cheyenne (32)	0	1	2	5	17	42	73	90	97	99	100	100

[1] Numbers in parentheses are the observed average annual EI.

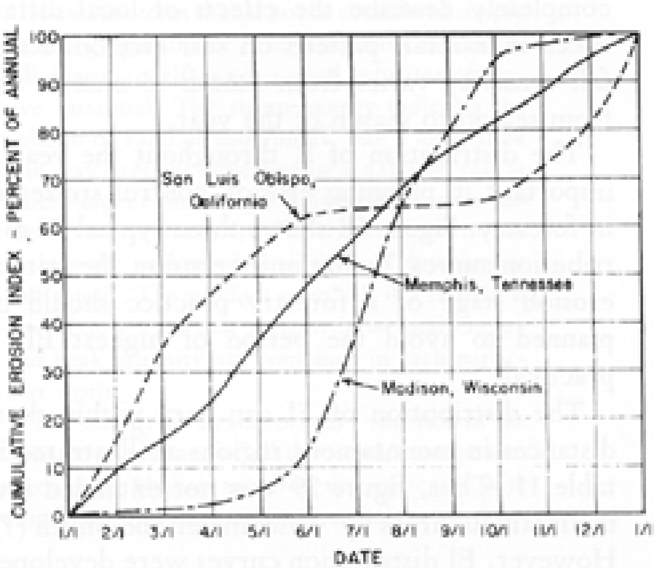

Figure 28.—Typical EI-distribution curves for three rainfall patterns.

Figure 29.—Key map for selection of applicable EI-distribution data from table 12.

Table 12.—Percentage of the average annual EI which normally occurs between January 1 and the indicated dates.[1] Computed for the geographic areas shown in figure 28.

Area No.	Jan.		Feb.		Mar.		Apr.		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.	
	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15	1	15
1	0	0	0	0	0	0	1	2	3	6	11	23	36	49	63	77	90	95	98	99	100	100	100	100
2	0	0	0	0	1	1	2	3	6	10	17	29	43	55	67	77	85	91	96	98	99	100	100	100
3	0	0	0	0	1	1	2	3	6	13	23	37	51	61	69	78	85	91	94	96	98	99	99	100
4	0	0	1	1	2	3	4	7	12	18	27	38	48	55	62	69	76	83	90	94	97	98	99	100
5	0	1	2	3	4	6	8	13	21	29	37	46	54	60	65	69	74	81	87	92	95	97	98	99
6	0	0	0	0	1	1	1	2	6	16	29	39	46	53	60	67	74	81	88	95	99	99	100	100
7	0	1	1	2	3	4	6	8	13	25	40	49	56	62	67	72	76	80	85	91	97	98	99	99
8	0	1	3	5	7	10	14	20	28	37	48	56	61	64	68	72	77	81	86	89	92	95	98	99
9	0	2	4	6	9	12	17	23	30	37	43	49	54	58	62	66	70	74	78	82	86	90	94	97
10	0	1	2	4	6	8	10	15	21	29	38	47	53	57	61	65	70	76	83	88	91	94	96	98
11	0	1	3	5	7	9	11	14	18	27	35	41	46	51	57	62	68	73	79	84	89	93	96	98
12	0	0	0	0	1	1	2	3	5	9	15	27	38	50	62	74	84	91	95	97	98	99	99	100
13	0	0	0	1	1	2	3	5	7	12	19	33	48	57	65	74	82	88	93	96	98	99	100	100
14	0	0	0	1	2	3	4	6	9	14	20	28	39	52	63	72	80	87	91	94	97	98	99	100
15	0	0	1	2	3	4	6	8	11	15	22	31	40	49	59	69	78	85	91	94	96	98	99	100
16	0	1	2	3	4	6	8	10	14	18	25	34	45	56	64	72	79	84	89	92	95	97	98	99
17	0	1	2	3	4	5	6	8	11	15	20	28	41	54	65	74	82	87	92	94	96	97	98	99
18	0	1	2	4	6	8	10	13	19	26	34	42	50	58	63	68	74	79	84	89	93	95	97	99
19	0	1	3	6	9	12	16	21	26	31	37	43	50	57	64	71	77	81	85	88	91	93	95	97
20	0	2	3	5	7	10	13	16	19	23	27	34	44	54	63	72	80	85	89	91	93	95	96	98
21	0	3	6	10	13	16	19	23	26	29	33	39	47	58	68	75	80	83	86	88	90	92	95	97
22	0	3	6	9	13	17	21	27	33	38	44	49	55	61	67	71	75	78	81	84	86	90	94	97
23	0	3	5	7	10	14	18	23	27	31	35	39	45	53	60	67	74	80	84	86	88	90	93	95
24	0	3	6	9	12	16	20	24	28	33	38	43	50	59	69	75	80	84	87	90	92	94	96	98
25	0	1	3	5	7	10	13	17	21	24	27	33	40	46	53	61	69	78	89	92	94	95	97	98
26	0	2	4	6	8	12	16	20	25	30	35	41	47	56	67	75	81	85	87	89	91	93	95	97
27	0	1	2	3	5	7	10	14	18	22	27	32	37	46	58	69	80	89	93	94	95	96	97	99
28	0	1	3	5	7	9	12	15	18	21	25	29	36	45	56	68	77	83	88	91	93	95	97	99
29	0	1	2	3	4	5	7	9	11	14	17	22	31	42	54	65	74	83	89	92	95	97	98	99
30	0	1	2	3	4	5	6	8	10	14	19	26	34	45	56	66	76	82	86	90	93	95	97	99
31	0	0	0	1	2	3	4	5	7	12	17	24	33	42	55	67	76	83	89	92	94	96	98	99
32	0	1	2	3	4	5	6	8	10	13	17	22	31	42	52	60	68	75	80	85	89	92	96	98
33	0	1	2	4	6	8	11	13	15	18	21	26	32	38	46	55	64	71	77	81	85	89	93	97

[1] For dates not listed in table, interpolate between adjacent values.

Computing R from Recording-Rain Gage Records

The procedure for computing R is presented here for use with mountainous locations or where R index data are not available.

The kinetic energy of a given amount of rain depends on the sizes and terminal velocities of the raindrops, and these are related to rainfall intensity. The computed energy per inch of rain at each intensity is shown [table 10]. The energy of a given storm depends on all the intensitities at which the rain occurred and the amount that occurred at each intensity. A recording-rain gage record of the storm will provide this information. Clock time and rain depth are read from the chart at each point where the slope of the pen line changes and are tabulated as shown in the first two columns of the sample computation in [table 9]. Clock times (col. 1) are subtracted to obtain the time intervals given in column 3, and the depths (col. 2) are subtracted to obtain the incremental amounts tabulated in column 4. The intensity for each increment (col. 5) is the incremental amount times 60, divided by column 3.

The energy per inch of rain in each interval (col. 6) is obtained by entering [table 10] with the intensity given in column 5. The incremental energy amounts (col 7) are products of columns 4 and 6. The total energy for this 90-minute rain is 1,284 foot-tons per acre. This is multiplied by a constant factor of 10^{-2} to convert the storm energy to the dimensions in which EI values are expressed.

The maximum amount of rain falling within 30 consecutive minutes was 1.08 in., from 4:27 to 4:57 I_{30} is twice 1.08, or 2.16 inches/hour. The storm EI value 12.84 (2.16) = 27.7 hundreds of (foot tons/acre) (inches/hour). When the duration of a storm is less than 30 minutes, I_{30} is twice the amount of the rain.

The EI for a specified time is the sum of the computed values for all significant rain periods within that time. The average annual erosion index for a specific locality, as given in [figure 1] is the sum of all the significant storm EI values over 20 to 25 years, divided by the number of years. For erosion index calculations, 6 hour or more with less than 0.5 inch of precipitation was defined as a break between storms. Rains of less than 0.5 in, separated from other showers by 6 hour or more, were omitted as insignificant unless the maximum 15-minute intensity exceeded 0.95 inch/hour.

Recent studies showed that the median dropsize of rain does not continue to increase for intensities greater than about 2.5 to 3 inches/hour. Therefore, energy per unit of rainfall also does not continue to increase, as was assumed in the derivation of the energy-intensity table published in 1958. The value given in [table 10] for rain at 3 inches/hour should be used for all greater intensities. Also, analysis of the limited soil loss data available for occasional storms with 30-min. intensities greater than 2.5 inches/hour showed that placing a limit of 2.5 inches (6.35 cm)/hour on the I_{30} component of EI improved prediction accuracy for these storms. Both of these limits were applied in the development of [figure 1]. They slightly lowered previously computed erosion index values in the Southeast, but average-annual EI values for the U.S. mainland other than the Southeast were not significantly affected by the limits because they are rarely exceeded.

APPENDIX II: SOIL ERODIBILITY FACTOR (K)

The meaning of the term 'soil erodibility' is distinctly different from that of the term 'soil erosion.' The rate of soil erosion, A, in the soil loss equation, may be influenced more by land slope, rainstorm characteristics, cover, and management than by inherent properties of the soil. However, some soils erode more readily than others even when all other factors are the same. This difference, caused by properties of the soil itself, is referred to as the soil erodibility.

Differences in the natural susceptibilities of soils to erosion are difficult to quantify from field observations. Even a soil with a relatively low erodibility factor may show signs of serious erosion when it occurs on long or steep slopes or in localities with numerous high-intensity rainstorms. A soil with a high natural erodibility factor, on the other hand, may show little evidence of actual erosion under gentle rainfall when it occurs on short and gentle slopes, or when the best possible management is practiced. The effects of rainfall differences, slope, cover, and management are accounted for in the prediction equation by the symbols R,L,S,C, and P. Therefore, the soil erodibility factor, K, must be evaluated independently of the effects of the other factors.

Definition of Factor K.

The soil erodibility factor, K, in the USLE is a quantitative value experimentally determined. For a particular soil, it is the rate of soil loss per erosion index unit as measured on a unit plot, which has been arbitrarily defined as follows: A unit plot is 72.6 ft. long, with a uniform lengthwise slope of 9 percent, in continuous fallow, tilled up and down the slope. Continuous fallow, for this purpose, is land that has been tilled and kept free of vegetation for more than 2 years. During the period of soil loss measurements, the plot is plowed and placed in conventional corn seedbed condition each spring and is tilled as needed to prevent vegetative growth and severe surface crusting. When all of these conditions are met, L, S, C, and P each equal 1.0, and K equals A/EI.

The 72.6 ft. length and 9 percent steepness were selected as base values for L, S, and K because they are the predominant slope length and about the average gradient on which past erosion measurements in the United States had been made. The designated management provides a condition that nearly eliminates effects of cover, management, and land use residual and that can be duplicated on any cropland.

Direct measurements of K on well-replicated, unit plots as described reflect the combined effects of all the soil properties that significantly influence the ease with which a particular soil is eroded by rainfall and runoff if not protected. However, K is an average value for a given soil, and direct measurement of the factor requires soil loss measurements for a representative range of storm sizes and antecedent soil conditions.

Values of K for Specific Soils

Representative values of K for most of the soil types and texture classes can be obtained from tables prepared by soil scientist using the latest available research information. These tables are available from the Regional Technical Service Centers or State offices of SCS. Values for the exact soil conditions at a specific site can be computed by use of the soil erodibility nomograph [figure 30].

Soil Erodibility Nomograph

The soil loss data show that very fine sand (0.05-0.10 mm) is comparable in erodibility to silt-sized particles and that mechanical-analysis data are much more valuable when expressed by an interaction term that describes the proportions in which the sand, silt, and clay fractions are combined in the soil. When mechanical analysis data based on the standard USDA classification are used for the nomograph in [figure 30], the percentage of very fine sand (.01-0.05 mm) must first be transferred from the sand fraction to the silt fraction. The mechanical analysis data are then effectively described by a particle-size parameter M, which equals percent silt (0.1-0.002 mm) times the quantity 100-minus-percent-clay. Where the silt fraction does not exceed 70 percent, erodibility varies approximately as the 1.14 power of this parameter, but prediction accuracy is improved by adding information on organic matter content, soil structure, and profile permeability class.

For soils containing less than 70 percent silt and very fine sand, the nomograph [figure 30] solves the equation:

$$K=2.1M^{1.14}(10^{-6})(12-a)+0.0325(b-2)+0.025(c-3)$$

where:

M =the particle-size parameter defined above,

a =percent organic matter,

b =the soil-structure code used in soil classification, and

c =the profile-permeability class.

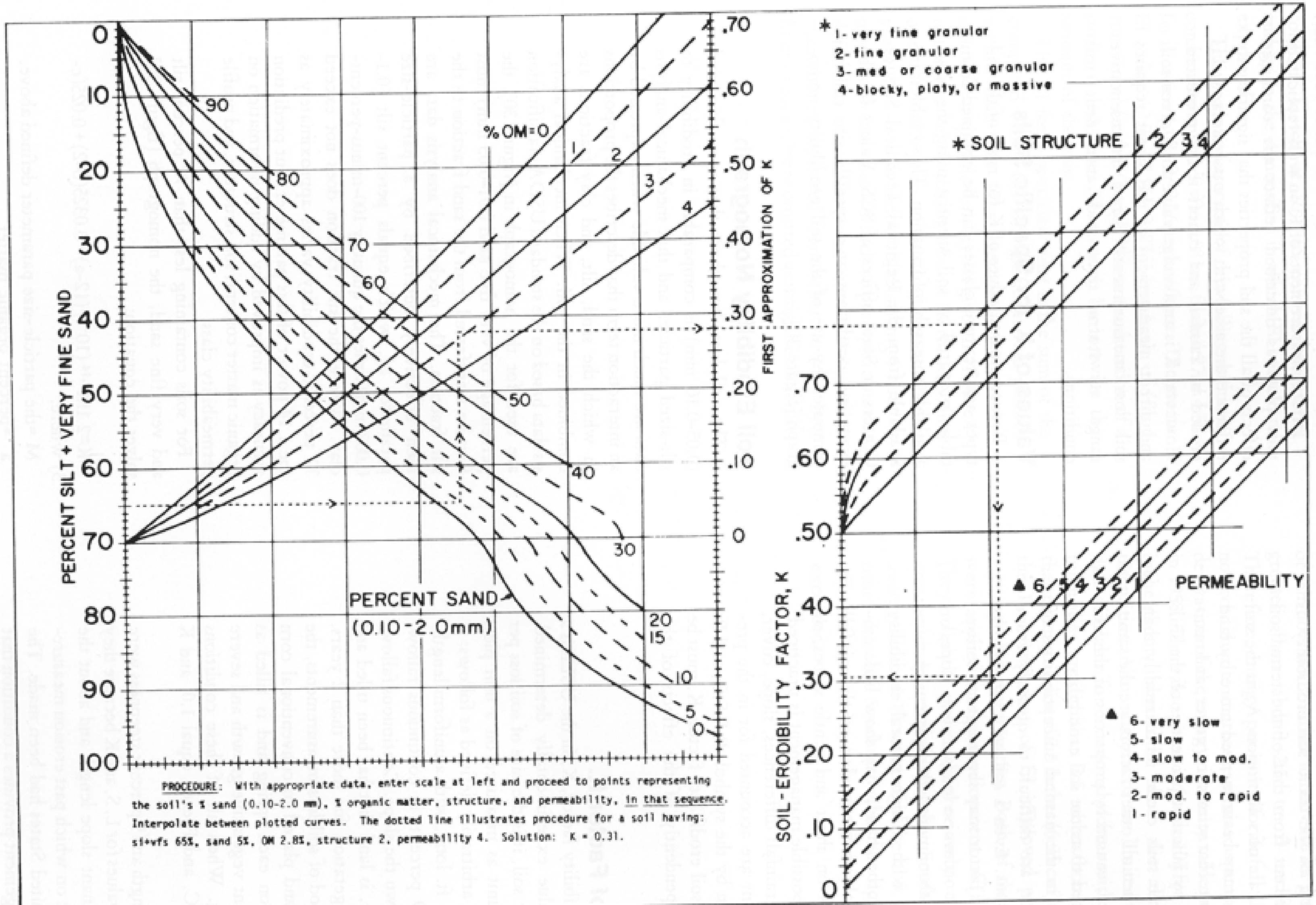

Figure 30.—The soil erodibility nomograph[1]

[1]Where the silt fraction does not exceed 70 percent, the equation is $K = 2.1M^{1.14}(10^{-4})(12-a) + 0.0325(b-2) + 0.025(c-3)$ where M = (percent si + vfs) (100-percent clay), a = percent organic matter, b = structure code, and c = profile permeability class.

The intersection of the selected percent-silt and percent-sand lines computes the value of M on the unidentified horizontal scale of the nomograph. (Percent clay enters into the computation as 100 minus the percentages of sand and silt.)

The data indicate a change in the relation of M to erodibility when the silt and very fine sand fraction exceeds about 70 percent. This change was empirically reflected by inflections in the percent-sand curves at that point, but has not been described by a numerical equation.

Nomograph Solution

With appropriate data, enter the scale at the left and proceed to points representing the soil's percent sand (0.10-2.0 mm), percent organic matter, structure code, and permeability class as illustrated by the dotted line on the nomograph. The horizontal and vertical moves must be made in the listed sequence. Use linear interpolations between plotted lines. The structure code and permeability classes are defined on the nomograph for reference.

Many agricultural soils have both fine granular topsoil and moderate permeability. For these soils, K may be read from the scale labeled "first approximation of K," and the second block of the graph is not needed. For all other soils, however, the procedure must be completed to the soil erodibility scale in the second half of the graph.

The mechanical analysis, organic matter, and structure data are those for the topsoil. For evaluation of K for desurfaced subsoil horizons, they pertain to the upper 6 inches of the new soil profile. The permeability class is the profile permeability. Coarse fragments are excluded when determining percentages of sand, silt, and clay. If coarse rock fragments cause a permanent mulch effect, they are considered as ground cover in the bare soil subfactor.

Confidence Limits

In tests against measured K values ranging from 0.03 to 0.69, tons/acre/EI unit, 65 percent of the nomograph solutions differed from the measured K values by less than 0.02, and 95 percent of them by less than 0.04 tons/acre/EI unit. Limited data available in 1971 for mechanically exposed B and C subsoil horizons indicated about comparable accuracy for these conditions. However, more recent data taken on desurfaced high-clay subsoils showed the nomograph solution to lack the desired sensitivity to differences in erodibilities of these soil horizons. For such soils the content of free iron and aluminum oxides ranks next to particle-size distribution as an indicator of erodibility.

APPENDIX III: TOPOGRAPH FACTOR (LS)

Both the length and the steepness of the land slope substantially affect the rate of soil erosion by water. The two effects have been evaluated separately in research and are represented in the soil loss equation by L and S, respectively. In field applications, however, considering the two as a single topographic factor, LS, is often more convenient.

Slope

Soil loss increases much more rapidly than runoff as slopes steepen. The slope-steepness factor, S, in the soil loss equation is evaluated by the equation

$$S = 65.42 \sin^2\theta + 4.56 \sin\theta + 0.065$$

where θ is the angle of slope in degrees.

Slope Length

Slope length is defined as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or the runoff becomes concentrated. A well defined stream channel or ditch need not be present.

The plot data showed average soil loss per unit area to be proportional to a power of slope length. Because L is the ratio of field soil loss to the corresponding loss from 72.6-ft slope length, its value may be expressed as $L = (\lambda/72.6)^m$, where λ is the field slope length in feet and m assumes approximately the values given in the LS equation in the following section.

In forest situations, the slope length will rarely be more than 400 feet. In natural landscapes, topographic depressions usually concentrate surface run off [figure 2]. Strong on-site evidence must be present showing that surface runoff does not concentrate until some point beyond 400 feet.

Topographic Factor (LS)

LS is the expected ratio of soil loss per unit area from a field slope to that from a 72.6-ft length of uniform 9-percent slope under otherwise identical conditions. This ratio for specified combinations of field slope length and uniform gradient may be obtained directly from the slope-effect chart [figure 3 or table 1] or from the following equation:

$$LS = (\lambda/72.6)^m (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$$

Where λ = slope length in feet;

θ = angle of slope in degrees; and

m = 0.5 if the percent slope is 5 or more, 0.4 on slopes of 3.5 to 4.5 percent, 0.3 on slopes of 1 to 3 percent, and 0.2 of uniform gradients of less than 1 percent.

Irregular Slopes

Soil loss is also affected by the shape of a slope. Many field slopes either steepen toward the lower end (convex slope) or flatten toward the lower end (concave slope). Use of the average gradient to enter [figure 3 or table 1] would underestimate soil movement to the foot of a convex slope and would overestimate it for concave slopes. Irregular slopes can usually be divided into segments that have a nearly uniform gradient, but cannot be evaluated as independent slopes when runoff flows from one segment to the next.

However, where two simplifying assumptions can be accepted, LS for irregular slopes can be routinely derived by combining selected values from the slope-effect chart and [table 13]. The assumptions are that (1) the changes in gradient are not sufficient to cause upslope deposition, and (2) the irregular slope can be divided into a small number of equal-length segments in such a manner that the gradient within each segment for practical purposes can be considered uniform.

Table 13.—Estimated relative soil losses from successive equal-length segments of a uniform slope.[1]

Number of segments	Sequence number of segment	Fraction of soil loss		
		m = 0.5	m = 0.4	m = 0.3
2	1	0.35	0.38	0.41
	2	.65	.62	.59
3	1	.19	.22	.24
	2	.35	.35	.35
	3	.46	.43	.41
4	1	.12	.14	.17
	2	.23	.24	.24
	3	.30	.29	.28
	4	.35	.33	.31
5	1	.09	.11	.12
	2	.16	.17	.18
	3	.21	.21	.21
	4	.25	.24	.23
	5	.28	.27	.25

[1]Derived by the formula:

$$\text{Soil loss fraction} = \frac{i^{m+1} - (i-1)^{m+1}}{N^{m+1}}$$

where i = segment sequence number; m = slope length exponent (0.5 for slopes ≥ 5 percent, 0.4 for 4 percent slopes, and 0.3 for 3 percent or less); and N = number of equal length segments into which the slope was divided.

After dividing the convex, concave, or complex slope into equal-length segments as defined earlier, the procedure is as follows: list the segment gradients in the order in which they occur on the slope, beginning at the upper end. Enter the slope-effect chart with the total slope length and read LS for each of the listed gradients. Multiply these by the corresponding factors from [table 13] and add the products to obtain LS for the entire slope. The following tabulation illustrates the procedure for a 400-ft convex slope on which the upper third has a gradient of 5 percent; the middle third, 10 percent; and the lower third, 15 percent:

(1) Segment	(2) Percent slope	(3) Table 1	(4) Table 13	(5) Product of (3)x(4)	(6)* Soil loss factor**	(7)* LS for segment (3)x(6)
1	5	1.07	0.19	.203	.57	.61
2	10	2.74	.35	.959	1.05	2.88
3	15	5.12	.46	2.355	1.38	7.07
			LS =	3.517		

For the concave slope of the same length, with the segment gradients in reverse order, the values in the third column would be listed in reverse order. The products would then be 0.973, 0.959, and 0.492, giving a sum of 2.42 for LS.

The product of LS (column 3) and the soil loss factor for a segment (column 6) gives the LS for the segment. This product times RKC and P gives an estimate of soil loss for individual segments.

Research has not defined just how much gradient change is needed under various conditions for deposition of soil particles of various sizes to begin, but depositional areas can be determined by observation. When the slope breaks are sharp enough to cause deposition, the procedure can be used to estimate LS for slope segments above and below the depositional area. However, it will not predict the total sediment moved from such an interrupted slope because it does not predict the amount of deposition.

*Columns 6 and 7 are not in Agricultural Handbook 537.
**Column 4 times the number of segments.

Changes in Soil Type or Cover Along the Slope

The procedure for irregular slopes can include evaluation of changes in soil type within a slope length. The products of values selected from table 1 or figure 3 and table 13 to evaluate LS for irregular slopes are multiplied by the respective values of K before summing. To illustrate, assume the K values for the soils in the three segments of the convex slope in the preceding example were 0.27, 0.32, and 0.37, respectively. The average KLS for the slope would be obtained as follows:

(1) Segment No.	(2) Table 1	(3) Table 13	(4) K	(5) Product (2) (3) (4)	(6)* Soil Loss factor**	(7)* KLS for segment product (2)(4)(6)
1	1.07	0.19	0.27	0.055	.57	.16
2	2.74	.35	.32	.307	1.05	.92
3	5.12	.46	.37	.871	1.38	2.61
		KLS =		1.233		

Column 7 gives the KLS for each of the three segments. These values, multiplied by RCP, give an estimate of soil loss for each segment. Note that the soil loss on segment 3 is 16 times that on segment 1.

Within limits, the procedure can be further extended to account for changes in cover along the slope length by adding a column of Segment C values. However, it does not apply where a practice change along the slope causes deposition. For example, a grass buffer strip across the foot of a slope on which substantial erosion is occurring induces deposition. The amount of this deposition is a function of transport relationships and cannot be predicted by the USLE.

APPENDIX IV: CONVERSION TO METRIC SYSTEM

With the spread of application of the USLE to other countries and the gradual adoption of the Système International de Unities (SI) in the United States, conversion factors to SI units are presented in table 14.

Table 14.—Conversion factors for USLE factors.

		To Convert From:	Multiply By:	To Obtain:	Units:
Rainfall intensity	i or I_{30}	in / hr	25.4	millimeter / hour	mm / h
Rainfall energy per unit of rainfall	e	ft-tons / acre in	2.638×10^{-4}	megajoules / hectare millimeter	MJ / ha mm
Storm erosivity	EI	ft-tons in / acre hr	0.1702	megajoules millimeter / hectare hour	MJ mm / ha h
Storm erosivity	EI	ft-tons in $\times 10^{-2}$* / acre hr	17.02	megajoules millimeter / hectare hour	MJ mm / ha h
Annual erosivity	R	ft-tons in $\times 10^{-2}$* / acre hr yr	17.02	megajoules millimeter / hectare hour year	MJ mm / ha h y
Erosivity	R or EI	ft-tons in $\times 10^{-2}$* / acre hr	1.702	Newtons / hour	N / h
Soil erodibility	K	tons acre hr / acre ft-ton in $\times 10^{-2}$*	0.1317	tons hectare hour / hectare megajoules millimeters	t ha h / haMJmm
Soil erodibility	K	tons acre hr / acre ft-tons in $\times 10^{-2}$*	1.317	tons hour / hectare Newton	t h / ha N
Soil loss	A	tons / acre	2.242	tons / hectare	t / ha
Soil loss	A	tons / acre	0.2242	kilograms / $meter^2$	kg / m^2
Soil loss	A	tons / hectare	0.1	kilograms / $meter^2$	kg / m2
Soil loss	A	kilograms / $meter^2$	1000.0	grams / $meter^2$	g / m^2

*By this notation, $\times 10^{2}$ means numerical values should be multiplied by 100 to obtain true numerical values in given units. For example, R = 125 (ft-tons in)/(acre hr) $\times 10^{2}$ = 12500 (ft-tons)/(acre hr). The converse is true for $\times 10^{-2}$ in the denominator (2).