United States
Department of
Agriculture

**Soil
Conservation
Service**

National Engineering Handbook

Section 3

Sedimentation

Chapter 3

Erosion

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Erosion

General

Erosion consists of a series of complex and interrelated natural processes that loosen or dissolve and move earth or rock material. The land surface is worn away through the detachment and transport of soil and rock materials by moving water, wind, or other geologic agents.

Erosion can be divided into two categories according to the conditions under which it occurs. The first category is normal (geologic) erosion, which has been occurring at variable rates, depending on climatic and terrestrial conditions, since the first solid materials formed on earth. Geologic erosion is extremely slow in most places. It is, in fact, an important process in soil formation. The underlying rock is attacked by air and water, and fragments are detached, decomposed, or dissolved. This process is termed weathering. Generally, a rough equilibrium is reached in natural environments between geologic erosion and soil formation. The rates of normal upland erosion and soil formation are determined mainly by climate, parent rocks, soil, precipitation, topography, and vegetal cover.

The second category is accelerated erosion caused by the activities of man. Accelerated erosion has been defined as "erosion occurring at a rate greater than normal for the site, usually through reduction of a vegetal cover" (Roehl 1965). Deforestation, cultivation, and destruction of vegetation accelerate erosion. Soil that normally would take 100 years to be eroded may vanish in 1 year or even a single day (United Nations 1953).

Both categories of erosion can be subdivided into two types: sheet and channel. This classification is helpful in (1) estimating the amount of erosion and sediment yield, (2) determining the relative importance of sediment sources, (3) formulating treatment measures to reduce erosion and sediment yield, and (4) evaluating the effectiveness of treatment measures.

In planning programs to reduce erosion and sediment yield, it is most important that the various types of erosion be thoroughly investigated as sources of sediment. Proper conservation practices and land stabilization measures can then be planned and applied.

Sheet erosion, which includes rill erosion, is the removal of soil or earth material from the land surface by the forces of raindrop impact, overland runoff, or wind. Although it occurs on all land surfaces, sheet erosion is particularly active on cultivated areas of mild slope where the runoff is not concentrated in well-defined channels but consists largely of overland flow. The numerous small but conspicuous rills caused by minor concentration of runoff are obliterated by normal field cultivation. This type of erosion occurs gradually over large areas as though the soil were removed in sheets (Bennett 1939, p. 92–115).

Materials derived from sheet erosion are fine grained because overland flow, which is usually laminar, seldom exceeds a velocity of 2 or 3 ft/s. Flow of this low velocity can transport only the fine particles detached by raindrop impact. Ellison (1945) reported a grain-size diameter of less than 0.05 mm for 95 percent of the sediment in prechannel runoff from a silt loam soil in Ohio.

Factors Involved

The basic factors in sheet erosion are rainfall, soil properties, slope length, slope gradient, and kind and condition of cover. Several equations incorporating these factors can be used to obtain a quantitative estimate of the amount of soil material moved by sheet erosion. These equations, originally developed for the humid areas east of the Rocky Mountains, are particularly well suited for determining the effects of land treatment measures on erosion.

Equations

From the late 1940's until 1972, SCS geologists, who are responsible for estimating yield, used the Musgrave Equation to compute the amount of sheet and rill erosion in a watershed. The Musgrave Equation was part of one of several procedures used to estimate sediment yield. Additional research on erosion resulted in the development of the Universal Soil Loss Equation (USLE) by the Agricultural Research Service (ARS) in cooperation with SCS and certain State experiment stations. In September 1972 the Musgrave Equation was replaced by the USLE for computing sheet erosion for project areas.

Both the Musgrave Equation and the USLE are empirical formulas in which sediment yield from subacre test plots is defined as "erosion" or "soil loss." The computed soil loss from large areas is usually greater than the sediment yield from the same area, and the larger the area, the greater the discrepancy between computed soil loss and sediment yield. Neither equation allows for deposition on upland areas. Soil loss computed by these equations represents nothing that can be located or measured in the field. It therefore is an abstract figure that must not be confused with sediment yield. Computed soil loss, however, is a valuable tool for comparing the soil loss from different areas or the effects of different land treatments on a given area.

The USLE initially was used only for cropland, hayland, and pastures in rotation, because erosion factors reflecting the effect of cover on uncultivated land areas were not available. Because the USLE had been used in much of the country as a tool in planning land treatment on individual operating units, use of this equation with its refined data was recommended for watersheds and other project areas in which SCS has responsibilities. Before this could be done, however, additional plant-cover factors (C) had to be determined for permanent pastureland, rangeland, woodland, and idle land to estimate the effect of these types of cover on soil losses.

In November 1971, SCS and ARS personnel tentatively agreed on the factors for types of cover on uncultivated lands, and subsequent analyses by ARS provided values for them. These factors are used in the USLE to estimate sheet and rill erosion for work in SCS projects such as watersheds, river basin studies, and resource conservation and development (RC&D).

The complete Universal Soil Loss Equation is

$$A = RKLSCP$$

where

A = the computed annual soil loss (sheet and rill erosion) in tons per acre. A is not the sediment yield.

R = the rainfall factor: the number of erosion index units in a normal year's rain.

K = the soil erodibility factor: the erosion rate per erosion index unit for a specific soil in cultivated continuous fallow on

9-percent slope 72.6 ft long.

L = the slope length factor: the ratio of the soil loss from the field slope length to that from a 72.6-ft length on the same soil type and gradient.

S = The slope gradient factor: the ratio of the soil loss from the field gradient to that from a 9-percent slope on the same soil type and slope length.

C = the cropping management factor: the ratio of the soil loss from a field with specified cropping and management to that from the fallow condition from which the K factor is evaluated.

P = the erosion control practice factor: the ratio of the soil loss with contouring, contour stripcropping, or contour-irrigated furrows to that with straight-row farming, upslope and downslope.

Rainfall Factor (R)

The energy of moving water detaches and transports soil materials. The energy intensity (EI) value is the product of the total raindrop energy of a storm and the maximum 30-min intensity. Soil losses are linearly proportional to the number of EI units. The EI values of the storms from a 22-year (maximum) record were summed to obtain an average annual rainfall-erosion index for a given location. This annual index serves as the R factor and can be obtained from figure 3–1, which is figure 1 in Agriculture Handbook 537 (Wischmeier and Smith 1978). This handbook also includes a procedure for determining the effect of snowmelt on the R factor.

Soil Erodibility Factor (K)

The resistance of a soil surface to erosion is a function of the soil's physical and chemical properties. The soil properties most significantly affecting soil erodibility are texture, organic-matter content, structure, and permeability. The K values assigned to named soils can be obtained from soil scientists, technical guides, or published lists.

Slope Length (L) and Slope Gradient (S)

Soil loss is affected by both length and degree of slope. For convenience in field application, these two factors are combined into a single topographic factor, LS.

The LS factor for a gradient as much as 50 percent and a slope length as much as 1,000 ft is obtained from the slope-effect chart (fig. 3–2). Similar data appear in tabular form in table 3–1. Values shown on the chart and table for slopes of less than 3 percent, greater than 20 percent, or longer than 400 feet are extrapolations of the formula to cover conditions beyond the range of research data. Computed soil loss determined from these LS values may need to be adjusted on the basis of experience and judgment.

Plant Cover or Cropping Management Factor (C)

The erosion equation, as applied to cropland and hayland, uses established factor relationships to estimate a basic soil loss that is determined by soil properties, topographic features, certain conservation practices, and expected rainfall patterns for a specific field. The basic soil loss is the rate at which the field would erode if it were continuously in tilled fallow. The C factor value indicates the percentage of this potential soil loss that would occur if the surface were partially protected by a particular combination of cover and management practices. Musgrave cover factors cannot be substituted for the C factor in the USLE because different base conditions were used to develop the cover factors (tilled continuous fallow for the USLE as opposed to uphill and downhill row crops for the Musgrave Equation).

Use of the C factor in other situations depends on three distinct but interrelated zones of influence: vegetal cover in direct contact with the soil surface, canopy cover, and the surface and beneath it.

C factor for cropland and hayland.—The C factor measures the effects of cropping sequences, cover, and management on soil losses from cropland and hayland. It is computed, on a local basis, for conventional and conservation (minimum-tillage) farming systems.

C factor for permanent pasture, grazed forest land, range, and idle land.—The effects of the three zones of influence are used in estimating the C factor for permanent pasture, grazed forest land, range, and idle land. The C factors are given in table 3–2.

C factor for forest land.—Permanent (undisturbed) forest land differs in several respects from the land for which C-factor values are given in table 3–2. A layer of compacted decaying duff or litter is extremely effective against water erosion. Research data, although limited, support a C value

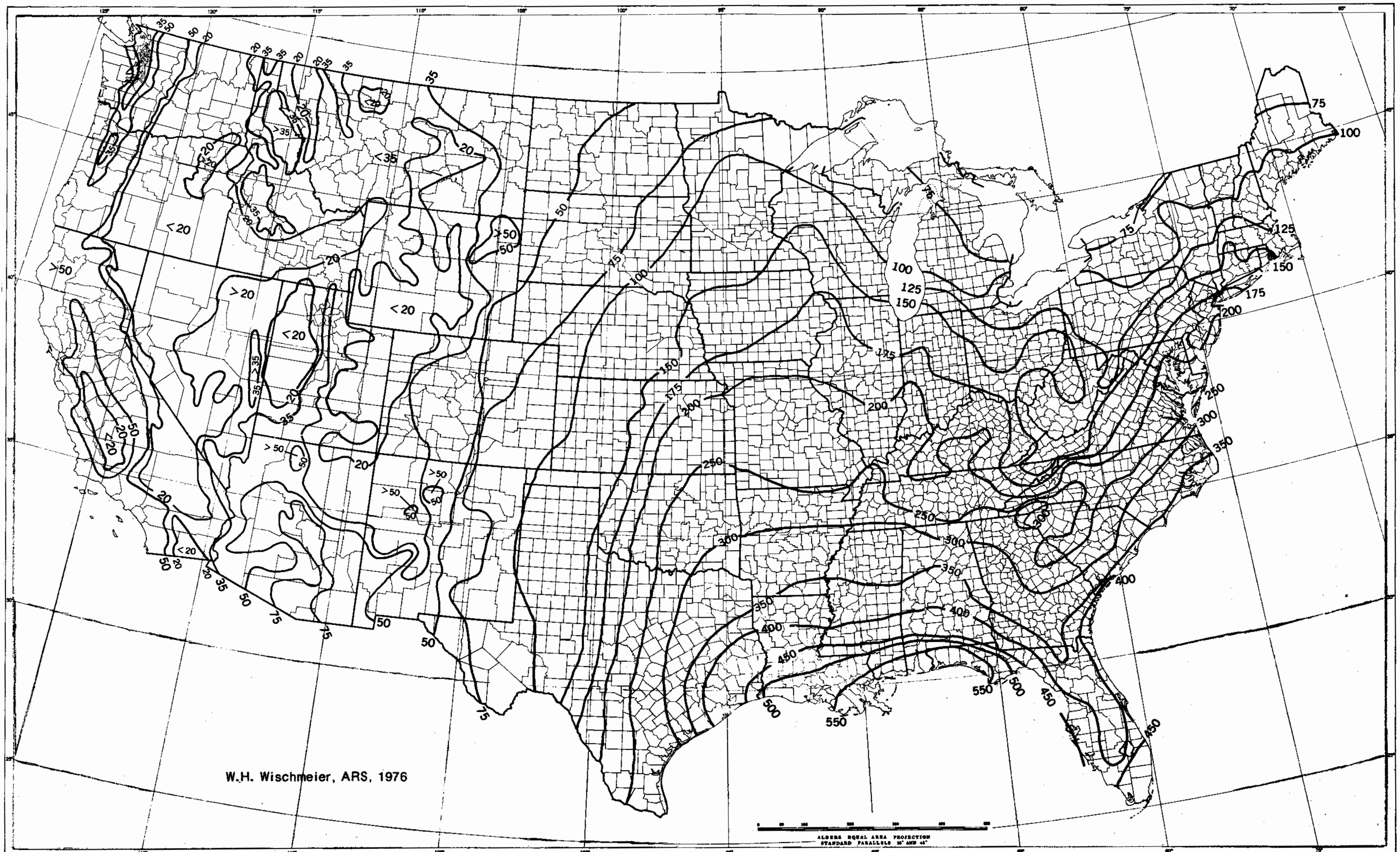
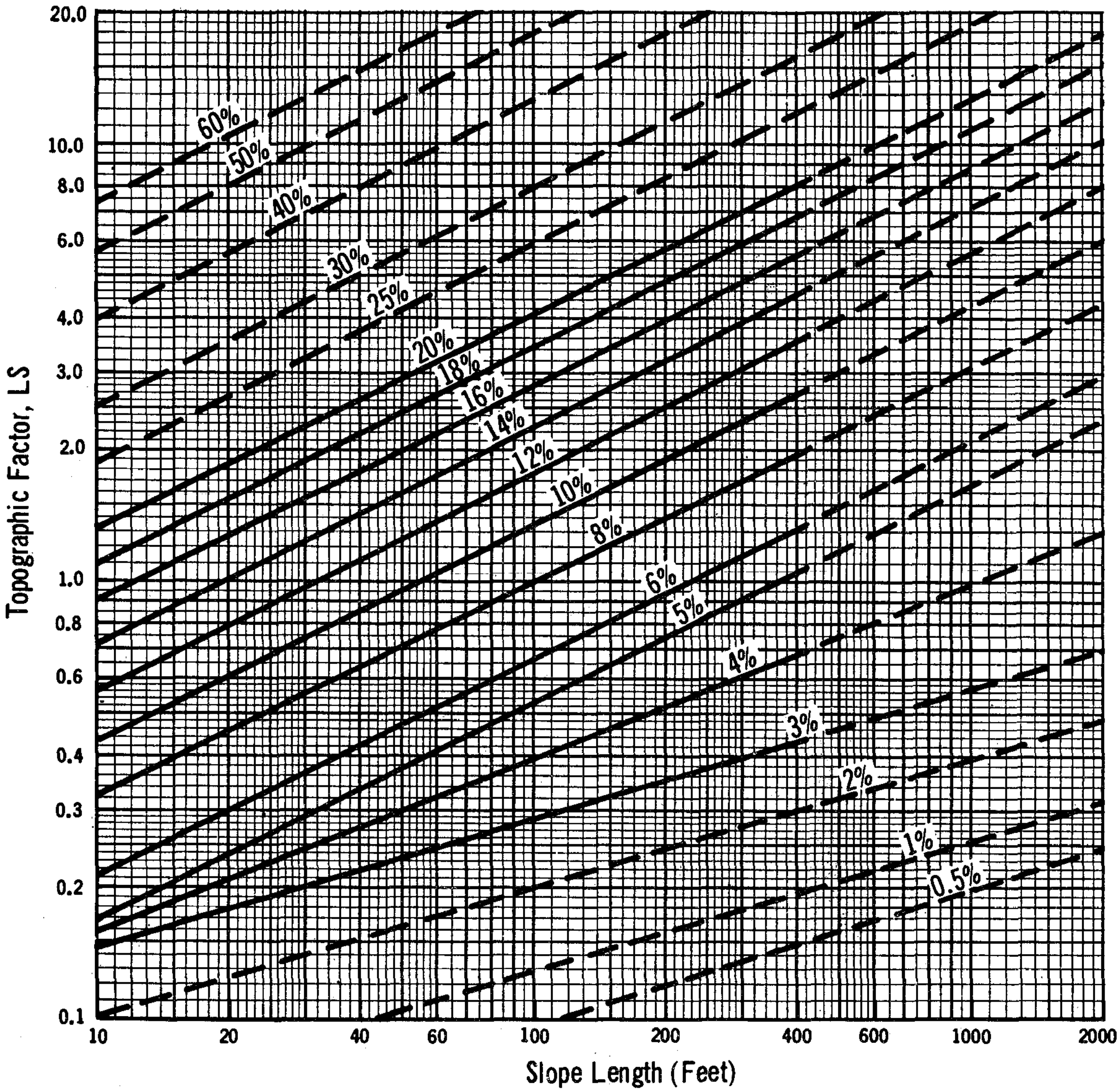


Figure 3–1.—Average annual values of the R factor.



*The dashed lines represent estimates for slope dimensions beyond the range of lengths and steepnesses for which data are available. The curves were derived by the formula:

$$LS = \left(\frac{\lambda}{72.6}\right)^m \left(\frac{430x^2 + 30x + 0.43}{6.57415}\right)$$

where λ=field slope length in feet and m=0.5 if s= 5% or greater, 0.4 if s=4%, and 0.3 if s=3% or less; and x=sin θ. θ is the angle of slope in degrees.

Figure 3–2.—Slope-effect chart (topographic factor, LS).

Table 3–1.—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	500	600	800	1,000
0.2	0.060	0.069	0.075	0.080	0.086	0.092	0.099	0.105	0.110	0.114	0.121	0.126
0.5	.073	.083	.090	.096	.104	.110	.119	.126	.132	.137	.145	.152
0.8	.086	.098	.107	.113	.123	.130	.141	.149	.156	.162	.171	.179
2	.133	.163	.185	.201	.227	.248	.280	.305	.326	.344	.376	.402
3	.190	.233	.264	.287	.325	.354	.400	.437	.466	.492	.536	.573
4	.230	.303	.357	.400	.471	.528	.621	.697	.762	.820	.920	1.01
5	.268	.379	.464	.536	.656	.758	.928	1.07	1.20	1.31	1.52	1.69
6	.336	.476	.583	.673	.824	.952	1.17	1.35	1.50	1.65	1.90	2.13
8	.496	.701	.859	.992	1.21	1.41	1.72	1.98	2.22	2.43	2.81	3.14
10	.685	.968	1.19	1.37	1.68	1.94	2.37	2.74	3.06	3.36	3.87	4.33
12	.903	1.28	1.56	1.80	2.21	2.55	3.13	3.61	4.04	4.42	5.11	5.71
14	1.15	1.62	1.99	2.30	2.81	3.25	3.98	4.59	5.13	5.62	6.49	7.26
16	1.42	2.01	2.46	2.84	3.48	4.01	4.92	5.68	6.35	6.95	8.03	8.98
18	1.72	2.43	2.97	3.43	4.21	4.86	5.95	6.87	7.68	8.41	9.71	10.9
20	2.04	2.88	3.53	4.08	5.00	5.77	7.07	8.16	9.12	10.0	11.5	12.9

[1]$LS = (\lambda/72.6)^m (65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065)$ where λ = slope length in feet; m = 0.2 for gradients <1 percent, 0.3 for 1- to 3-percent slopes, 0.4 for 3.5- to 4.5-percent slopes, 0.5 for 5-percent slopes and steeper; and θ = angle of slope. (For other combinations of length and gradient, interpolate between adjacent values.)

as low as 0.0001 for woodland with a 100-percent duff cover. Values of the C factor for undisturbed forest land are given in table 3–3. Table 3–4 gives values for forest land that has been harvested and cropland that has been converted to woodland, both of which required some mechanical preparation for planting.

Tables 3–2, 3–3, and 3–4 provide a wide range of values for the C factor. Although some land situations may not fit neatly in any of the three general categories, a representative C factor for most situations can be obtained from these tables.

Erosion Control Practice Factor (P)

The P factor measures the effect of control practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, and runoff velocity. Practices for which P factors have been established are contouring and contour stripcropping. The latter values are also used for contour-irrigated furrows. In contour stripcropping, strips of sod or meadow are alternated with strips of row crops or small grains. Terraces and diversions, where used, reduce the length of slope. The P values for computing sediment yield reduction for terraces and diversions are given in table 3–5.

Water Quality and Sediment Yield

The computed soil loss for large areas is not sediment yield, and it is not directly related to water quality. Overland sediment transport is a complex process of transport and deposition. The USLE estimates the transport component and specifically excludes the deposition component. For example, only 5 percent of the computed soil loss may appear as sediment yield in a drainage area of 500 mi^2. The remaining 95 percent is redistributed and deposited on uplands or flood plains and is not a net soil loss from the area. Procedures for computing sediment yield are given in Chapter 6.

Example of Use of USLE in Watershed Planning

Assume a watershed area of 600 acres above a proposed floodwater-retarding structure in Fountain County, Ind. (fig. 3–3). Compute the average annual soil loss from sheet erosion for present conditions and that for future conditions after the recommended land treatment has been applied on all land in the watershed.

Present conditions.—Cropland: 280 acres of continuous corn with residue removed, cultivated upslope and downslope, average yield of 70 bu/acre; soil is Fayette silt loam; slopes are 8 percent and 200 ft long.

Table 3-2.—C factors for permanent pasture, grazed forest land, range, and idle land[1]

Vegetative canopy		Cover that contacts the soil surface						
			Percent ground cover					
Type and height[2]	Percent cover[3]	Type[4]	0	20	40	60	80	95+
No appreciable canopy		G	0.45	0.20	0.10	0.042	0.013	0.003
		W	.45	.24	.15	.091	.043	.011
Tall grass, weeds, or short brush with average drop fall height of 20 in. or less	25	G	.36	.17	.09	.038	.013	.003
		W	.36	.20	.13	.083	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.076	.039	.011
	75	G	.17	.10	.06	.032	.011	.003
		W	.17	.12	.09	.068	.038	.011
Appreciable brush or bushes, with average drop fall height of 6½ ft	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.087	.042	.011
	50	G	.34	.16	.08	.038	.012	.003
		W	.34	.19	.13	.082	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.078	.040	.011
Trees, but no appreciable low brush. Average drop fall height of 13 ft	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.089	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.087	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.084	.041	.011

[1]The listed C values require that the vegetation and mulch are randomly distributed over the entire area. For grazed forest land multiply these values by 0.7.
[2]Canopy height is measured as the average fall height of water drops falling from the canopy to the ground. Canopy effect is inversely proportional to drop fall height and is negligible if fall height exceeds 33 ft.
[3]Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a bird's-eye view).
[4]G: cover at surface is grass, grasslike plants, decaying compacted duff, or litter. W: cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface) or undecayed residues or both.

R = 185
K = 0.37
LS = 1.4
C = 0.43
P = 1.00

$$A \text{ (annual soil loss)} = 185 \times 0.37 \times 1.4 \times 0.43 \times 1.0 = 41.2 \text{ tons/acre}$$

Pasture: 170 acres; 50 percent of area has canopy cover of short brush (0.5-m [1.6-ft] fall height); 80 percent of surface is covered by grass and grasslike plants; soil is Fayette silt loam; slopes are 8 percent and 200 ft long.

R = 185
K = 0.37
LS = 1.4
C = 0.012

$$A \text{ (annual soil loss)} = 185 \times 0.37 \times 1.4 \times 0.012 = 1.15 \text{ tons/acre}$$

Forest: 150 acres; 30 percent of area has tree; canopy; 50 percent of surface is covered by litter; undergrowth is unmanaged; soil is Bates silt loam; slopes are 12 percent and 100 ft long.

$$R = 185$$
$$K = 0.32$$
$$LS = 1.8$$
$$C = 0.009$$

$$A \text{ (annual soil loss)} = 185 \times 0.32 \times 1.8 \times 0.009 = 0.96 \text{ ton/acre}$$

Future conditions.—Cropland: 280 acres in rotation of wheat, meadow, corn, corn with residue left, contour stripcropped; soil is Fayette silt loam;

Table 3–3.—C factors for undisturbed forest land[1]

Percentage of area covered by canopy of trees and undergrowth	Percentage of area covered by duff[2]	C factor[3]
100–75	100–90	0.0001–0.001
70–45	85–75	.002 - .004
40–20	70–40	.003 - .009

[1]Where effective litter cover is less than 40 percent or canopy cover is less than 20 percent, use table 3–2. Also use table 3–2 where woodlands are being grazed, harvested, or burned.
[2]Percentage of area covered by duff is dominant. Interpolate on basis of duff, not canopy.
[3]The ranges in listed C values are caused by the ranges in the specified forest litter and canopy covers and by variations in effective canopy heights.

Table 3–4.—C factors for mechanically prepared woodland sites

Site preparation	Mulch cover[1]	Soil condition[2] and weed cover[3]: Excellent NC	Excellent WC	Good NC	Good WC	Fair NC	Fair WC	Poor NC	Poor WC
	Percent								
Disked, raked, or bedded[4]	None	0.52	0.20	0.72	0.27	0.85	0.32	0.94	0.36
	10	.33	.15	.46	.20	.54	.24	.60	.26
	20	.24	.12	.34	.17	.40	.20	.44	.22
	40	.17	.11	.23	.14	.27	.17	.30	.19
	60	.11	.08	.15	.11	.18	.14	.20	.15
	80	.05	.04	.07	.06	.09	.08	.10	.09
Burned[5]	None	.25	.10	.26	.10	.31	.12	.45	.17
	10	.23	.10	.24	.10	.26	.11	.36	.16
	20	.19	.10	.19	.10	.21	.11	.27	.14
	40	.14	.09	.14	.09	.15	.09	.17	.11
	60	.08	.06	.09	.07	.10	.08	.11	.08
	80	.04	.04	.05	.04	.05	.04	.06	.05
Drum chopped[5]	None	.16	.07	.17	.07	.20	.08	.29	.11
	10	.15	.07	.16	.07	.17	.08	.23	.10
	20	.12	.06	.12	.06	.14	.07	.18	.09
	40	.09	.06	.09	.06	.10	.06	.11	.07
	60	.06	.05	.06	.05	.07	.05	.07	.05
	80	.03	.03	.03	.03	.03	.03	.04	.04

[1]Percentage of surface covered by residue in contact with the soil.
[2]*Excellent* soil condition—Highly stable soil aggregates in topsoil with fine tree roots and litter mixed in. *Good*—Moderately stable soil aggregates in topsoil or highly stable aggregates in subsoil (topsoil removed during raking), only traces of litter mixed in. *Fair*—Highly unstable soil aggregates in topsoil or moderately stable aggregates in subsoil, no litter mixed in. *Poor*—No topsoil, highly erodible soil aggregates in subsoil, no litter mixed in.
[3]NC—No live vegetation. WC—75-percent cover of grass and weeds having an average drop fall height of 20 in. For intermediate percentages of cover, interpolate between columns.
[4]Modify the listed C values as follows to account for effects of surface roughness and aging. *First year after treatment*: multiply listed C values by 0.40 for rough surface (depressions >6 in.); by 0.65 for moderately rough; and by 0.90 for smooth depressions <2 in.) *For 1 to 4 years after treatment*: multiply listed factors by 0.7. *For 4+ to 8 years*: use table 3–2. *More than 8 years*: use table 3–3.
[5]*For first 3 years*: use C values as listed. *For 3+ to 8 years after treatment*: use table 3–2. *More than 8 years after treatment*: use table 3–3.

slopes are 8 percent and 200 ft long.

R = 185
K = 0.37
LS = 1.4
C = 0.119
P = 0.3

A (annual soil loss) = 185 × 0.37 × 1.4 × 0.119 × 0.3
= 3.4 tons/acre

Pasture: 170 acres with improved management; 25 percent of area has canopy cover (4-m [13-m] fall height); ground cover in an area not protected by canopy is increased to 95 percent; soil is Fayette silt loam; slopes are 8 percent and 200 ft long.

R = 185
K = 0.37
LS = 1.4
C = 0.003
P = 0.3

A (annual soil loss) = 185 × 0.37 × 1.4 × 0.003
= 0.29 ton/acre

Forest: 150 acres with improved management; canopy cover increased to 60 percent; litter cover increased to 80 percent; soil is Bates silt loam; slopes are 12 percent and 100 ft long.

R = 185
K = 0.32
LS = 1.8
C = 0.003

A (annual soil loss) = 185 × 0.32 × 1.8 × 0.003
= 0.32 ton/acre

Summary of average annual soil loss.—Present conditions:

Cropland:	280 acres × 41.2 tons/acre	= 11,536 tons/year
Pasture:	170 acres × 1.15 tons/acre	= 196 tons/year
Forest:	150 acres × 0.96 ton/acre	= 144 tons/year

Future conditions:

Cropland:	280 acres × 3.4 tons/acre	= 952 tons/year
Pasture:	170 acres × 0.29 ton/acre	= 49 tons/year
Forest:	150 acres × 0.32 ton/acre	= 48 tons/year

Table 3-5.—P values for contour-farmed terraced fields[1]

	Farm planning		Computing sediment yield[2]	
Land slope (percent)	Contour factor[3]	Stripcrop factor	Graded channels, sod outlets	Steep backslope, underground outlets
1 to 2	0.60	0.30	0.12	0.05
3 to 8	.50	.25	.10	.05
9 to 12	.60	.30	.12	.05
13 to 16	.70	.35	.14	.05
17 to 20	.80	.40	.16	.06
21 to 25	.90	.45	.18	.06

[1]Slope length is the horizontal terrace interval. The listed values are for contour farming. No additional contouring factor is used in the computation.

[2]These values include entrapment efficiency and are used for control of offsite sediment within limits and for estimating the field's contribution to watershed sediment yield.

[3]Use these values for control of interterrace erosion within specified soil-loss tolerances.

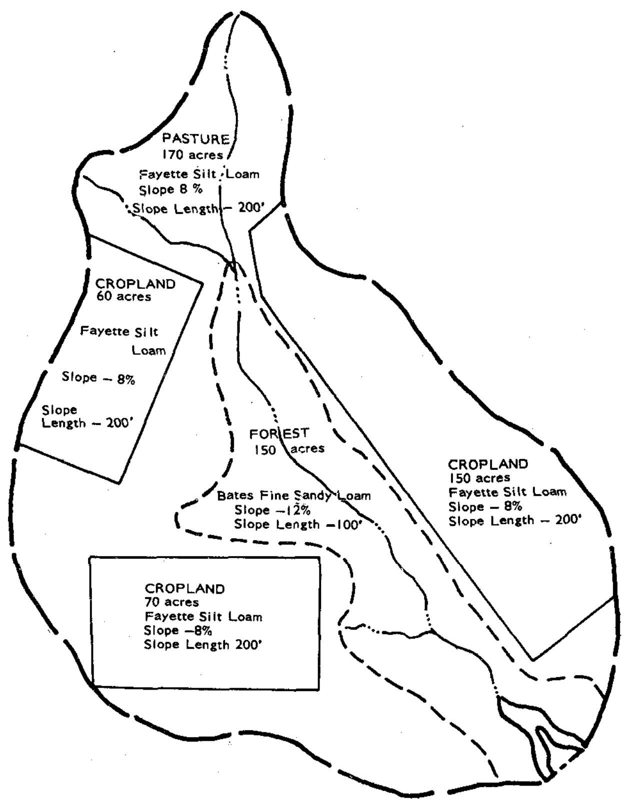


Figure 3-3.—Hypothetical 600-acre watershed used in example.

Enter these values on Form SCS-ENG-309 (Rev. 1974) and follow the procedure set forth in Chapter 8, Sediment-Storage Design Criteria, to obtain the sediment yield at the proposed floodwater-retarding structure.

Channel Erosion

Channel erosion consists of the removal of soil and rock by a concentrated flow of water. Concentrated flow permits a more concerted local attack on the soil and associated materials. Channel erosion includes gully erosion, streambank erosion, streambed degradation, flood-plain scour, valley trenching, and much roadbank erosion.

Factors Involved

Gullies usually follow sheet erosion. They begin in a slight surface depression into which, in time, the concentrated flow cuts a channel a foot or more deep. The shape of the channel is usually determined by the relative resistance of the soil.

Streambank erosion and bed degradation are affected primarily by the bank materials and the resistance of the channel bottom to the character and direction of flow. Removal of the natural vegetation from streambanks increases bank erosion. The presence of coarse bed material that a stream cannot pick up during reduced flows results in an attack on the banks by the flowing water.

When estimating long-term streambank erosion, keep in mind that bank erosion is a natural process and occurs even on streams that tend to maintain a long-term constant width. On these streams, bank erosion is offset by less obvious deposition and accretion. Therefore, streams of this type are not primary sources of sediment.

Streambed erosion is not a significant long-term sediment source because the material subject to this type of erosion is limited in both extent and volume. Compared with other potential sources of sediment, streambed erosion usually is minor.

Flood-plain scour is the removal of flood-plain soil by flows sweeping across the flood plain. It may occur in the form of channelization or sheet removal of the surface soil. This form of sheet erosion cannot be computed by the USLE or similar equations.

Computation Procedures

Methods of determining soil loss by the various types of channel erosion are: (1) comparing aerial photographs of different dates to determine the annual growth rate of channels; (2) rerunning existing cross sections to determine the difference in total channel cross-sectional area; (3) assembling historical data to determine the average age of channels and their average annual growth; and (4) making field studies to estimate the average annual growth rate (volume per unit length of channel).

Formulas for computing annual channel erosion from data obtained in these determinations are:

For bank erosion

$$S = H \times L \times R$$

where

- S = annual soil loss from streambank erosion (cubic feet).
- H = average height of bank (feet).
- L = length of bank being eroded, each side of channel (feet).
- R = annual rate of bank recession (feet).

Example: If H = 5 ft, L = 1,800 ft, and R = 0.1 ft,[1]

$$S = 5 \text{ ft} \times 1{,}800 \text{ ft} \times 0.1 \text{ ft} = 900 \text{ ft}^3$$

For channel degradation

$$S = W \times L \times R$$

where

- S = volume voided by channel degradation (cubic feet).
- W = average bottom width of channel (feet).
- L = length of channel bottom being eroded (feet).
- R = annual rate of degradation (feet).

Example: If W = 20 ft, L = 900 ft, and R = 0.2 ft,[2]

$$S = 20 \text{ ft} \times 900 \text{ ft} \times 0.2 \text{ ft} = 3{,}600 \text{ ft}^3$$

[1] *Annual recession rates of more than 0.1 ft are common on the outside of bends and meanders. This cut-bank recession is usually offset by sediment accretion on the opposite slip-off slope, which results in channel migration with no substantial change in channel width. Significant long-term changes in channel width cannot occur without equally drastic changes in discharge, slope, or depth.*

[2] *An annual degradation rate of 0.2 ft for 100 years (normal project life) would deepen the channel by 20 ft. This rate is not likely to occur in a perennial stream.*

Figure 3–4 is a nomograph that can be used to estimate the volume of material lost annually because of various types of channel erosion. A procedure for calculating gully erosion is presented in more detail in Technical Release No. 32 (Soil Conservation Service 1966).

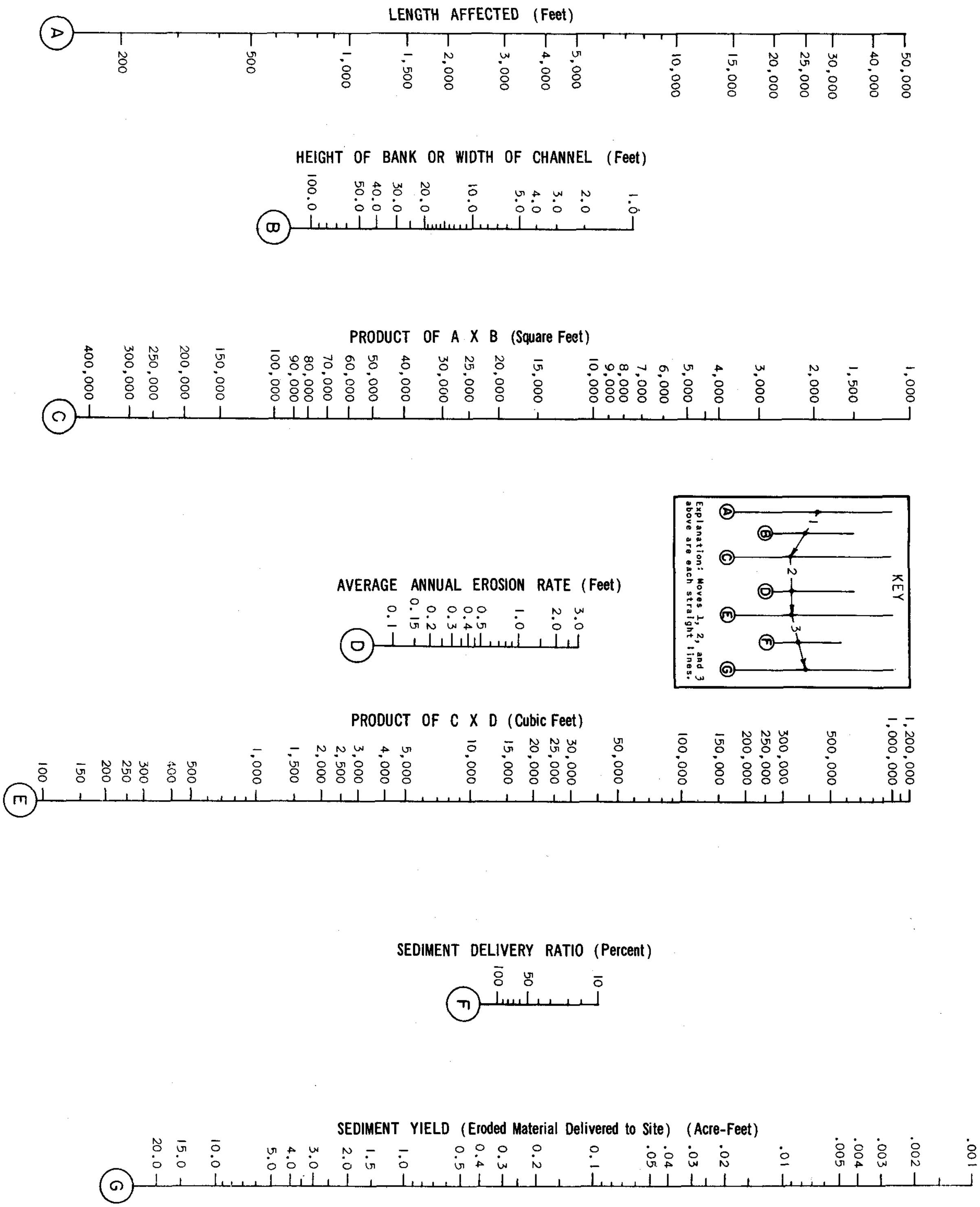


Figure 3–4.—Nomograph for computing average annual gully erosion, streambank erosion, channel entrenchment, and flood-plain scour in acre-feet.

Wind erosion is the detachment and transport of soil material by wind. The process is called deflation, and the resultant deposits are classified as eolian. The rate of erosion depends on the intensity and persistence of the wind, size and availability of soil particles, and amount of protective cover. Dry soil is necessary for maximum deflation rates.

In the United States, the conditions generally most favorable for wind erosion are in semiarid or arid areas west of the 100th meridian, although wind erosion does occur elsewhere. Although water erosion is dominant even in arid areas, wind erosion can approach it in amount in deserts and during periods of intensive drought in other areas.

Eolian deposits are characterized by highly sorted particles, by cross-bedded or lenticular structures, and by dunes oriented by the prevailing winds. A hummocky surface develops when wind-blown sediment lodges around isolated bushes or grass. Fence-line deposits are confined to the area alongside the fence and can be several feet thick.

Deflation areas contain scoured-out depressions or pock-marked surfaces. Such features are usually in exposed places and are not associated with water drainage rills or channels. Remnants of grass or even single pebbles may rest on small pedestals in the eroded zone. Some shrubs or bunches of grass may persist with the root system exposed above ground. In gravelly sands, selective removal of the smaller particles can produce a gravel pavement on the surface.

The amount of deflation can be determined by comparing the voided area with the original ground surface. Measure enough cross sections to delineate an average-sized depression and determine the number of depressions on recent aerial photographs or count the number per unit area.

Wind-deposited materials may have come from outside a watershed. Conversely, a watershed under study may have lost much soil to distant areas. Windblown sediment moves progressively in the direction of the prevailing winds rather than downslope.

The most important aspect of wind erosion to be considered in studies of sediment yield is the deposition of windblown sediment in channels from which it is easily flushed and added to the sediment yield of the watershed. Channels act as natural traps for airborne sediment whether they contain water or not. If eolian deposition in channels is a factor in the watershed being studied, measure the annual volume of deposition. A sampling process will usually be adequate. Unless channel capacity is decreasing because of these deposits, add the volume of these sediments to the sediment yield. The sediment delivery ratio depends on the kind of material. Wind erosion does not occur every year in most areas. Adjust the annual sediment yield rates downward to account for years in which wind erosion does not occur.

In some areas a significant amount of windblown soil may be deposited on snow. During snowmelt the soil is carried by water into streams or drainage ditches. This snow-caught sediment can be measured by pushing metal tubes into the snow and weighing the contents after the snow in the sample melts.

Many factors affect the amount of soil moved by wind erosion. An equation has been developed (Chepil and Woodruff 1963) to predict the average annual soil loss from wind erosion:

$$E = f(I, C, K, L, V)$$

where

E = average annual soil loss (tons per acre).
I = annual soil erodibility (tons per acre).
C = local wind-erosion climatic factor (percent).
K = soil surface roughness (ratio).
L = equivalent width of field (feet).
V = equivalent quantity of vegetal cover (proportionate factor).

Soil erodibility (I) is determined from the percentage of the nonerodible soil fraction greater than 0.84 mm in diameter (Chepil 1962). The local wind-erosion climatic factor (C) is estimated from a wind-erosion climatic map developed by Chepil, Siddoway, and Armbrust (1962). Surface soil roughness (K) is measured in terms of the height of standard ridges spaced at right angles to the wind, with a height-spacing ratio of 1 to 4. The equivalent width of the field (L) is the unsheltered distance along the prevailing wind-erosion direction. The equivalent quantity of vegetation (V) is a proportionate factor determined by the quantity, type, and orientation of the vegetal cover. Instructions for use of these factors, as well as maps, charts, and tables, are in Agriculture Handbook 346 (Agricultural Research Service 1968).

Mass movement includes slumps, mud flows, soil and rock falls, rotational and planar slides, avalanches, and soil creep. Unlike wind and water, mass movement does not carry soil or rock out of the general region in which it formed, but mass movement is often an important factor in soil removal. It can increase or decrease erosion from one source, change a stream channel regime, and alter the drainage area of a watershed.

Factors Involved

Mass movement occurs when shear stress exceeds shear strength. High shear stress can be caused by removal of lateral support; added weight of rain, snow, or talus accumulations; construction or other human activities; transitory earth stresses, such as earthquakes; regional tilting; removal of underlying support; and lateral pressure from water in cracks and caverns, freezing of water, or swelling of clay or anhydrite (Highway Research Board 1958).

Low shear strength can be caused by:

1. Composition. Inherently weak materials such as saturated clay and silt are examples.
2. Texture, such as loose arrangement of particles or roundness of grains.
3. Gross structure, including discontinuities from faults, bedding planes, or joints, or strata inclined toward a free face.
4. Changes resulting from weathering and other physiochemical reactions.
5. Changes in intergranular forces resulting from pore water.
6. Changes in internal structure, such as fissuring in preconsolidated clays or the effect of disturbance or remolding on sensitive materials (Highway Research Board 1958).

Gravity is, of course, the main force in these mass movements. Usually, landslides are precipitated by some combination of the factors listed above. No movement can occur, however, unless the topographic conditions help to create the instability.

Estimation Procedures

No standard procedures for calculating erosion by mass movement have been developed; it must therefore be estimated.

Numerous measurements have been made in the semiarid West to determine the maximum angles at which slopes stand with and without vegetal cover. Nonvegetated talus material stands at gradients between 68 and 80 percent (angles of about 34 to 38 degrees). Vegetated slopes underlain by fine-textured soils derived from the same parent material as the barren talus stand at gradients of as much as 173 percent (angle of 60 degrees). Without vegetation, slopes of fine material would not stand, even at gradients as high as those of coarse talus (Bailey 1941).

The hazard of debris flows can be estimated on the basis of slope. These flows usually originate on slopes of more than 30 percent. The terminal slope of debris flows is between 7 and 10 percent.

A procedure for calculating erosion from mass movement would require measuring the volume of materials moved. For large masses, comparing the findings of a topographic survey of the mass with the original topography (from standard quadrangle sheets if available) provides an estimate of the volume of materials moved. For smaller masses, a grid of hand-auger borings extending into the original soil profile can provide a basis for estimating the volume.

Other types of erosion not described in detail here do occur and must be evaluated if found in areas under study.

Wave Erosion

Caused by wind and water, wave erosion is an important source of sediment along shorelines of oceans, lakes, and rivers. Wave erosion can change shorelines markedly and can be measured in many places (Jones and Rogers 1952, Glymph and Jones 1937). The rate of erosion from wave action can be measured by comparing two sets of aerial photographs taken on different dates, as in estimating channel erosion. Historical data form another basis for estimating wave erosion rates. Unless the shoreline was mechanically shaped during reservoir construction, wave erosion along a reservoir shore can also be determined by comparing the present shore profile with an extrapolation of the slope of the profile above the influence of wave action (fig. 3–5.).

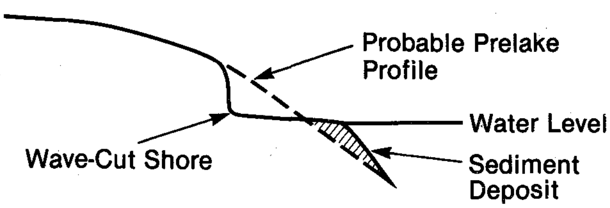


Figure 3–5.—Projecting lines of undisturbed bank to determine probable prelake profile.

Erosion from Strip Mining and Construction

Strip mining or excavating operations and construction of highways, industrial areas, public buildings, housing, shopping centers, and related areas greatly accelerate erosion of exposures and spoil banks. Each condition must be evaluated as a separate problem.

Holeman and Geiger (1959) estimated that the Lake Barcroft, Va., watershed yielded 25 acre-ft of sediment in 1951, when 9 percent of the area (13 mi^2) was under construction, an increase of 21.3 acre-ft over the pre-1938 average annual rate of 3.7 acre-ft. The sediment yield was 16.3 acre-ft/mi^2 for the area under construction and 0.257 acre-ft/mi^2 for the watershed in the earlier period of agricultural use. Before 1938, 18 percent of the watershed was cultivated, 23.5 percent in pasture, 53 percent in woods, and 5.5 percent residential. Construction activities are believed to have increased the sediment yield to more than 63 times the pre-1938 level.

Wolman and Schick (1967) found that the sediment yield in construction areas averaged 72 times that in rural areas. Collier et al. (1964) found that in 1959 a watershed near Somerset, Ky., with 6 percent of its area strip mined, yielded 69 times more sediment than a similar adjacent watershed that was wooded and unmined.

These findings do not mean that areas under construction always yield 70 times the sediment that they would under rural conditions, but the figures do indicate the general size of the increase. In areas undergoing urbanization, the average annual amount of soil exposed can be estimated from such factors as population curves and the number of sewer connections, to determine annual trends.

The USLE is the most promising method for calculating erosion on construction sites or strip-mined areas, but appropriate values for factors of the equation must be carefully selected. Keep in mind that the soil surface is probably not in the same condition as it would be under any agricultural use. The microrelief and soil surface conditions are likely to vary much more over short distances than they do in any agricultural situation. The USLE K values are indexed to "tilled continuous fallow" and a specific microrelief and surface texture that may not be common on construction sites. Topsoil K values are currently determined by use of a nomograph (Wischmeier, Johnson, and Cross 1971). Recent research (Roth, Nelson, and Romkins 1974) indicates that factors other than those considered by Wischmeier et al. may be significant in determining the erodibility of exposed cohesive subsoil.

Sediment yield from construction sites and strip-mined areas can be estimated from the computed erosion and a sediment delivery ratio. Consider projected erosion-control measures realistically when determining the sediment delivery ratio.

Ice Erosion

In watersheds likely to be studied in the SCS small watershed program, erosion by ice probably falls into one of three categories: (1) glacial gouging around the margin of mountain glaciers, (2) erosion by ice along river channels during spring freshets, and (3) erosion by ice shoved along the shores of northern lakes. Ice erosion usually is not an important source of sediment.

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