Hillslope Erosion by Water

In the early 1940's, experimental work by W. D. Ellison demonstrated the role of raindrops in splashing soil particles into motion. Earlier work in Europe and the United States had pointed out that the raindrops composing a storm of moderate size and intensity possess tremendous amounts of kinetic energy by virtue of their mass and their velocity of fall (kinetic energy = 0.5 × mass × velocity^2). Ellison showed that a significant part of this energy mobilizes soil, and is the major process initiating soil erosion at both the geologically normal and accelerated rates in areas subject to Horton runoff. He took high-speed photographs of the rainsplash erosion, as shown in Figure 15-4. It is possible to see clearly from the photographs that the impact of the drop generates a small explosion of soil and water. Large soil aggregates are dispersed and the smaller particles are splashed

Figure 15-4 High-speed photograph of a raindrop impact on a soil surface. Soil particles are splashed in all directions, but those traveling downhill move farther than those splashed uphill. (USDA–Soil Conservation Service.)

over several feet. The soil particles splashed downhill travel farther than those that move uphill, causing a net downslope transport of soil. Repeated billions of times per rainstorm, this downslope transport is what we measure as *rainsplash erosion.* After centuries of concern the fundamental cause of soil erosion finally became apparent from Ellison's work.

To appreciate this process, you may recall occasions when you have walked in the desert or on a construction site during a heavy rainstorm. Your trouser legs record a profile of the heights to which soil particles can be splashed by raindrops. After the rainstorm each area of soil protected by a pebble stands up on a small earth pillar, indicating the depth of soil moved by rainsplash.

Rainsplash erosion is particularly important on steep slopes devoid of vegetation, just the conditions created during parts of the year on agricultural fields, road cuts, and mining and construction sites. A thick vegetation cover intercepts virtually all the kinetic energy of rainfall (see Figure 15-5) and herein lies the critical and dominant role of vegetation in reducing soil erosion. Many cultivated crops leave the soil exposed to raindrop impacts (Figure 15-6). In general, the denser the vegetative cover, the lower the rate of erosion; this factor, which is controlled in turn by climate and land use, dominates the effects of all other controls such as rainfall energy and hillslope gradient. In fact, the area of the United States that experiences the heaviest rainfalls, namely the southeast, also has one of the lowest geologic rates of erosion because of the thick natural forest cover. When the forests of the region were cleared for planting corn, tobacco, and cotton in the late

Figure 15-5 Thick ground cover of grass and clover. A thick vegetation cover protects the soil very efficiently from the kinetic energy of raindrops. Few if any drops reach the soil directly but rather drop from a small height, often onto organic litter. (USDA–Soil Conservation Service.)

Figure 15-6 Under a corn crop bare ground is exposed to raindrop impact and sheetwash. In this picture overland flow is running off a hillslope on a Maryland farm. (USDA–Soil Conservation Service.)

Figure 15-5 Thick ground cover of grass and clover. A thick vegetation cover protects the soil very efficiently from the kinetic energy of raindrops. Few if any drops reach the soil directly but rather drop from a small height, often onto organic litter. (USDA–Soil Conservation Service.)

Figure 15-6 Under a corn crop bare ground is exposed to raindrop impact and sheetwash. In this picture overland flow is running off a hillslope on a Maryland farm. (USDA–Soil Conservation Service.)

eighteenth and early nineteenth centuries, however, the result was catastrophic accelerated erosion. Parts of Brazil, the Malagasy Republic, Maláwi, and many other tropical and subtropical regions have suffered the same fate.

Another important factor controlling the intensity of rainsplash erosion is the resistance of soil to dispersal. High organic content and moderate amounts of clay and calcium seem to be the factors promoting the development of stable soil aggregates. Silt and sand are more easily splashed, and many tillage operations break down the aggregates to the detriment of soil resistance. The factors controlling resistance to splash are reviewed by Bryan (1968).

As described in Chapter 9, in areas where rainfall intensity exceeds the infiltration capacity of the soil, water accumulates on the land surface and runs downslope as an irregular sheet. The depth and velocity of this water increase downslope as more water is generated by precipitation excess, until the force applied to the soil by the water is sufficient to exceed the resistance of soil to erosion. The intensity of erosion depends on the product of water depth and hillslope gradient. It may increase or decrease with distance downslope depending on the combination of water depth and hillslope gradient along the hillslope profile. A common situation is for erosion to increase with distance as the gradient steepens downslope, and then for erosion to decrease, or even for some deposition to take place on the gentle footslope. These relationships are summarized in Figure 15-7. Our picture

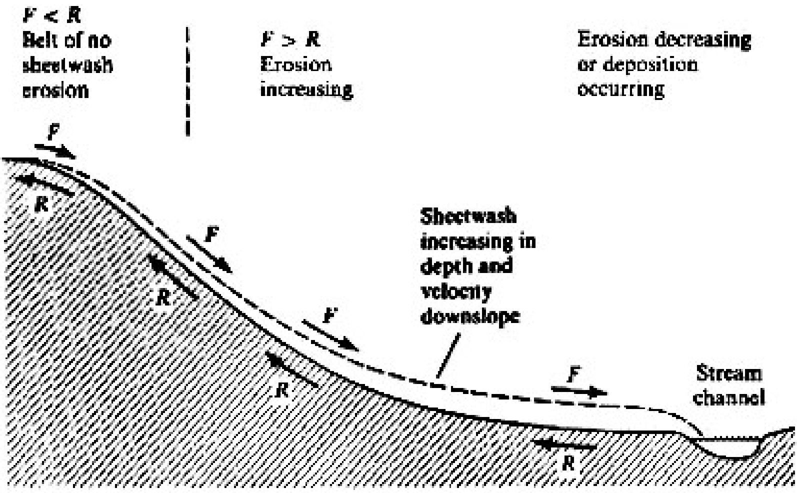

Figure 15-7 The relative magnitudes of the eroding force of sheetwash (F) and the resistance (R) of the soil to erosion determine the width of a belt of no sheetwash erosion near the top of a hillslope. Below this belt the intensity of sheetwash erosion depends on the erosive force F (which is proportional to the product of hillslope gradient and water depth). Note that rainsplash erosion does occur in the belt of no sheetwash erosion.

Figure 15-8 A hillslope undergoing rapid rainsplash and sheetwash erosion as a result of heavy grazing, cutting, and burning. The pedestals of soil surviving under each tree indicate that the hillslope, which has a gradient of only two percent, has lost 60 cm of topsoil during the last 50 years. In the foreground, the soil surface shows signs of vigorous surface wash.

of a uniform sheet of water is an idealization. In fact, the sheet contains tiny streams and threads of water that are slightly deeper and faster than the average. They move back and forth across the hillslope during the rainstorm and together with rainsplash are responsible for most of the erosion and transportation of soil from the hillslope. We will refer to this erosion process, however, as *sheetwash erosion*, because the net effect of the movement of these threads through many rainstorms is to remove a more or less uniform depth of soil from the hillslope. Often the term sheetwash erosion encompasses rainsplash erosion because the two are difficult to separate in the field, but we have chosen to discuss them separately here. The effects of combined sheetwash and rainsplash erosion are apparent in Figure 15-8.

Some of the controls of rainsplash erosion also affect sheetwash erosion. Rainfall intensity determines the amount and rate of precipitation excess and therefore of the amount and depth of runoff. Vegetation supplies organic matter to the soil, provides favorable conditions for soil microfauna, which with plant roots promote loose topsoil with a high infiltration capacity and low rates of sheetwash. Soil texture is another determinant of infiltration capacity, as we discussed in Chapter 6.

The resistance of soil to erosion is another important factor, though one that is not clearly understood. Large soil particles are more difficult to move than finer ones, but the very finest silt and clay particles are more difficult to move than sand. A good soil structure in which particles are held together

Figure 15-8 A hillslope undergoing rapid rainsplash and sheetwash erosion as a result of heavy grazing, cutting, and burning. The pedestals of soil surviving under each tree indicate that the hillslope, which has a gradient of only two percent, has lost 60 cm of topsoil during the last 50 years. In the foreground, the soil surface shows signs of vigorous surface wash.

of a uniform sheet of water is an idealization. In fact, the sheet contains tiny streams and threads of water that are slightly deeper and faster than the average. They move back and forth across the hillslope during the rainstorm and together with rainsplash are responsible for most of the erosion and transportation of soil from the hillslope. We will refer to this erosion process, however, as *sheetwash erosion*, because the net effect of the movement of these threads through many rainstorms is to remove a more or less uniform depth of soil from the hillslope. Often the term sheetwash erosion encompasses rainsplash erosion because the two are difficult to separate in the field, but we have chosen to discuss them separately here. The effects of combined sheetwash and rainsplash erosion are apparent in Figure 15-8.

Some of the controls of rainsplash erosion also affect sheetwash erosion. Rainfall intensity determines the amount and rate of precipitation excess and therefore of the amount and depth of runoff. Vegetation supplies organic matter to the soil, provides favorable conditions for soil microfauna, which with plant roots promote loose topsoil with a high infiltration capacity and low rates of sheetwash. Soil texture is another determinant of infiltration capacity, as we discussed in Chapter 6.

The resistance of soil to erosion is another important factor, though one that is not clearly understood. Large soil particles are more difficult to move than finer ones, but the very finest silt and clay particles are more difficult to move than sand. A good soil structure in which particles are held together by organic material and cations into a porous aggregate is known to resist sheetwash erosion as it resists dispersal by rainsplash. A moderate amount of clay in the soil binds sand particles together, but high clay content lowers the infiltration capacity and promotes runoff.

Hillslope gradient affects sheetwash erosion by increasing the erosive force the runoff applies to the soil surface, and hillslope length is important because, as indicated in Figure 15-7, the depth of overland flow increases with the distance downslope and its ability to erode is proportional to its depth. At the top of a hillslope, the depth of the sheet is not sufficient for the eroding force to overcome the resistance of the soil to erosion. There will be a zone near the top of the slope in which sheetwash erosion cannot occur, though rainsplash erosion can. The relative importance of rainsplash and the force applied by sheetwash changes with the distance downslope. On very long hillslopes with low infiltration rates, sheetwash usually becomes the dominant process, although rainsplash is still exceedingly important in mobilizing soil which is then transported by the sheetwash. The combination of the two processes can be appreciated by closely observing surface runoff during a lull in a storm when abundant water is moving over the surface, but only an occasional large raindrop falls. The drop passes through the sheet of overland flow and splashes soil up into the flow. A small, faint plume of sediment can be seen drifting downslope with the sheetwash.

If the minute streams of water cut separate channels, as shown in Figure 15-9, the process is known as *rill erosion*. The concentration of runoff in

Figure 15-9 Rill erosion on an agricultural field in Illinois. (USDA–Soil Conservation Service.)

these small channels causes an increase in the efficiency and intensity of soil removal. On agricultural fields, tillage operations may obliterate the rills each year, causing their significance to be overlooked.

If the rills become engraved into the land surface to depths of more than about one foot, and especially if they are not obliterated by cultivation and do not migrate back and forth across the hillslope, they are generally classified as gullies (Figure 15-10). *Gully erosion* produces incisions ranging in size from a foot in depth and width and a few feet long to several tens of feet deep, hundreds of feet wide and miles long. Geomorphologists do not yet understand exactly how rills and gullies form and remain stable, but they are generally associated with very intense water erosion under the most severe combinations of the controlling factors listed above.

The amount of soil exported by gully erosion is usually small by comparison with that removed by rainsplash and sheetwash erosion, but the process can do great damage to an individual piece of land. In a heavily cut and grazed region in northern Kenya, gully erosion measured by Dunne has mobilized only 1 percent as much sediment as sheet erosion. Leopold et al. (1966) found that gully growth supplied only 1.4 percent of the sediment yield of a small grazed catchment in a semi-arid area near Santa Fe. Rainsplash and sheetwash erosion supplied 97.8 percent and soil creep 0.7

Figure 15-10 Gully erosion after land was cleared and graded for housing construction. In a single winter the main gully was cut to a depth of 8 feet and an average width of 50 feet, and was more than 500 feet long. Juanita Creek basin, Kirkland, Washington. (USDA–Soil Conservation Service.)

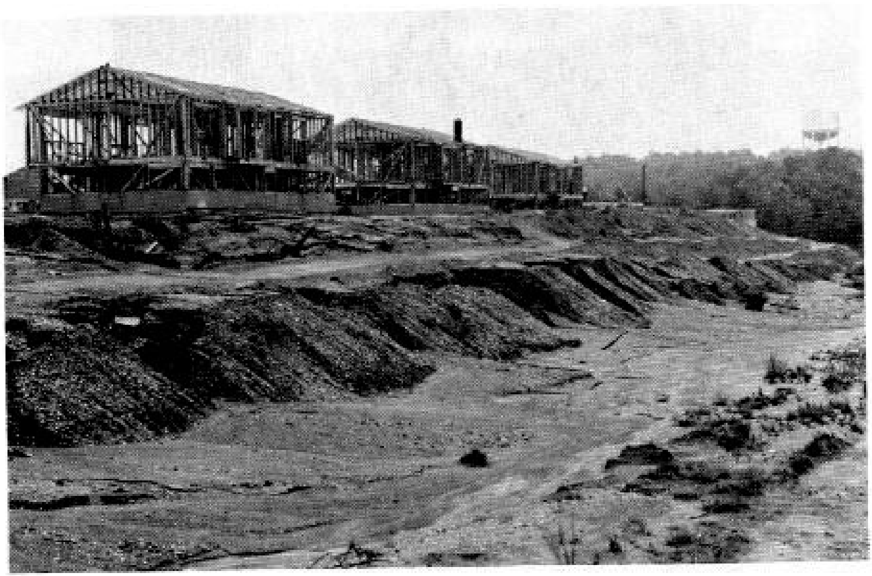

Figure 15-11 Construction sites undergo intense sheetwash and gully erosion because the vegetative cover is removed and the surface is continually steepened, churned, and compacted. (USDA–Soil Conservation Service.)

percent. Brune (1950) measured gully contributions of 3.4 to 4.0 percent in an agricultural basin in Illinois; sheet erosion supplied 79–96 percent, with the remainder coming from erosion in the valley bottom, and probably from soil creep. Glymph (1957) compared gully and sheetwash erosion at many localities in the agricultural lands of the east and central United States. Gullies supplied from 0 to 89 percent of the total sediment yield, but most of the high values came from one region of Mississippi where the process is particularly severe. Seventy-five percent of Glymph's values were less than 30 percent.

We do not yet have any quantitative estimates of the contributions of rill and gully erosion on urban construction sites, road cuts, or mined areas and spoil heaps, where conditions favor all types of water erosion. As we will show in the next section, rates of soil loss from such areas are very high because the vegetative cover is removed, the permeable topsoil is removed, and the dense subsoil is exposed, compacted, and graded into steep slopes and is frequently disturbed by heavy machinery. Some of the conditions encountered on these sites are shown in Figure 15-11. Mined areas and their spoil heaps suffer rapid water erosion for the same reasons.

Even in forested and agricultural areas, roads are important sources of sediment and need constant care to minimize damage to stream systems (Figure 15-12). More will be said in Chapter 17 about the effect of urbanization and other types of land use on the sediment yields of drainage basins.

Figure 15-12 Sediment washing from a rural road in eastern Kenya.

Rates of Water Erosion

Because of the difficulties of separating rainsplash, sheetwash, and rill erosion, their effects are usually measured together by monitoring the amount of sediment lost from hillside plots like those shown in Figure 15-13, or from small catchments. Another method of obtaining the same data is by repeated measurement of the exposure of stakes or nails (Figure 15-14). A detailed discussion of techniques for evaluating various kinds of erosion is provided by Leopold et al. (1966) and by Dunne (1977).

Thousands of measurements of rates of soil loss have been made from hillslopes with different gradients, length, vegetative covers, and soil conservation techniques. We make no attempt to summarize this literature, except to present a few representative measurements under different types of land use. They simply emphasize the overriding importance of vegetative cover and therefore of land use. Figure 15-15(a) is perhaps the most widely quoted summary of soil loss from agricultural plots in the midwestern United States. Figure 15-15(b) shows a similar compilation from studies in Tanzania. The results speak for themselves in view of our foregoing discussion. A sample of data is listed in Table 15-1.

Figure 15-13 Experimental plots for measuring runoff and soil erosion under various crops and cultivation practices at Marlboro, New Jersey. The large tanks trap the water and sediment caught in the trough at the bottom of each plot. (USDA–Soil Conservation Service.)

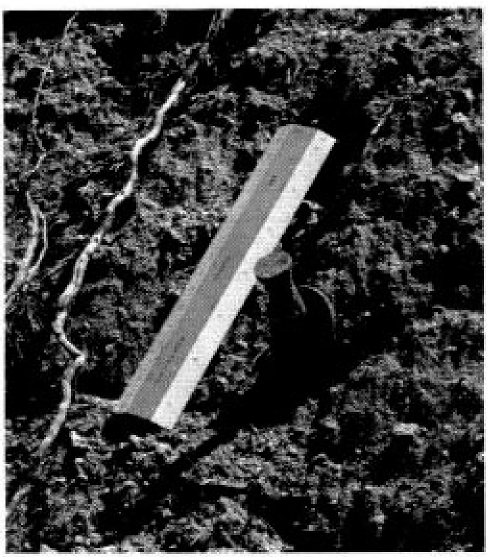

Figure 15-14 Erosion pins on a hillside near Santa Fe, New Mexico. Nails and washers are placed in lines on the slope, and the height from the top of the nail to the washer is measured annually with a millimeter scale.

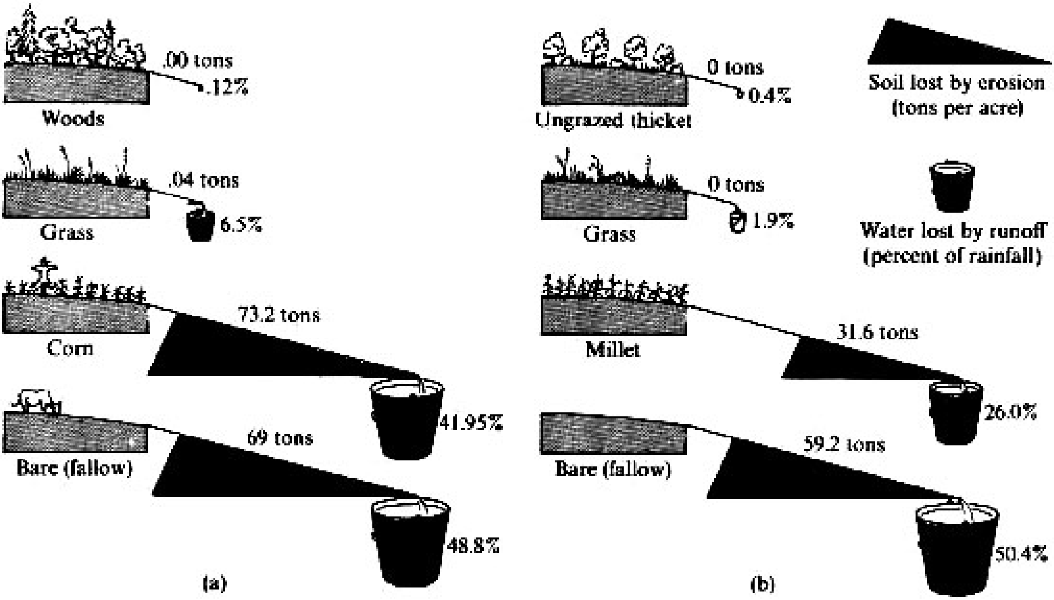

Figure 15-15 Results from plot studies of runoff and erosion under various types of land use. (a) Midwestern United States. (Soil Conservation Service.) (b) Mpwapwa, Tanzania. (From Rapp et al. 1972.)

Table 15-1 Some measurements of soil loss from hillside plots.

LAND USE	LOCATION	SOIL LOSS (TONS/ACRE/YR) [1 TONNE/HECTARE = 0.4474 TONS/ACRE]	SOURCE
FOREST			
Primeval	Oklahoma	0.01	Smith and Stamey (1965)
Burned annually	Oklahoma	0.11	Smith and Stamey (1965)
Primeval	North Carolina	0.002	Smith and Stamey (1965)
Primeval	Kenya	0.09	Dunne, unpublished
Burned semiannually	North Carolina	3.08	Smith and Stamey (1965)
Second growth	Ivory Coast	0.40	Nye and Greenland (1960)
Woodland, protected	Texas	0.05	Smith and Stamey (1965)
Woodland, burned annually	Texas	0.36	Smith and Stamey (1965)
Woodland, protected	Ohio	0.01	Smith and Stamey (1965)
Woodland, protected	North Carolina	0.08	Dils (1953)

continued

Table 15-1, *continued*

LAND USE	LOCATION	SOIL LOSS (TONS/ACRE/YR) [1 TONNE/HECTARE = 0.4474 TONS/ACRE]	SOURCE
AGRICULTURE, CULTIVATED GRASSLANDS			
Bluegrass	Midwestern U.S.	0.02-0.34	Smith and Stamey (1965)
Alfalfa	Midwestern U.S.	0.03-0.15	Smith and Stamey (1965)
Clover and grass	Virginia	0.01-0.07	Smith and Stamey (1965)
Bermuda grass	S.W. United States	0.00-0.10	Smith and Stamey (1965)
Fescue grass	Georgia	0.20	Barnett (1965)
Hayland	Washington	0.01-0.08	Smith and Stamey (1965)
Hayland	North Carolina	0.31	Smith and Stamey (1965)
Tropical perennial grasses	Puerto Rico	1.20	Smith and Stamey (1965)
Tropical kudzu	Puerto Rico	0.18	Smith and Stamey (1965)
Hayland	India	1.05-8.30	Vasudevaiah et al. (1965)
Tropical pasture grasses	India	0.20	Vasudevaiah et al. (1965)
Dubgrass	India	0.47	Battawar and Rao (1969)
Grass	India	1.4–1.8	United Nations (1951)
AGRICULTURE, CROPLANDS			
Bare fallow	Georgia	100	Barnett (1965)
Bare fallow	Tanzania	59.2	Rapp et al. (1972)
Bare fallow	Ivory Coast	45	Dabin (1959)
Bare fallow	Midwestern U.S.	69	Bennett (1939)
Bare fallow	India	14.6-15.4	United Nations (1951)
Maize (corn)	India	4.7	Battawar and Rao (1969)
Maize	India	10.54	Vasudevaiah et al. (1965)
Maize	Midwestern U.S.	17.86	Jamison et al. (1968)
Maize	Rhodesia	2.1-4.5	Hudson and Jackson (1959)
Maize	Midwestern U.S.	73.2	Bennett (1939)
Millet	Tanzania	31.6	Rapp et al. (1972)
Hill rice	India	1.0	Battawar and Rao (1969)
Hill rice	India	9.4	Vasudevaiah et al. (1965)
Hill rice	Java	11.2	Nye and Greenland (1960)
Hill rice	Guinea	0.4-1.8	Nye and Greenland (1960)
Arhar grain	India	5.5	Battawar and Rao (1969)
Cowpeas	India	1.9	Battawar and Rao (1969)
Urid grain	India	21.0	Vasudevaiah et al. (1965)
Peanuts	India	6.2	Vasudevaiah et al. (1965)

continued

Table 15-1. *continued*

LAND USE	LOCATION	SOIL LOSS (TONS/ACRE/YR) [1 TONNE/HECTARE = 0.4474 TONS/ACRE]	SOURCE
RANGELAND			
Dry woodland and rangeland	Southern California	2.7	Krammes (1960)
Dry woodland and rangeland, after fire	Southern California	24.7	Krammes (1960)
Dry woodland and rangeland	New Mexico	21.2	Leopold et al. (1966)
Sparse grassland	Alberta	7.7	Campbell (1970)
Dry woodland and rangeland, heavily cut and grazed	Kenya	13–76	Dunne, measurement
Grass and scrub	India	1.5–1.8	United Nations (1951)
URBAN			
Road cuts	Georgia	79–237	Diseker and Richardson (1961)
Building sites	Maryland	125–219	Wolman and Schick (1967)
Building sites	Maryland	189	Guy (1965)
MINING			
Land devegetated by smelter fumes	Ontario	26.1	Pearce (1973)
Spoil bank	Ohio	87	*Geotimes* (1971, Dec)
RURAL ROADS			
Forest roads in a jammer unit	Idaho	29.7	Megahan and Kidd (1972)
Forest roads	Idaho	7.9	Copeland (1965)
Rural road	N. Kenya	53.7	M. Norton–Griffiths,

Prediction of Soil Erosion

In the planning of agricultural land use, rural development schemes, and small water-resource developments, it is frequently necessary to estimate the rate at which soil is being lost from hillslopes, or the rate at which it will be lost if a new crop is introduced, if soil conservation programs are begun, or if there is a fluctuation of the weather, such as a run of very wet years.

This is being done with increasing frequency, care, and success as we accumulate unfortunate experiences about the potential impact of soil erosion upon agricultural production and engineering works, and as the techniques for making predictions of erosion improve.

The best method of predicting soil loss is to have some local field data that are representative of the range of conditions found in the area of interest. Most planners are not in a position to monitor soil erosion in the field. They should be aware, however, that some agricultural engineers, geomorphologists, and hydrologists do monitor soil loss, and that data are available in some areas. This is particularly true in agricultural regions where the Soil Conservation Service, and the Agricultural Research Service in the United States, and similar organizations elsewhere have accumulated a great deal of information about soil loss from cultivated fields. Planners are often in a position to encourage further collection of such data to document both the impact of human activities and of natural fluctuations of weather. The necessary fieldwork is not expensive and can yield valuable information for planning.

A second method of predicting erosion is by the use of multivariate equations developed from data collected at large numbers of experimental sites. Many examples of multiple regression equations are available in the literature, but they are only useful in the area for which they were developed. The prediction-equation approach has been most highly and usefully developed by the Soil Conservation Service and the Agricultural Research Service over the past 35 years, and many predictive equations have evolved. The most comprehensive and useful of these has become known as the *Universal Soil-Loss Equation* (Wischmeier and Smith 1965) and continues to undergo refinement and testing both within the United States and in other countries (Battawar and Rao 1969, Hudson 1971). The technique can also be used to predict soil loss from construction sites (Wischmeier and Meyer 1973).

The equation predicts *only* the amount of soil moved from its original position on a field or hillside. It does not estimate the net soil erosion resulting from the difference between erosion and deposition. Nor can its results be compared with the sediment yield of a river basin. The following computations provide an index of net soil erosion that allows the planner to recognize sensitive sites and to plan strategies to minimize soil loss.

The Universal Soil-Loss Equation is

$$A = RKLSCP \tag{15-1}$$

where A = soil loss (tons per acre)
R = the rainfall erosivity index
K = the soil erodibility index
L = the hillslope-length factor
S = the hillslope-gradient factor
C = the cropping-management factor
P = the erosion-control practice factor.

The rainfall erosivity index is calculated from the kinetic energy (E) of each rainstorm multiplied by the maximum 30-minute intensity of the storm

(I_{30}). The kinetic energy varies with the rainfall intensity (I) according to the relationship

$$E = 916 + 331 \log_{10} I \tag{15-2}$$

where the energy is expressed in foot-tons per acre per inch of rainfall and the rainfall intensity in inches per hour. The rainstorm is divided into portions of uniform intensity for the application of this equation. The energy per inch of rain is calculated from Equation 15-2 and is multiplied by the amount of rain falling during the time interval. Increments of energy are then summed to obtain E for the whole storm.

The rainfall erosivity index can then be calculated from the sum of the $E \times I_{30}$ product for each storm during the period of interest, such as a year or a season, according to the equation

$$R = \frac{\sum_{i=1}^{n} E_i I_{30_i}}{100} \tag{15-3}$$

The factor can be calculated from the rainfall intensity values obtained with a recording gauge. For the eastern and central United States, annual erosivity values have been mapped (see Figure 15-16), and graphs of seasonal distribution and probability of occurrence of various amounts of rainfall energy are given by Wischmeier and Smith.

The soil erodibility factor, K, is the average soil loss, in tons per acre, per 100 foot-tons per acre of rainfall erosivity (i.e., per unit value of the erosivity index given in Equation 15-3) when the soil is exposed as cultivated bare fallow under specified conditions of hillslope length and gradient. Values of K were obtained by direct field measurement on a few agricultural soils in the United States (see Figure 15-17), and K values for other soils can be estimated from these by comparing their physical properties. For most of the major soil series in the United States such erodibility factors can be obtained from the Agricultural Research Service or from the Soil Conservation Service. Wischmeier et al. (1971) have extended the method by the development of Figure 15-18, which can be used to estimate K values for both agricultural soils and for the dense subsoils exposed on construction sites. The soil properties needed for the newer technique are the percentage of soil particles between 0.002 and 0.1 mm, the percentage greater than 0.1 mm, the organic matter content, the soil structure, and the permeability. The use of the nomograph is illustrated by the path of the dashed line. The authors of the work claim that about 95 percent of all K values estimated in this way should lie within ± 0.04 of the true value.

The length and slope factors are usually evaluated together from Figure 15-19. If convex or concave hillslopes are being studied, the length and slope values used should be modified. If the lower end of the hillslope is much steeper than the upper portion, the gradient of the steeper portion should be used with the overall length. On a concave hillslope the gradient and length of the upper, steeper segment only should be used.

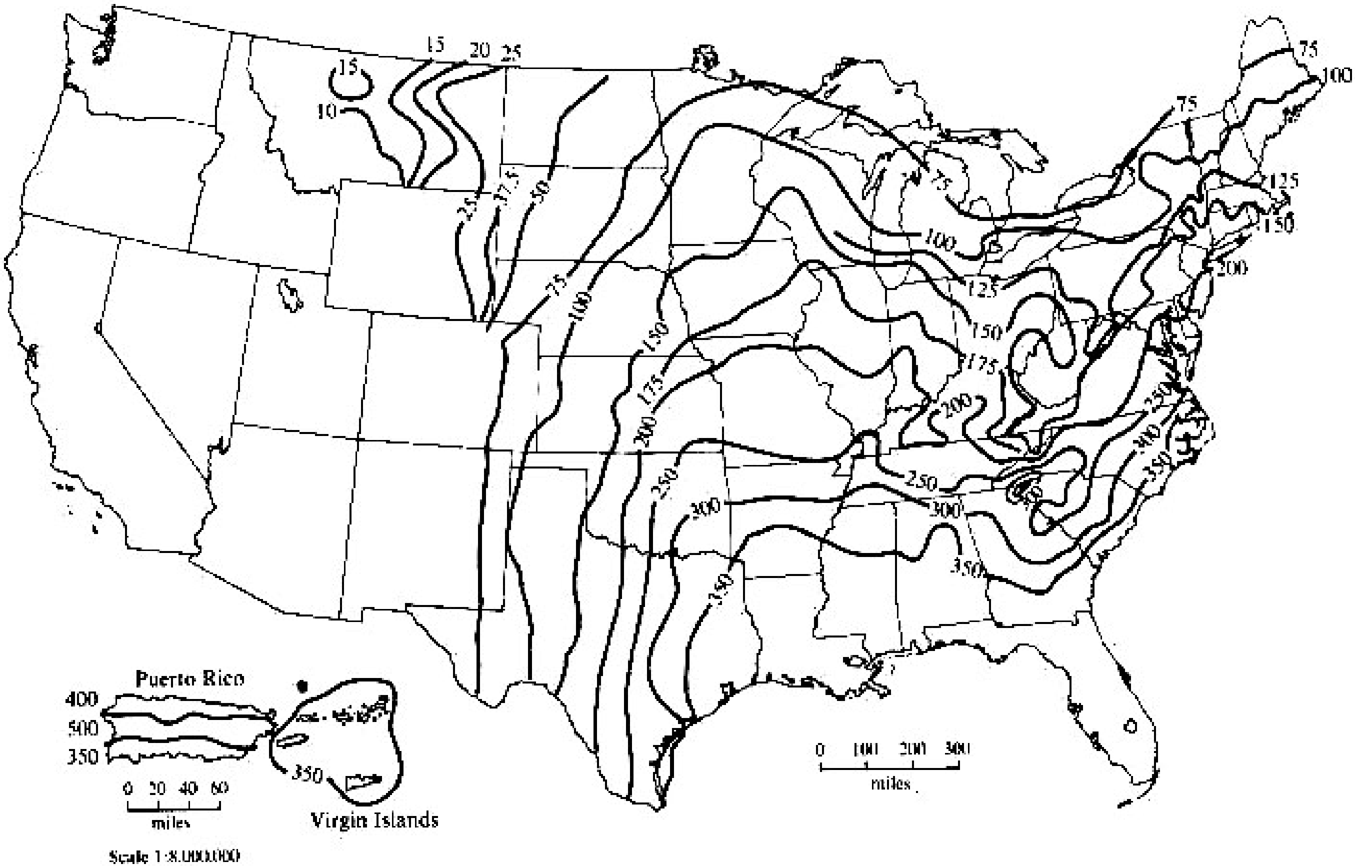

Figure 15-16 Average annual totals of erosivity in hundreds of foot-tons per acre for the eastern and central United States. Note that the values on this map differ from those given by Wischmeier and Smith (1965). The Agricultural Research Service has determined that the higher values shown in *Agricultural Handbook 282* are unrealistically high. (From U.S. Soil Conservation Service 1975b.)

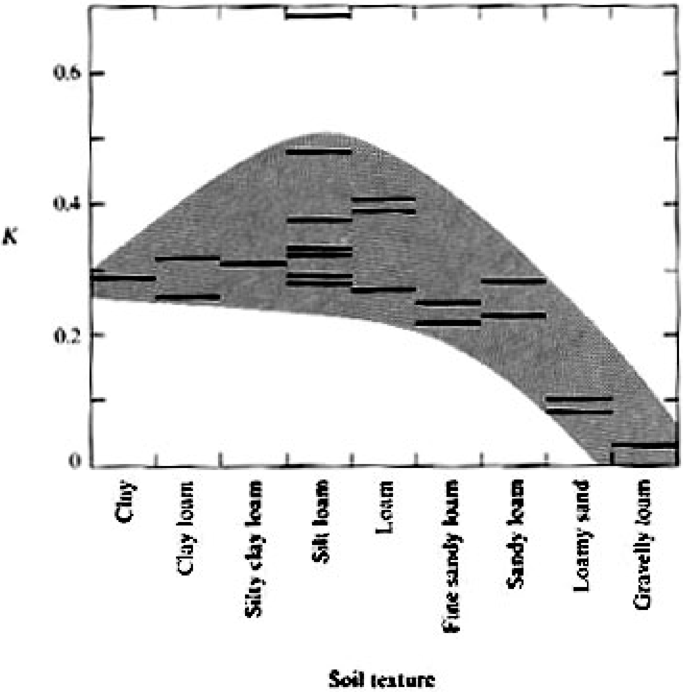

Figure 15-17 Summary of measured K values for a range of soils in the eastern and central United States. Each horizontal bar indicates one plot measurement. The shaded area represents the range of the data available so far, apart from a single measurement on a silt loam. (Data from Wischmeier and Smith 1965.)

The cropping-management factor, C, includes the effect of vegetative cover, the sequence of crops in a rotation, the stage of the crop, tillage practices, and residue management. Values of C are given in the Wischmeier and Smith report for many different crop rotations and for seven field conditions covering four crop stages and the fallow period. The C value for each crop stage in Table 15-2 can be weighted by the proportion of the annual total erosivity for the location (also given for the United States by Wischmeier and Smith) to calculate a weighted average value of the crop-management factor, C_w.

Thus,

$$C_w = \frac{\sum_{i=1}^{n} C_i \cdot \%R_i}{100} \qquad (15\text{-}4)$$

where $\%R_i$ is the percentage of rainfall erosivity units occurring in the ith crop stage. The U.S. Soil Conservation Service (1975c) also releases C values for other agricultural regions, and for woodland and pasture, as illustrated in Tables 15-3 and 15-4. Wischmeier and Meyer (1973) provide some guidance on C values for construction sites.

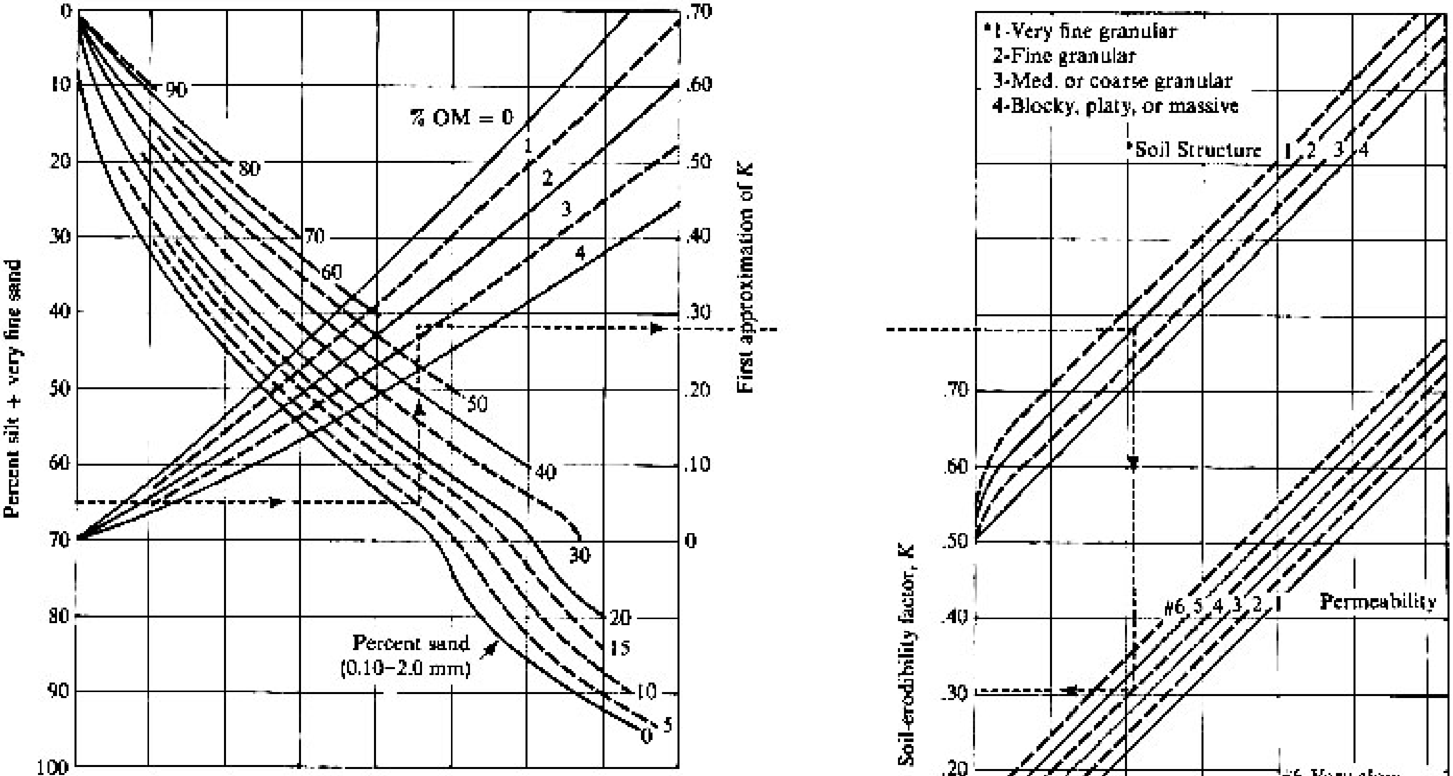

Figure 15-18 Nomograph for estimating erodibility indices for the Universal Soil-Loss Equation. The soil properties needed for use of the nomograph are available in County Soil Survey Reports or detailed profile descriptions, and are defined in the U.S. Soil Conservation Service (1951) Soil Survey Manual. *Procedure:* With appropriate data, enter scale at left and proceed to points representing the soil's percentage of sand (0.10-2.0 mm), percentage of organic matter (OM), structure, and permeability, *in that sequence.* Interpolate between plotted curves. The dotted line illustrates procedure for a soil having silt and very fine sand 65%, sand 5%, OM 2.8%, structure 2, permeability 4. Solution: $K = 0.31$. (From Wischmeier et al. 1971.)

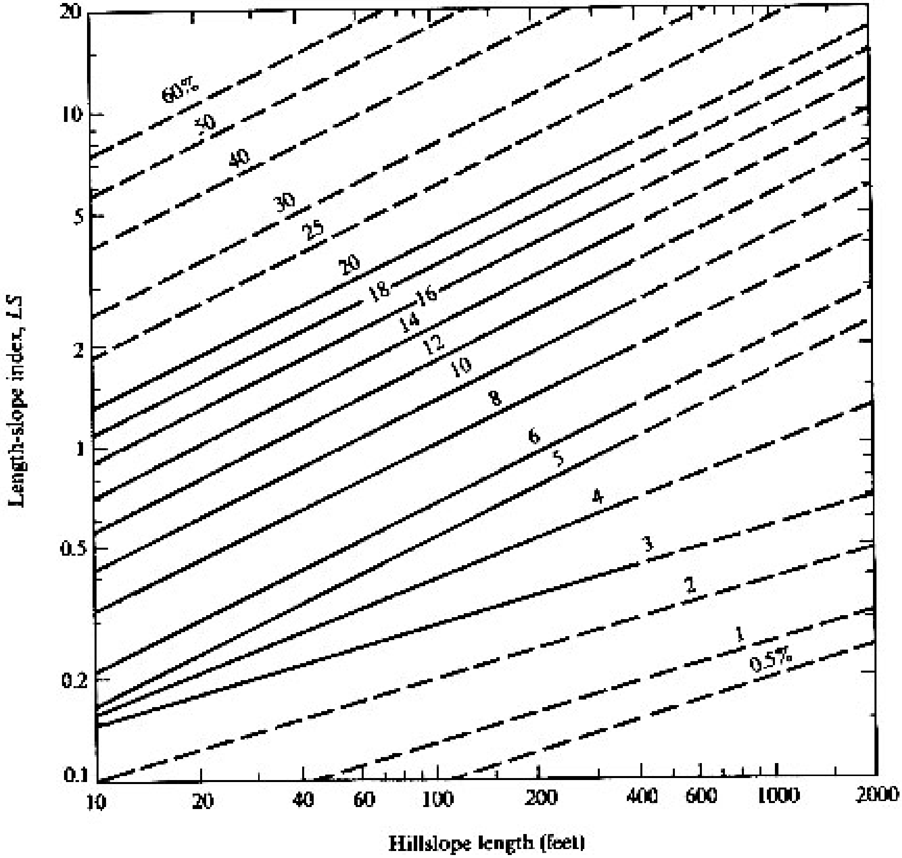

Figure 15-19 Chart for evaluating the length-slope factor, *LS*, in the Universal Soil-Loss Equation. The solid lines represent conditions within the range of data from which the curves were derived. The dashed lines are based on extrapolations and should be used with care. (From U.S. Soil Conservation Service 1975b.)

Table 15-2 Examples of cropping-management factors, *C* in the Universal Soil-Loss Equation, for agricultural land. Many other crop combinations are listed in the original reference as well as in technical releases for particular regions. The crop stages are also defined in the original source. (From Wischmeier and Smith 1965.)

	CROP STAGE				
CROP	FALLOW	SEEDLING	ESTABLISHMENT	MAJOR GROWTH	RESIDUE
Corn with conventional tillage in rotation with small grains and grass	0.36	0.63	0.50	0.26	0.30
Alfalfa					0.02

Table 15-3 Cropping-management factors, *C* in the Universal Soil-Loss Equation, for woodland. (From U.S. Soil Conservation Service 1975b.)

TREE CANOPY (% OF AREA)	% OF AREA COVERED BY > 2 INCHES OF FOREST LITTER	UNDERGROWTH	*C*
100–75	100–90	Grazing and burning controlled	0.001
		Heavily grazed and burned	0.003–0.011
70–40	80–75	Grazing and burning controlled	0.002–0.004
		Heavily grazed and burned	0.01–0.04
35–20	70–40	Grazing and burning controlled	0.003–0.009
		Heavily grazed and burned	0.02–0.09
<20	Treated as grassland or cropland		

Table 15-4 Cropping-management factors, *C* in the Universal Soil-Loss Equation, for pasture, rangeland, and idle land. (From U.S. Soil Conservation Service 1975b.)

TYPE OF CANOPY AND AVERAGE FALL HEIGHT OF WATER DROPS	CANOPY COVER (%)	GROUND COVER*	PERCENT GROUND COVER					
			0	20	40	60	80	95–100
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds or short brush (0.5 m fall ht)	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
Appreciable brush or brushes (2 m fall ht)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable low brush (4 m fall ht)	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

*G = Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep.
W = Cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface, undecayed residue, or both).

Table 15-5 Erosion-control practice factor (P) for the Universal Soil-Loss Equation. (From U.S. Soil Conservation Service 1975b.)

LAND SLOPE (%)	P VALUES			
	CONTOURING	CONTOUR STRIP CROPPING*	CONTOUR IRRIGATED FURROWS	TERRACING†
2.0–7	0.50	0.25	0.25	0.10
8.0–12	0.60	0.30	0.30	0.12
13.0–18	0.80	0.40	0.40	0.16
19.0–24	0.90	0.45	0.45	0.18

*Using a 4-year rotation of maize, small grain, meadow, and meadow.
†For prediction of contribution to off-field sediment load.

The erosion-control practice factor, P, varies with such techniques as contour cultivation, strip cropping, and terracing. Recommended values are given in Table 15-5.

The Universal Soil-Loss Equation can be extended from individual fields and hillslopes to small drainage basins by dividing the basin map into areas of uniform soil type, topography, and agronomic conditions, and computing the soil loss for each combination.

In the United States, a concept has been developed of a "tolerable soil-loss rate," which is the erosion rate below which land productivity can be maintained. The values of tolerable erosion estimated for different soils in the United States vary from about one to six tons per acre per year. In planning agricultural development, therefore, this rate can be substituted for A in Equation 15-1, and for the fixed values of R, K, L, and S for a field, the values of C and P can be manipulated to balance the equation. This exercise indicates the management options available for keeping the erosion rate below the tolerable level, and policies can then be followed to encourage the adoption of these practices among farmers. It should be realized, however, that the values decided upon for the agricultural areas of the United States refer mostly to good conditions of soil and climate, a high level of management skills on the farm, and a situation in which fertilizers and energy inputs have been very cheap. These last two conditions are not likely to last much longer, even in North America. In many other countries with a soil-erosion problem, conditions are even less encouraging for all the factors referred to. It is likely, therefore, that tolerable rates of soil erosion in some areas are lower than one ton per acre per year.

On urban construction sites, road cuts, and rural roads, the Universal Soil-Loss Equation can be used to predict rates of sediment production and their impact upon turbidity levels of receiving streams, as well as to design strategies for sediment control within the disturbed area (Wischmeier and Meyer 1973).

The approach incorporated in the equation has many possibilities for application and refinement. Its application to other countries is limited by lack of field data, but this might be remedied by a survey of the few such data that exist in a country (see Fournier 1967, Temple 1972, and Hudson 1971 for valuable summaries of past work on soil erosion in tropical countries). A relatively few field measurements and some educated guesses by experienced soil scientists, agricultural engineers, geomorphologists, and hydrologists could also be used to extend the approach. Valuable information of this kind is now beginning to accumulate in several countries and is published in such outlets as the Journal of Soil and Water Conservation in India, the Interafrican Soils Conference, and the Soils Bulletins of FAO. Battawar and Rao (1969), for example, have evaluated the trend of C values through the cropping stages of several important crops in India.

Even where it is not possible to make such quantitative estimates of soil loss, it is still possible to map the distribution of erosion intensity in a region, to gain insights into the major controls, and to make predictions of the relative soil-loss rates to be expected from some change of land use. This can be done by means of an *erosion survey,* in which the degree of erosion is estimated visually on an ordinal scale, as indicated in Table 15-6. The scale could, of course, be altered to suit any regional conditions. Such a survey can be carried out rapidly over large areas with individual fields or hillslopes, or over areas of up to 100 acres classified together. At each site, other factors can be noted, such as average land gradient, drainage density, rock type, soil type, vegetation, land use, and climate. By means of a graphical portrayal or statistical analysis, the intensity of erosion in a region can be related to its controls and the results can be used to make semi-quantitative predictions of what to expect under various management alternatives. An early example of this methodology was given by Renner (1936), and in the rush to practice multiple regression analysis on two or three years of plot measurements of soil loss, the potentialities of the erosion survey for use in planning over larger areas has been neglected.

Significance of Soil Erosion

The total cost of accelerated soil erosion, either in monetary terms or in human suffering, has never been calculated and probably never could be. In the United States during the 1930's, soil erosion was recognized as a major threat to the continued productivity of the land, and a great deal of research and investment went into soil conservation. Important advances were made and the productivity of most of the nation's agricultural and grazing lands was stabilized and often increased. This was accomplished, however, with the aid of vast amounts of cheap energy and fertilizer. The effects of the rising costs of these commodities on the soil conservation program are uncertain. More recently, concern about soil erosion has shifted to