Chapter IV

SURFACE EROSION

this chapter was prepared by the following individuals:

Gordon E. Warrington
Coordinator

with major contributions from:

Kerry L. Knapp
Glen O. Klock
George R. Foster
R. Scott Beasley

CONTENTS

LIST OF EQUATIONS

LIST OF FIGURES

LIST OF TABLES

LIST OF WORKSHEETS

INTRODUCTION

Over the past 50 years, many attempts have been made to identify soil and site characteristics that can be used as parameters to quantify the amount of accelerated soil erosion on agricultural and forest lands. Most of the models that have been developed are unique to the areas where they were tested and may not be applicable to other locations. Models which estimate the movement of eroded material through a forest environment to a stream channel have not been extensively tested.

The most acceptable model that is used to estimate surface soil erosion on agricultural lands is the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965). Since this equation is not universally applicable to forest environmental conditions, attempts have been made to develop a Modified Soil Loss Equation (MSLE). To adapt the USLE to forest conditions, the cropping management factor (C) and the erosion control practice factor (P) have been replaced by a vegetation-management factor (VM) in the MSLE. Although this approach for quantifying surface soil loss on forest lands appears to be the best method at this time, it has not been extensively tested or validated on forest lands throughout the United States.

The MSLE does not quantify the amount of material that may come from gully erosion or soil mass movement. A suggested method for evaluating gully erosion is presented in appendix IV.A.

The MSLE model is one of several tools to be used when attempting to understand the effects of different management practices on a given piece of land. This erosion model provides only a long term estimate or an index of the amount of soil loss from a given site (Wischmeier 1976). It is only an estimate because: (1) A model, no matter how complex, is a representation of reality and should never be confused with reality (Bekey 1977), and (2) planning creates a model of the future, and hence is an estimate of something that has not yet occurred. However, this model can still be an effective tool for guiding management decisions by testing different approaches against an objective (such as minimizing the amount of sediment that is delivered to a stream) and evaluating the relative magnitudes of the answers.

This chapter also presents a simple graphic model for estimating the quantity of sheet and rill eroded soil material delivered from the source area to a stream channel. Although this model appears feasible for application on all forest lands, it has not been extensively tested. With additional field testing and experience, the range and nature of this model's sediment delivery factors will be modified.

Many of the techniques used to evaluate surface erosion and sediment delivery are based on subjective evaluations of land characteristics. Persons who have the responsibility for evaluating erosion and sediment delivery need a general technical background in soil science and hydrology, as well as field experience in forest management. This chapter presents charts, tables, and formulas that are needed to use the MSLE and sediment delivery index procedures. Examples are provided in both this chapter and chapter VIII to illustrate a systematic approach to quantifying surface soil erosion on forest lands.

DISCUSSION: SURFACE SOIL LOSS

GENERAL CONCEPTS OF SURFACE SOIL LOSS

Surface erosion is the wearing away of the land surface by water, wind, ice, or other geological agents. In this chapter, surface soil loss is dealt with specifically as the mechanical detachment by water of mineral soil particles and organic material from the soil surface. Other forms of erosion such as soil mass movement, piping, and gully are not covered.

The energy for soil particle detachment by water may be provided by rainfall impact and/or shear from flowing water (e.g., runoff). The impact of raindrops on an exposed soil surface breaks down the surface structure and detaches soil particles and individual aggregates from the soil. Unless the soil surface is protected in some way by a low vegetative canopy and a mineral or organic surface mulch, this raindrop and runoff energy can detach tremendous quantities of mineral and organic soil.

Detachment by raindrop impact removes soil uniformly over a broad area of exposed soil. Such soil loss may be almost imperceptible and is usually referred to as sheet or rill erosion. Raindrop splash enables thin, sheet flow to transport detached particles a short distance to areas of more concentrated water flow.

Detachment by overland flow usually occurs with small concentrations of flowing water in rills. Enough flow energy must be available so the hydraulic forces exceed the soil's resistance to detachment. Consequently, little soil detachment by water flow will occur on areas with thin sheet flow, near ridge tops, on very flat slopes, or where surface runoff rates are low.

The separation of surface erosion into rill and sheet components is conceptually useful. Sheet erosion is a product of either raindrop impact or sheet flow and is relatively uniform over the surface. This distinction is important in determining the type of control strategy that might be used (see "Chapter II, Control Opportunities"). If it can be demonstrated that rill erosion is the primary contributor to the surface erosion total, then the control strategy would be directed toward dealing with overland flow as an eroding agent. Such a strategy would vary somewhat both in scope and in general approach from one designed to deal with erosion from raindrop impact or sheet flow.

Further discussion on surface erosion concepts may be found in articles by Bennett (1934), Bennett (1974), Cruse and Larson (1977), Ellison (1947), Foster and Meyer (1975), Guy (1970), Horton (1945), Meyer and others (1975 and 1976), and Smith and Wischmeier (1962).

Detachment By Raindrop Impact

Three principal factors affect the amount of soil detached by raindrop impact. The first factor is the interception of rainfall by the overstory or tree canopy. Dohrenwend (1977) reports that overstory canopies are not likely to protect the forest floor from the erosive impact of raindrops. In some cases raindrop energy is amplified by the canopy when the intercepted water falls as larger drops (Chapman 1948, Trimble and Weitzman 1954). The second factor is interception by the understory. The rainfall energy transmitted through the overstory canopy may be intercepted by an understory canopy — of shrubs, herbs or grass — growing near the surface. The amount of energy reduction, if any, depends upon drop size and fall distance (Dohrenwend 1977). In a natural forest the surface is protected by a third factor, a mat of litter consisting of leaves, needles, and other organic debris accumulated from the overstory and understory canopies. This litter mat absorbs a great deal of the energy reaching the soil surface. If the depth of the litter mat exceeds the penetration depth of the raindrops, it is assumed that no mineral soil will be detached (Simons and others 1975). The net effect of the three layer screen — overstory canopy, understory canopy, and litter — can be a reduction of rainfall impact energy to very near zero at the soil surface.

The litter layer and organic material in contact with the soil will contribute the greatest erosion protection. Reduction of precipitation energy by the overstory canopy is not generally considered to be significant. The overstory plays a greater, though less direct, role by replenishing the litter.

Detachment By Surface Runoff

Any surface runoff that may occur in the natural forested environment generally moves over the soil below the litter layer. The rate of energy expended for this flow is low because water moves through litter at a lower velocity than it would over the surface of bare ground. Consequently, the detachment energy of the water flow and thus the quantity of soil that is detached, both become very low where good litter cover is present.

Where the litter layer is removed or the soil is compacted, the infiltration rate is decreased. This allows a given volume of rainfall to produce a greater proportion of overland flow than would otherwise occur, and more runoff energy is available to be expended on the soil surface.

Environmental Changes Created By Silvicultural Activities Which Affect Surface Soil Loss Potential

In the natural forest environment, soil loss from sheet and rill erosion is usually small. Only when the natural environment is disturbed by logging, road building, fires, or unusual activities, does soil loss increase (Fredriksen 1972) and become a major source of non-point pollution. The environmental changes due to silvicultural activities that are discussed on the following pages often result in increased soil loss due to destruction of the natural protective soil cover, exposure and disturbance of the soil surface, and/or increased runoff.

Reduction of the overstory canopy. — The primary silvicultural activity is felling and logging. Reduction of the overstory canopy decreases rainfall interception and may either cause an increase or decrease in rainfall energy reaching the ground surface, depending on the nature of the storm and characteristics of the canopy. There is some indication that rainfall energy under hardwood canopies may be greater than under conifer canopies (Swank and others 1972, Trimble and Weitzman 1954). If particular canopies intercept and coalesce water droplets, then removal of these canopies could result in lower rainfall energy at the ground surface.

Removal or alteration of understory. — Silvicultural activities often remove or seriously alter the understory vegetation when the objective is to eliminate vegetative competition to promote the regrowth of timber. The result of brush removal is a net reduction in the effectiveness of the understory to intercept precipitation. When this interception value is lost, the rainfall energy moves closer to the ground surface.

Disturbance of the litter layer. — The litter layer, probably the most important factor in the forest environment for absorbing rainfall energy, is subject to damage by forest management activities, such as logging. In cases where logs are dragged repeatedly over the same area, the litter layer may be destroyed and bare mineral soil exposed. Where the litter layer is shallow, the amount of exposed mineral soil may be great. Furthermore, planting and site preparation, designed to favor the establishment of trees, may involve destruction of the protective litter layer. Burning for site preparation may consume the litter layer and expose mineral soil, especially if the fuel is heavy and/or the site is dry. Other activities, such as raking or piling slash, also tend to destroy the litter layer and expose large quantities of mineral soil. The overall effects of these activities are elimination of protective material covering the mineral soil, and soil compaction, which affects the infiltration and erodibility properties of the soil surface.

Creation of bare soil areas. — In addition to the possible changes within felling and logging units, machine-construction of areas such as roads (required to access and remove the timber) and landings can expose extensive areas of mineral soil. These constructed areas usually have few rainfall intercepting surfaces above the soil and are frequently the major source of erosion produced sediment.

Creation of channels. — Using heavy equipment and skidding logs across the soil surface creates ruts, gouges, or channels. When water is collected and concentrated in these channels, flow energy and erosion potential are greater than if an equal amount of water were dispersed over the entire slope area.

Creation of hydrophobic conditions from fire. An extremely hot fire will consume essentially all of the overstory foliage, understory vegetation, and surface litter layer leaving the soil surface exposed to the rainfall energy of future storms. If the soil is coarse textured, it may become hydrophobic following intense burning, i.e., shedding water as runoff rather than allowing infiltration to occur. A hydrophobic soil condition frequently occurs when volatile organic compounds condense on cooler subsurface soil particles during burning and, thereby, leave a thin waxy surface that resists wetting. Since soil non-wettability can increase surface runoff, greater flow energies are available for soil particle detachment and transport.

Creation of other situations. — Soil mineralogy can promote non-wettability in some cases. For example, soils with high amounts of volcanic ash become hydrophobic if they become very dry. Soil microorganisms often create barriers to water infiltration during dry periods. Although these organisms, such as lichens, may protect the soil against erosion, the additional runoff may contribute to soil loss elsewhere on the slope.

PROCEDURAL CONCEPTS: ESTIMATING SURFACE SOIL LOSS

This section discusses the concepts necessary for estimating surface soil loss and for evaluating the individual parameters involved. It is organized according to a conceptual understanding of surface soil loss and corresponds to the flow chart (fig. IV.1).

An outline of the overall procedure for estimating sediment delivery to a stream from surface erosion sources is presented in "The Procedure" section of this chapter. A detailed example for estimating surface soil loss is provided in "Chapter VIII: Procedural Examples." All concepts discussed here are necessary for using the overall procedure.

Two different approaches are recognized by agricultural and forest scientists for estimating surface soil loss. The first of these is an empirical approach — predictive equations developed from analyses of data. The second is the use of process models — models developed through an analysis of cause and effect relationships. Although process models may ultimately be a more flexible tool producing more accurate answers over a wider range of conditions that can be obtained from empirical models, they are still in the development stage. In addition, process models often require more data than are generally available. For these reasons, process models are not recommended as tools for predicting soil loss within the forest environment.

This chapter presents an empirical procedure for estimating soil loss and adapts it to specific silvicultural problems. The Universal Soil Loss Equation (USLE), originally developed by Wischmeier and Smith (1965) for use on midwest agricultural soils, has been modified for use in forest environments. The cropping management (C) factor and the erosion control practice factor (P) used in the USLE have been replaced by a vegetation-management (VM) factor to form the Modified Soil Loss Equation (MSLE). The following discussion of MSLE and its various factors is based on discussions in "Agricultural Handbook 282" (Wischmeier and Smith 1965) and "Upslope Erosion Analysis" (Wischmeier 1972).

The modified soil loss model (MSLE) is:

$$A = R\ K\ L\ S\ VM \qquad \text{(IV.1)}$$

where:

- A = the estimated average soil loss per unit area in tons/acre for the time period selected for R (usually 1 year.) It is not intended to reflect climatic extremes of a given year.
- R = the rainfall factor, usually expressed in units of the rainfall-erosivity index, EI, and evaluated from the iso-erodent map, figure IV.2 (U.S. Department of Agriculture, Soil Conservation Service 1977).
- K = the soil-erodibility factor, is usually expressed in tons/acre/EI units for a specific soil in cultivated continuous fallow tilled up and down the slope.
- L = the slope length factor is the ratio of soil loss from the field slope length to that from a 72.6-foot (22.1 m) length on the same soil, gradient cover, and management.
- S = the slope gradient factor, is the ratio of soil loss from a given field gradient to that from a 9-percent slope with the same soil, cover, and management.
- VM = the vegetation-management factor, is the ratio of soil loss from land managed under specified conditions to that from the fallow condition on which the factor K is evaluated.

Numerical values for each of the factors have been determined from research data. These values may differ somewhat from one field or locality to another; however, approximate numerical values for any site may be estimated using figures and tables present in this chapter or in the example in chapter VIII.

The MSLE procedure can be used as a guide for quantification of potential erosion of different land management strategies *only* if the principle interactions on which the equation is based are thoroughly understood. Failure to understand the equation and its background will lead to misuse and/or invalid interpretation. Each MSLE factor is discussed on the following pages to clarify the assumptions of the model. If the assumptions do not represent the actual processes in the forest environment, then predicted erosion values will not be the same as actual erosion. The MSLE model may be used to compare effects of different land uses on soil loss if the assumptions used for evaluating each factor in the MSLE do not change with changing land uses.

The Rainfall Factor, R

Wischmeier and Smith (in press) reports that the function of the rainfall factor, R, is to quantify the interrelated erosive forces of rainfall and runoff that are a direct and immediate consequence of rainstorms. It reflects all erosive rains occurring throughout the year in addition to annual maxima.

Since the rainfall factor, R, represents an average annual value, the MSLE estimates average annual soil loss. Soil loss estimates should not be made for specific storms or specific time periods without modifying the R factor to include a runoff variable and using other MSLE values appropriate for the specific events. Even then, soil loss estimates for specific events are subject to much greater error than estimates of average annual soil loss.

Energy-Intensity Values, EI

Factor R is based on a rainfall energy-intensity, EI, parameter which is linearly proportional to soil loss when all other factors are held constant (Wischmeier 1972).

The iso-erodent map (fig. IV.2) presents average annual EI values for the contiguous United States. The lines on the map join points with the same erosion-index value (which implies equally erosive average annual rainfall) and are called iso-erodent lines. The value of R in erosion units per year along each iso-erodent is the value of R in the erosion equation.

The average and the maximum storm values at a particular location will vary widely from year to year. An analysis of rainfall records at 181 stations indicated that maximum storm values tend to follow log-normal frequency distributions that are usually well defined by continuous records of from 20 to 25 years (Wischmeier and Smith in press).

EI is an interaction term that reflects the combination of raindrop splash erosion and runoff detachment of soil particles from bare soil. The sum of computed storm EI values for a given time period is a numerical measure of the erosivity of all the rainfall within that period. The rainfall erosion index at a particular location is the longtime-average yearly total of the storm EI values. The storm EI values reflect the interrelations of significant rainstorm characteristics. Summing these values to compute the erosion index adds the effect of the frequency of erosive storms within the year.

Increases in rainfall energy due to driving winds were not included in the rainfall factor (Wischmeier and Smith 1958, 1965). Megahan (1978) suggests that wind can increase rainstorm erosion by as much as one order of magnitude because the force vector of wind increases with the sin of the slope angle. Therefore, on steep slopes wind becomes an important factor.

Determining The Rainfall Factor

R is the number of erosion index units occurring in an average year's rainfall for a site and may either be computed or taken from a prepared map (fig. IV.2).

It is defined as:

$$R = \frac{EI}{100} \qquad \text{(IV.2)}$$

where:

- E = the total kinetic energy in foot-tons/acre inch of rain for each storm. For a storm to be included, it must be greater than 0.5 inches (12.7mm) and be separated from other storms by more than 6 hours.
- I = the maximum 30-minute intensity in inches/hour for the area, over the same time period used for estimating soil loss.

The EI value for any particular rainstorm can be computed from recording rain gage data with the help of a rainfall energy table published by Wischmeier and Smith (1958).

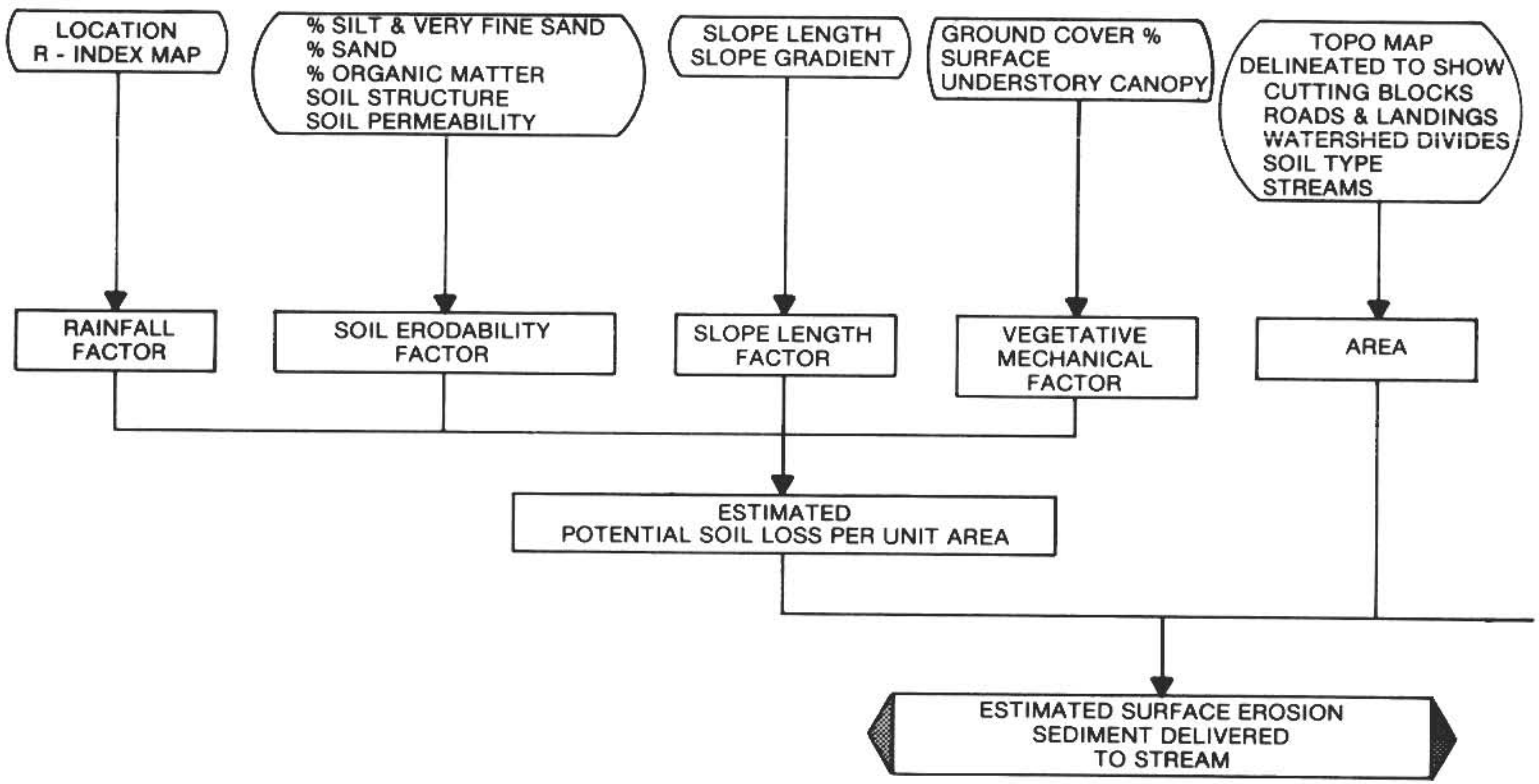


Figure IV.1.—Flowchart of the procedural concepts involved in estimating sediment delivery from surface erosion sources.

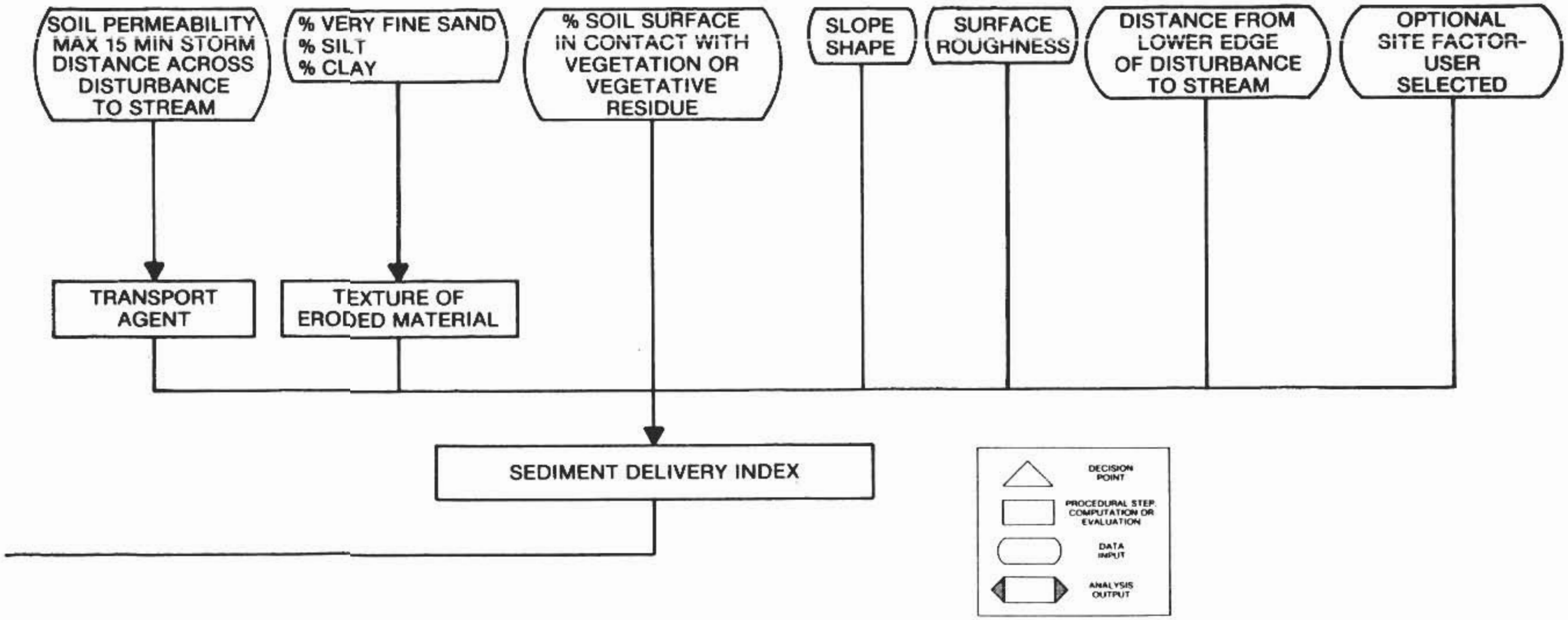


Figure IV.1.—Flow chart of the procedural concepts involved in estimating sediment delivery from surface erosion sources — continued.

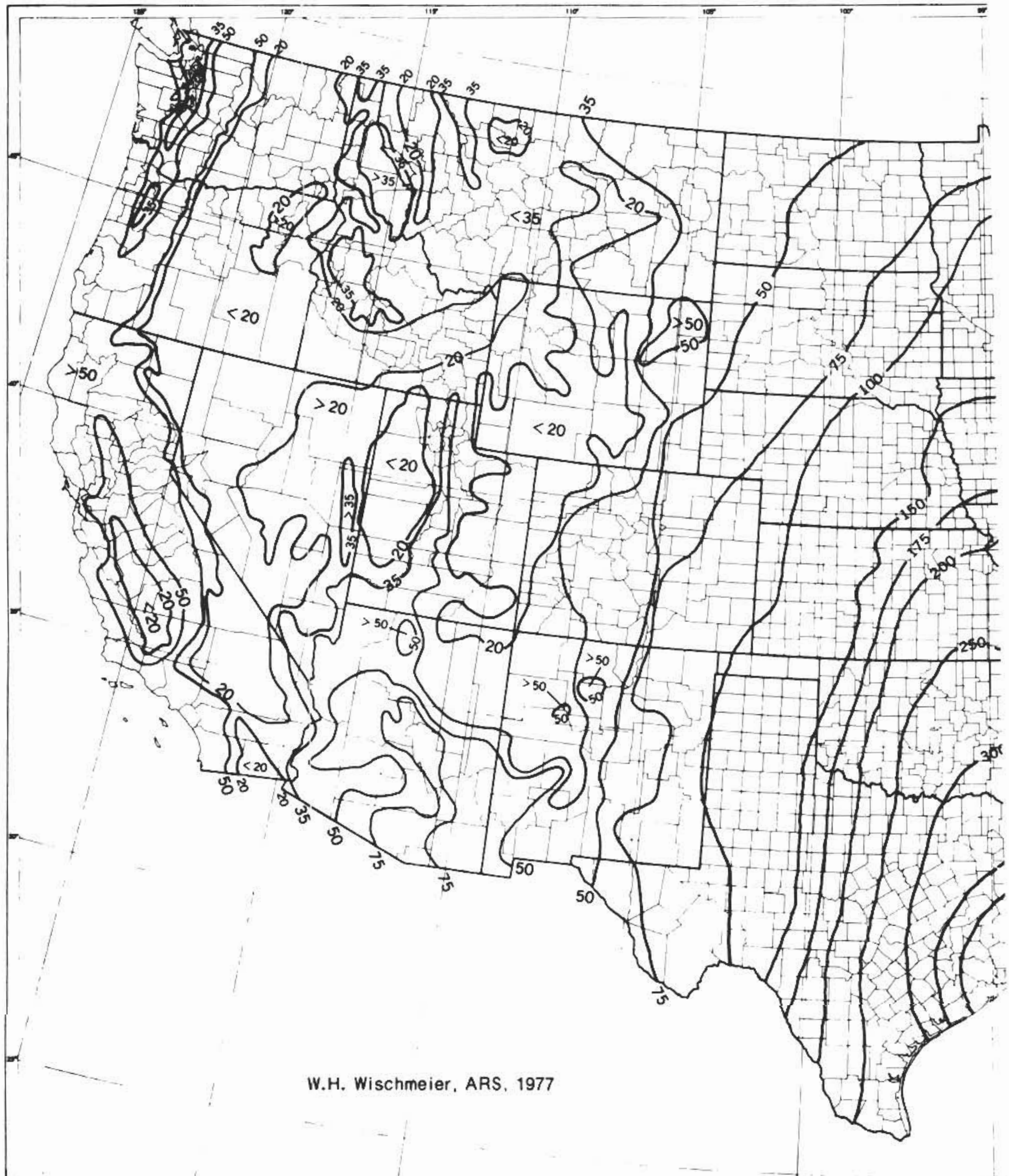


Figure IV.2.—Iso-erodent map illustrating average annual values of the rainfall factor, R.

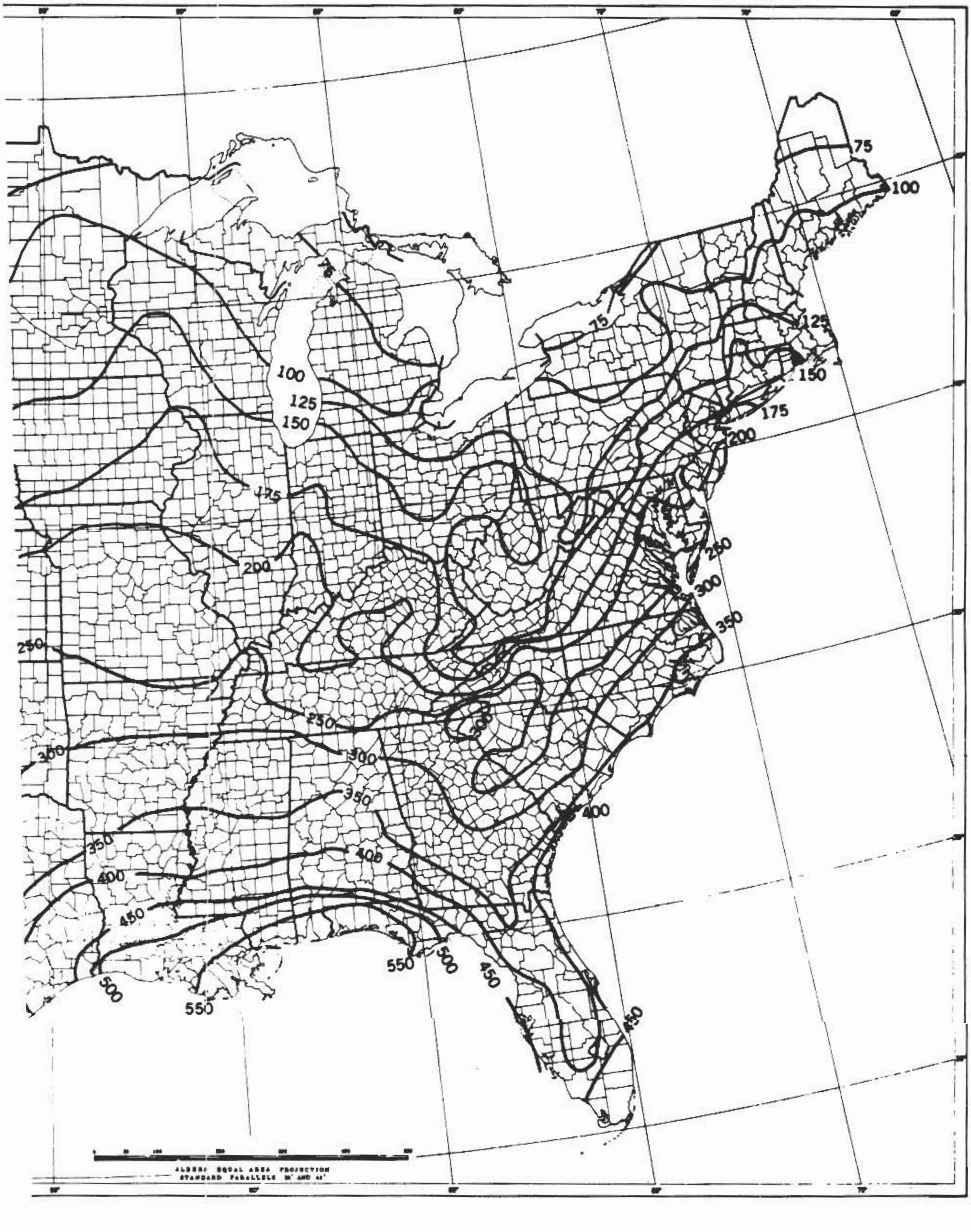


Figure IV.2.—Iso-erodent map illustrating average annual values of the rainfall factor, R — continued.

Research exploring the drop size and terminal velocity of various storm events (Gunn and Kinzer 1949, Laws and Parsons 1943) led to derivation of an equation for E in terms of the intensity of the storm in foot-tons/acre inch as (Wischmeier and Smith 1958):

$$E = 916 + 331 \log_{10} i \qquad (IV.3)$$

where:

E = storm kinetic energy in foot-tons/acre inch

i = the intensity of the storm in inches/hour

An optional method of determining R requires rain gage data from sites which have 30-minute rainfall records available. Using equation IV.3 and rainfall data, calculate the E value for each storm. Using equation IV.2 and rainfall data, calculate R.

The more commonly used method for determining R is to take locational values of the rainfall factor, R, directly from the iso-erodent map (fig. IV.2) (USDA, Soil Conservation Service 1977). The iso-erodent map shows R values ranging from <20 to 550. The erosion index measures **only** the effect of rainfall when separated from all other factors that influence erosion. Points lying between the indicated iso-erodents may be approximated by linear interpolation.

If all soil and topography factors were exactly the same everywhere, average annual soil losses from plots maintained in continuous fallow, tilled up and down the slope, would differ in direct proportion to the erosion-index values. This potential difference is, however, partially offset by differences in soil, topography, vegetal cover, and surface litter. On fertile soils in the high rainfall areas of the United States, good vegetal cover protects the soil surface throughout most of the year; heavy plant residues, where present, provide excellent ground cover during the dormant season. In the regions where the erosion index is extremely low, good ground cover is often limited to a relatively short period of time. Natural soil erosion may occur both in semiarid regions because of poor ground cover, and in humid regions (with good ground cover) due to high precipitation.

R Values For Thaw And Snowmelt

Wischmeier and Smith (in press) have observed that, in the Pacific Northwest, up to 90 percent of the erosion on the deep loess agricultural soils has been associated with surface thaws and snowmelt runoff. This type of erosion is not accounted for by the rainfall erosion index, but it occurs frequently both in the northwest and in portions of the central western states. With this erosion, the linear precipitation relationship would not account for peak losses in early spring since as the winter progresses, the soil becomes increasingly more erodible. As the soil moisture profile is filled by winter precipitation, the surface soil structure breaks down by repeated freezing and thawing, resulting in puddling, surface sealing and a reduction in infiltration. Additional research on the erosion processes and means of erosion control during snowmelt runoff is needed.

Until research designs a more acceptable method of calculating erosion indices, Wischmeier and Smith (in press) suggest that the early spring erosion by runoff from snowmelt, thaw or light rain on frozen soil may be used in the soil loss computations by adding a subfactor, R_s, to the erosion index to obtain the R factor. Investigations with only limited data indicate that the best estimate of R_s may be obtained by taking 1.5 times the local, December through March, precipitation, measured as inches of water. For example, a location in the northwest that has an erosion index of 20 (fig. IV.2) and averages 12 inches (304.8mm) of precipitation between December 1 and March 31 would have an estimated average annual R factor of [1.5(12) + 20] or 38.

Snowmelt runoff erosion may also be a significant factor in the northcentral and eastern states, particularly on loessal soils. Where experience indicates that this type of runoff exists, it should be included in factor R evaluation.

The Soil Erodibility Factor, K

The term "soil erodibility" is distinctly different from "soil erosion." The rate of soil erosion, designated by 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. This difference in soil erosion, due only to soil properties, is referred to as soil erodibility.

The physical properties of the soil, as they relate to the inherent susceptibility of that soil to erode, are discussed in soil science literature (Barnett and Rogers 1966, Browning and others 1947, Lillard and others 1941, Middleton and others 1932, Olsen and Wischmeier 1963, Peele and others 1945, Wischmeier and Mannering 1967). Wischmeier and

Mannering (1969) developed an empirical expression of soil erodibility as a function of 15 soil properties and their interrelationships. Their equation, however, appeared to be too complex and demanding for general use, and the soil erodibility factor was later redefined in terms of five soil properties.

Soil characteristics that influence soil erodibility by water are: (1) those that affect the infiltration rate, permeability, and total water-holding capacity, and (2) those that resist the dispersion, splashing, abrasion, and transporting forces of the rainfall and runoff (Adams and others 1958). A number of attempts have been made to determine criteria for characterizing soils according to erodibility (Lillard and others 1941, Middleton and others 1932, Peele and others 1945, Smith and Wischmeier 1962). Generally, however, soil classifications used for erosion prediction have been largely subjective and have led only to relative rankings.

The relative erosion hazard (erodibility) of different soils is difficult to judge from field observations. Even soils with a relatively low erodibility factor may show signs of serious erosion under certain conditions, such as on long or steep slopes or in localities having 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, length and degree of slope, and vegetative cover management are accounted for in the MSLE equation by the symbols R, L, S, and VM. The soil-erodibility factor, K, is evaluated independently of the effects of the other factors and will vary depending on the intrinsic properties of the soil.

Original values of the soil-erodibility factor, K, in the MSLE were determined experimentally for agricultural lands. A standard plot for determining K experimentally is 72.6 feet (22.1m) long with a uniform lengthwise slope of 9 percent, in continuous fallow, tilled up and down the slope. Continuous fallow, in this case, is land that has been tilled and kept free of vegetation for a period of at least 2 years or until prior crop residues have decomposed. 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 vegetal growth or serious surface crusting. This provides a reproducible soil surface condition.

When **all** of these conditions are met, each of the factors, L, S, and VM, has a value of 1.0 and K equals A/EI, where A is the soil loss per unit area (tons/yr) and EI is the erosion index.

For a particular soil, K is the rate of erosion per unit of erosion index from standard plots on that soil. Conditions selected as unit values in the USLE represent the predominant slope length and the median gradient on which past erosion measurements in the United States were made. It is not known if a K factor determined in this manner is completely appropriate for use on forest soils. Until research clarifies this point, K will have to be used on the basis of its original derivation.

Direct measurements of K on replicated standard plots reflect the combined effects of all the variables that significantly influence the ease with which a soil is eroded by rainfall and runoff. To evaluate K for soils that do not usually occur on a 9-percent slope, soil loss data from plots that meet all other specified conditions should be adjusted to a 9-percent slope by means of the slope factor in the Universal Soil Loss Equation (Wischmeier 1972).

Determining The Soil Erodibility Factor

Both the equation and nomograph (fig. IV.3) (Wischmeier and others 1971) for determining K values are discussed. The nomograph can be used for all soils; however, the given equation is limited as described below.

Soil erodibility equation. — Solution of the soil erodibility equation is possible with data normally available from standard soil profile descriptions and routine laboratory analysis. The equation should not be used with soils having more than 70 percent silt and very fine sand or with soils having a low clay content because beyond 70 percent, equation IV.4 no longer fits the nomograph curve. The equation for soil erodibility is:

$$K = (2.1 \times 10^{-6})(12 - Om)(M^{1.14}) + 0.0325(S-2) + 0.025(P-3) \qquad (IV.4)$$

where:

K = soil erodibility factor used in the MSLE.

Om = percent organic matter; if organic matter is >4%, use 4%.

M = particle size parameter: [percent silt (100 − % clay)] where very fine sand (0.05-0.1 mm) is included in the silt fraction.

S = code for soil structure:

Soil Structure Class	MSLE Code
very fine granular	1
fine granular	2
medium or coarse granular	3
blocky, plately, or massive	4

P = Code for Soil Conservation Service permeability classes.
These are for the soil profile as a whole (Wischmeier and others 1971), based on estimated water flow in inches/hour through saturated, undisturbed cores under ½-inch head of water (U.S. Department of Agriculture, Soil Conservation Service 1974):

Permeability class	Permeability rates *in/hr*	MSLE Code
very slow	<0.06	6
slow	0.06-0.2	5
slow to moderate	0.2 -0.6	4
moderate	0.6 -2.0	3
moderate to rapid	2.0 -6.0	2
rapid	>6.0 -20.0	1

General permeability classification guides and discussion from the USDA Soil Survey Manual are presented to help determine the appropriate permeability classification. Soil permeability is that quality of the soil that enables it to transmit water or air. It can be measured quantitatively in terms of rate of flow of water through a unit cross section of saturated soil in unit time, under specified temperature and hydraulic conditions. Percolation under gravity with a ½-inch head and drainage through cores can be measured by a standard procedure involving presaturation of samples. Rates of percolation are expressed in inches per hour.

In the absence of precise measurements, soils may be placed into relative permeability classes through studies of structure, texture, porosity, cracking, and other characteristics of the horizons in the soil profile in relation to local use experience. The observer must learn to evaluate the changes in cracking and in aggregate stability with moistening. If predictions are to be made of the responsiveness of soils to drainage or irrigation, it may be necessary to determine the permeability of each horizon and the relationship of the soil horizons to one another and to the soil profile as a whole. Commonly, however, the percolation rate of a soil is set by that of the least permeable horizon in the solum or in the immediate substratum.

The infiltration rate, or entrance of water into surface horizons, or even into the whole solum, may be rapid; yet permeability may be slow because of a slowly permeable layer directly beneath the solum that influences water movement within the solum itself. The rate of infiltration and the permeability of the plow layer may fluctuate widely from time to time because of differences in soil management practices, kinds of crops, and similar factors (U.S. Department of Agriculture, Soil Survey Staff 1951).

Some guides for using the permeabililty codes are: (1) fragipan soils fall into category 6; (2) soils with surface permeability underlain by massive clays or silty clays should be coded 5; (3) silty clay or silty clay loam soils having a weak angular or subangular blocky structure and moderate surface permeability should be coded 4; (4) if the subsoil structure remains moderate or strong, or texture is coarser than silty clay loam, the code should be 3; and (5) if the soil remains open, does not form surface seals, and the profile does not restrict intake, the code should be 1 or 2.

Soil erodibility nomograph for factor K. — Equation IV.4 is based on the nomograph with one exception — the relationship for K changes when the silt-very fine sand fraction exceeds 70 percent. This change is not included in the equation, but is incorporated into the nomograph (fig. IV.3). Instructions for use of the nomograph are included in the figure.

In certain situations, improved K values may be obtained by using the following suggestions:

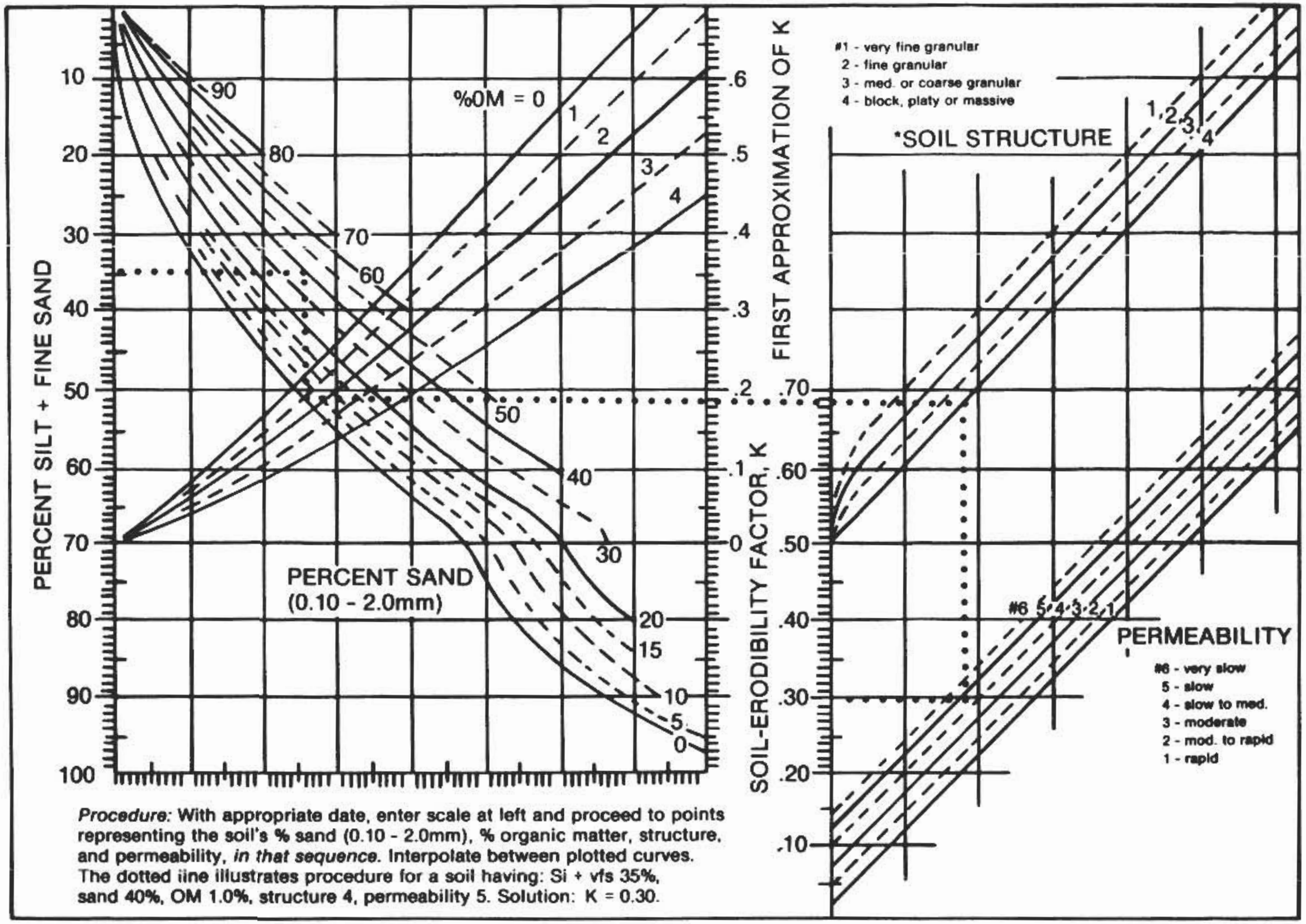
1. For claypans and fragipans, it may be desirable to use separate erodibility factors for dry and wet seasons by using different permeability ratings in the nomograph. Permeabilities should be reduced in wet seasons, but not for thunderstorms during the dry season (Wischmeier and others 1971). Weighted annual mean erodibility factors for wet and dry seasons can be computed as follows:

$$K = \frac{(K_w M_w + K_d M_d)}{M_w + M_d} \qquad \text{(IV.5)}$$

where:

K = weighted mean erodibility,

K_w = soil erodibility during wet season,



Procedure: With appropriate date, enter scale at left and proceed to points representing the soil's % sand (0.10 - 2.0mm), % organic matter, structure, and permeability, *in that sequence*. Interpolate between plotted curves. The dotted iine illustrates procedure for a soil having: Si + vfs 35%, sand 40%, OM 1.0%, structure 4, permeability 5. Solution: K = 0.30.

Figure IV.3.—Nomograph for determining the soil erodibility factor, K.

M_w = number of wet months with erosive rainfall and/or snowmelt runoff,

K_d = soil erodibility during dry season,

M_d = number of dry months with erosive rainfall and/or snowmelt runoff,

2. Large surface material, such as gravel, is not included in K value determinations, but rather is a part of the vegetation-management factor (VM) as it relates to mulch or ground cover.
3. High clay subsoils containing iron and aluminum oxides react differently than surface soils containing those oxides (Roth and others 1974). In this situation the nomograph solution for K may not apply (Wischmeier 1976).

The Soil Conservation Service has determined K factor values for some soils. Information about these tables should be obtained from Soil Conservation Service soil scientists who are familiar with the soils in a given area.

The Topograhic Factor For Slope Length and Gradient, LS

The rate of soil erosion by water is affected by both slope length and slope gradient (percent slope). The two effects are represented in the erosion equation by L and S, respectively. In field application of the equation, however, it is convenient to consider the two as a single topographic factor, LS, because of the interactions between the two parameters.

Slope Length Factor, λ

Slope length is defined as the distance from the point of origin of overland flow to: (1) the point where the slope decreases to the extent that deposition begins; (2) the point where runoff enters a well-defined channel that may be part of a drainage network or a constructed channel such as a terrace or diversion (Wischmeier and Smith 1965); or (3) the downslope boundary of a disturbance. A change in land use on a slope does not change the effective slope length unless the runoff from the upper slope is diverted off of the area in some manner.

Numerous plot studies (Wischmeier 1966) have shown that soil loss in tons/unit area is proportional to some power of slope length. Since the factor L is the ratio of soil loss from the slope length of interest to that from a standard 72.6-foot(22.lm) slope, the value of L may be expressed as:

$$L = (\lambda/72.6)^m \qquad \text{(IV.6)}$$

where:

λ = slope length in feet, and

m = 0.2 for slope gradients that are ≤1.0%

m = 0.3 for slope gradients >1.0 but≤3.0%

m = 0.4 for slope gradients >3.0 but ≤5.0%

m = 0.5 for slope gradients that are >5.0%

m = 0.6 for slope gradients over 12% with a natural permeability code of 5 or 6 where infiltration is very low, such as on construction sites and roads (Wischmeier and Smith in press).

The effect of slope length on soil loss is due primarily to a greater accumulation of runoff on longer slopes. Runoff velocity increases as water volumes increase, and both detachment and transport capacity increase geometrically with increased velocity (Wischmeier 1972).

The exponent m is significantly influenced by the interaction of slope length and gradient, but it may also be influenced by soil characteristics, type of vegetation, and management practices. Generally, increases in slope gradient, slope length, or increases in runoff (due to reduced infiltration caused by either soil type or vegetation-management practices) create a need for a larger slope length exponent (m) in equation IV.6 (Foster and others 1977).

Slope Gradient Factor, S

A. W. Zingg (1940) concluded that soil loss varies as the 1.4 power of percent slope. Musgrave (1947) recommended use of the 1.35 power of percent slope. Based on analyses of the data, Smith and Wischmeier (1957) proposed the relationship:

$$S = \frac{(0.43 + 0.30s + 0.043s^2)}{6.613} \qquad \text{(IV.7)}$$

where:

s = slope gradient expressed as percent slope, and

S = slope gradient factor.

The data adequately support this slope relationship up to a 20 percent slope. Since the equation is parabolic, slope relationships cannot be extrapolated indefinitely beyond gradients of 20 percent and still obtain accurate estimates of soil loss from the MSLE. However, the MSLE may be used on slopes over 20 percent to compare the soil loss effects of several different management activities.

Determining The Topographic Factor

The LS factor is the expected ratio of soil loss/unit area (tons/yr) on a slope as compared to a corresponding soil loss from the standard plot (9-percent slope, 72.6 feet (22.1 m) long). For specific combinations of slope length and slope gradient, this ratio may be taken directly from a length-slope nomograph (fig. IV.4). For example, a 10-percent slope that is 360 feet (109.7 m) long would have an LS ratio of 2.6.

Values of LS for slope gradients and lengths not shown on the nomograph may be computed using the following equation. A correction factor has been added to equation IV.7 to avoid using sines of angles.

$$LS = \left(\frac{\lambda}{72.6}\right)^m \left(\frac{0.43 + 0.30s + 0.043s^2}{6.613}\right) \left(\frac{10{,}000}{10{,}000+s^2}\right) \quad \text{(IV.8)}$$

s = slope gradient in percent, and

m = an exponent based on slope gradient from equation IV.6.

The use of equation IV.8 or figure IV.4 assumes that the slopes are uniform from top to bottom.

Irregular Slopes

Slopes are usually convex or concave. Use of an average gradient for the entire slope length substantially underestimates soil loss from the convex slopes and overestimates the loss from concave slopes (Foster and Wischmeier 1973). If equation IV.8 or the nomograph (fig. IV. 4) is used on convex slopes, the gradient of the steeper segment should be used as the overall slope gradient for estimating the LS factor. On a concave slope, where deposition may occur on the lower end of the slope, the appropriate length and gradient to use is the point where the slope flattens enough for deposition to occur.

In cases where the slope characteristics change from top to bottom, averaging the slope characteristics and applying one LS factor will not accurately estimate soil loss. The calculations for irregular slopes (Foster and Wischmeier 1973) are recommended on areas where several slopes are combined. This equation accounts for situations where runoff comes from one slope segment and flows to the next. However, if substantial sediment deposition will occur due to a change in vegetative cover or diversion of water, this procedure cannot be used because it does not account for sediment deposition.

Foster and Wischmeier's (1973) equation is presented here, and an example of its use may be found in chapter VIII.

$$LS = \frac{1}{\lambda e} \cdot \sum_{j-1}^{n} \left[\left(\frac{S_j \lambda_j^{m+1}}{(72.6)^m} - \frac{S_j \lambda_{j-1}^{m+1}}{(72.6)^m}\right) \left(\frac{10{,}000}{10{,}000 + s_j^2}\right)\right] \quad \text{(IV.9)}$$

in which:

λe = overall slope length in feet,

j = slope segment index,

λ_j = the length in feet from the top to the lower end of any segment j,

$\lambda_{j\text{-}1}$ = total slope length above segment j,

s = slope in percent,

m = an exponent based on slope gradient from equation IV.6, and

S_j = slope factor $\frac{0.43 + 0.30s + 0.043s^2}{6.613}$ *for s^2 segment j (Eq. IV.7)*

Foster and Wischmeier (1973) developed an alternative procedure for performing several steps in the solution of equation IV.9 for irregular slopes. The set of graphs (figs. IV.5 and IV.6) eliminates the need for logarithms, a slide rule, or an electronic calculator to raise the slope length values to needed powers. These figures are a family of curves for specific slopes ranging from 0.5 percent to 140 percent. Each figure uses the appropriate value for m as previously discussed.

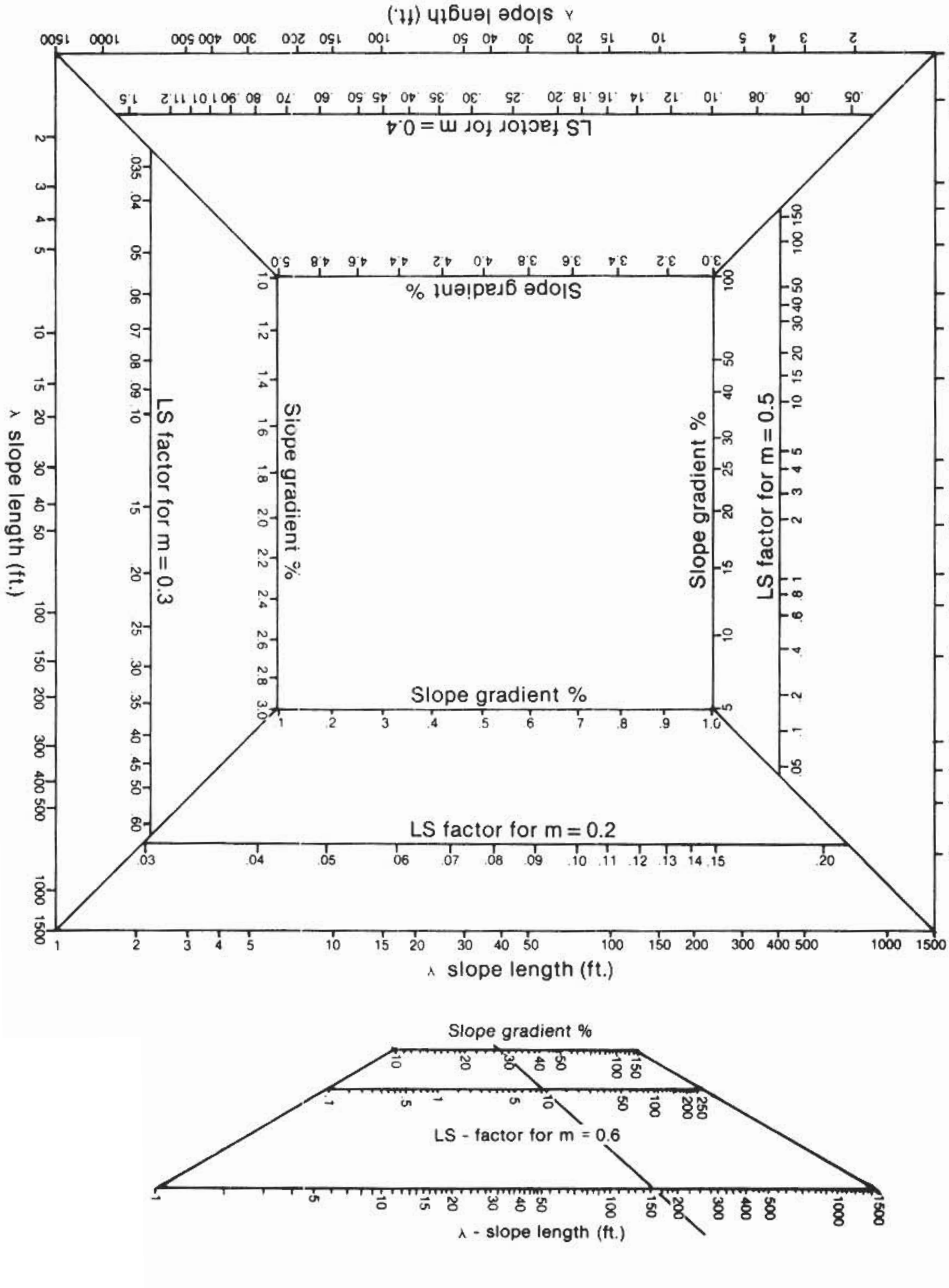


Figure IV.4.—Nomograph for determining the topographic factor, LS, on simple slopes.

The graphs (figs. IV.5 and IV.6) are based on the following equation which is a portion of equation IV.9.

$$\mu = S\left(\frac{\lambda^{m+1}}{72.6^m}\right)\left(\frac{10{,}000}{10{,}000 + s^2}\right) \qquad \text{(IV.9a)}$$

where:

- μ = derived factor for simplifying calculation of LS on irregular slopes,
- S = slope steepness factor from equation IV.7,
- s = slope gradient in percent,
- λ = slope length in feet, and
- m = an exponent based on slope gradient from equation IV.6.

The symbol μ is plotted on log-log graph paper against values of slope length with curves for specific slopes within the body of the graphs.

To illustrate the graphic procedure for obtaining the LS factor for irregular slopes, a road with cut-and-fill slopes (fig. IV.7) has been divided into segments representing the cut slope, the roadbed surface, and the fill slope. It has been assumed that sediment will not accumulate on the roadbed. The first segment (cut slope) has a slope length of 4.8 feet (1.46 m) at 66.7 percent gradient, the second segment (roadbed surface) has a slope length of 12 feet (3.66 m) at 0.5 percent gradient, and the third segment (fill slope) has a slope length of 4.8 feet (1.46 m) at 66.7 percent. The values are λ_1 = 4.8, λ_2 = 16.8, and λ_3 = 21.6 = λ_e. Data for this procedure are tabulated into table IV.1.

For the first segment, enter figure IV.6 at 4.8 on the horizontal axis, move upward to the curve for 70 percent slope (for greater accuracy, values between can be interpolated) and read μ_2 = 29 on the vertical scale. The upper end of this segment is at zero length so $\mu_2 - \mu_1$ = 29.

For the second segment, use the graph for 0.5 percent slope entering the graph with lengths of 16.8 feet and 4.8 feet. For those, μ_2 = 1, μ_1 = 0.25 and $\mu_2 - \mu_1$ = 0.75. Repeat this procedure for segment 3.

The effective LS for any segment is obtained by dividing ($\mu_2 - \mu_1$) by the length of the segment as illustrated. The overall LS value of 5.8 shown in the last column was obtained by dividing the sum of the ($\mu_2 - \mu_1$) by the total length (124.7/21.6 = 5.8). The detail provided by the last two columns of the tabulation may be helpful in designing effective erosion control practices for each segment.

These values for LS, using this graphic approach, are not exactly the same as those calculated from equation IV.9, as shown in chapter VIII. This is due to errors inherent in using graphs. Although these small errors exist, the numbers determined with the graphs are sufficiently accurate for general use.

Table IV.1.—Example of data tabulation when using graphs for obtaining LS value for irregular slopes

Segment	Slope (%)	λ_j (ft)	λ_{j-1} (ft)	μ_2	μ_1	$\mu_2 - \mu_1$	Segment Length (ft)	Segment LS
1	66.7	4.8	0.0	29	0.0	29	4.8	6.0
2	0.5	16.8	4.8	1	0.25	0.7	12.0	0.1
3	66.7	21.6	16.8	270	175	95	4.8	19.8
						124.7	21.6	5.8

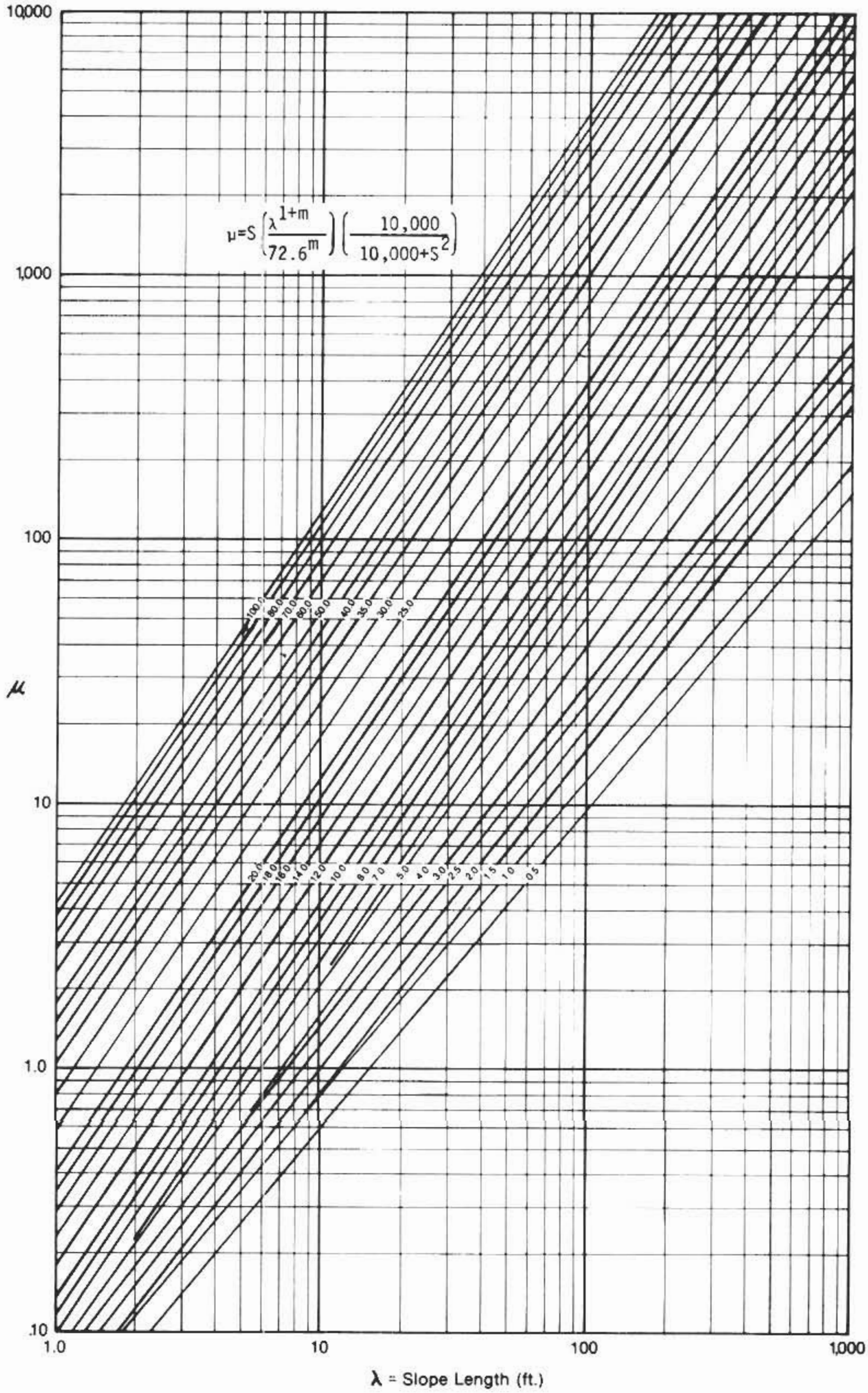


Figure IV.5.—Values of μ for use with irregular slopes (0.5 - 100%) with appropriate values of m (0.2, 0.3, 0.4, and 0.5).

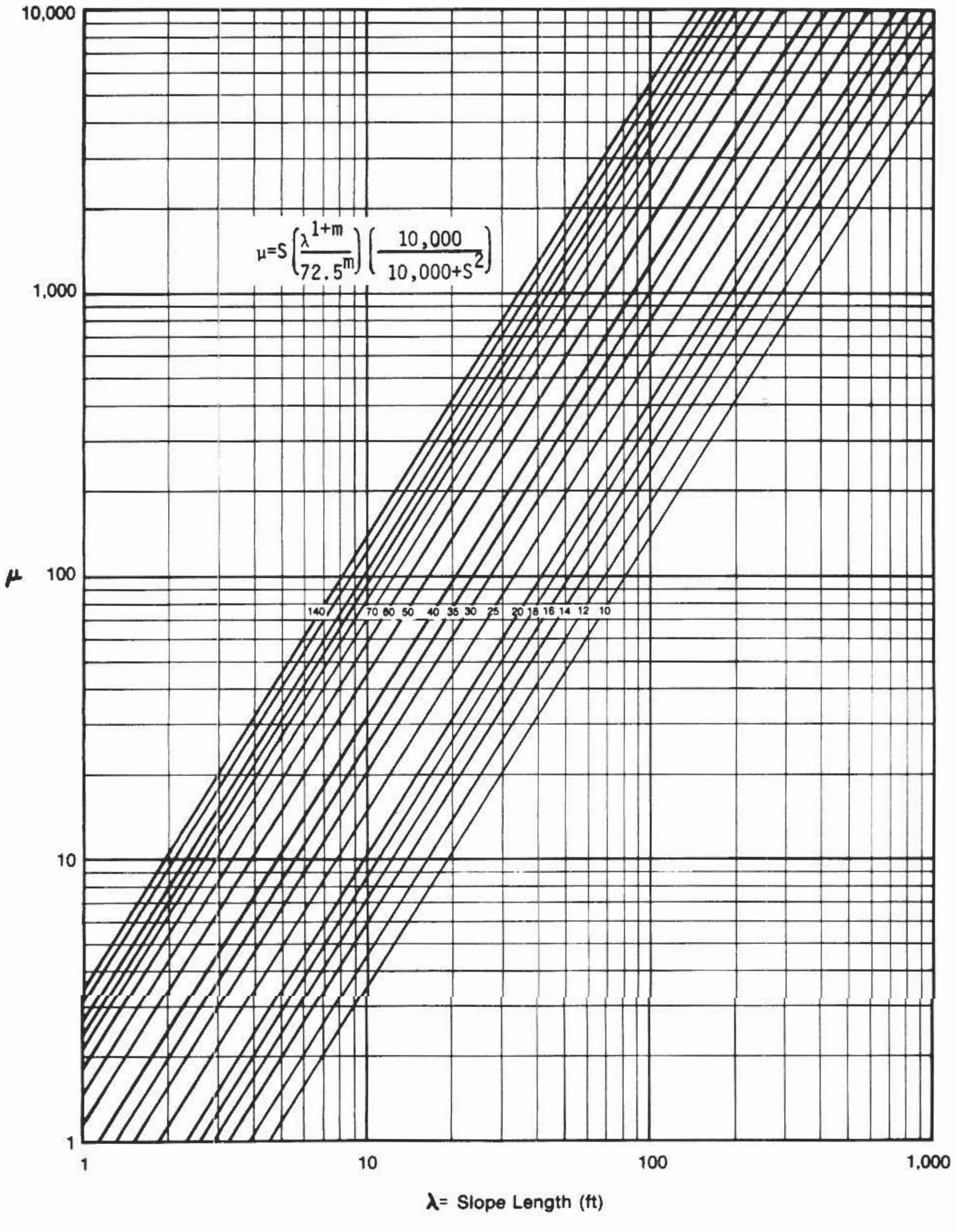


Figure IV.6.—Values of μ for use with irregular slopes (10-140%) where m = 0.6.

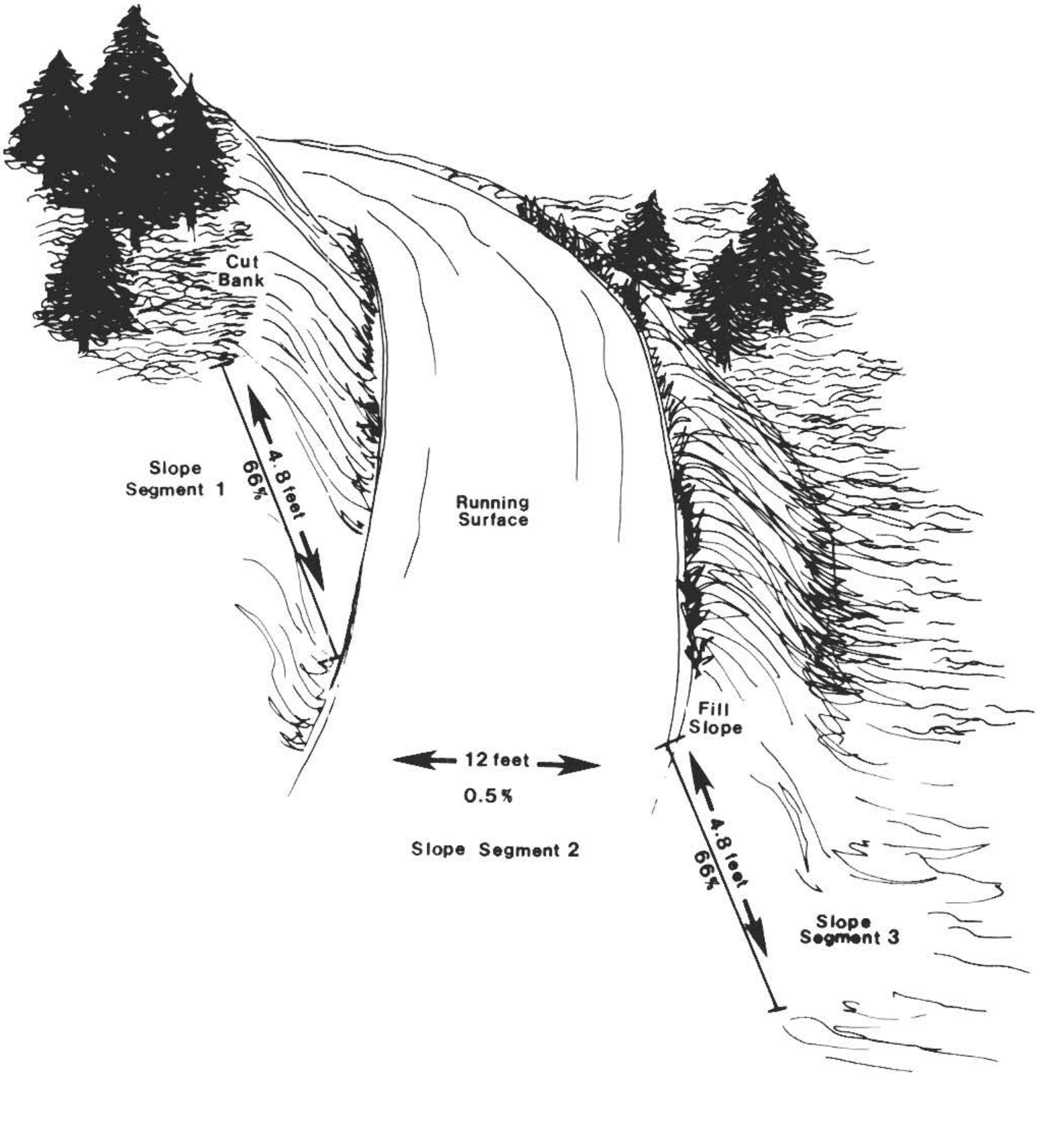


Figure IV.7.—Generalized cross section of outsloped road.

The Vegetation-Management Factor, VM

The effects of vegetative cover and forest silvicultural activities on soil detachment by rainfall and runoff are numerous and varied. Forest residues from silvicultural activities may be removed, left on the surface, incorporated near the surface, plowed under, or burned. When left on the surface, they may be chopped or they can remain as left by the harvesting operation. Seedbeds may be left rough with the capacity for surface storage of rainfall and sediment, or they can be left smooth. Different combinations of these variables and possibly other conditions will have different effects on a soil's susceptibility to erosion. In addition, the effectiveness of residue management will depend on the volume and distribution of remaining residues. This in turn depends on rainfall distribution, on the soil fertility level, and on other management decisions that affect the amount of vegetative productivity on a given site.

The VM factor in the Modified Soil Loss Equation is the ratio of soil loss from land managed under specified conditions to the corresponding loss from tilled, continuously fallow conditions of a standard plot. This factor measures the combined effect of all the interrelated cover and management variables discussed above.

Soil loss that would occur on a particular site if it were in a continuous fallow condition is computed by a product, R K L S, in the MSLE. Actual loss from an area is usually much less than the computed amount; just how much less depends on the particular stage of growth and development of the vegetal cover, and the condition of the soil surface at the time when rain or snowmelt occurs.

The VM factor of the MSLE attempts to combine vegetative cover and soil surface conditions into one numerical factor. Use of the VM factor is facilitated by separating it into three distinct kinds of effects and evaluating each type as a subfactor: Type I — effects of canopy cover, Type II — effects of mulch or close growing vegetation in direct contact with the soil surface, and Type III — residual effects of land use (Wischmeier 1975).

Effects Of Canopy Cover, Type I

Leaves and branches that do not directly contact the soil surface are effective only as canopy cover. Canopies close to the surface have some influence on the impact energy of falling raindrops. Waterdrops falling from a canopy may have appreciable force at the soil surface depending on canopy height and drop size (Dohrenwend 1977).

Figure IV.8, taken from Wischmeier (1975) shows canopy effects of water drops for different amounts of canopy ground cover and canopy heights. If possible, increase in drop size because of canopy interception is ignored, or is assumed to be offset by the fact that some of the intercepted water moves down the stems to the ground. The canopy factors for various percentages of cover at heights of 0.5, 1, 2, and 4 m may be obtained directly from figure IV.8. For a 60 percent canopy cover at a height of 1m, for example, the canopy factor is 0.58. This means that the effective EI with the canopy is only 58 percent of the actual EI of the rainfall, and the expected erosion would also be only 58 percent of that predicted by the EI obtained from the isoerodent map.

Table IV.2—Velocities (m/sec) of falling waterdrops of different sizes (mm) falling from various heights (m) in still air

Median drop diam.	Drop fall height						
	0.5	1.0	2.0	3.0	4.0	6.0	20.0[3]
2.00[1]	2.89	3.83	4.92	5.55	5.91	6.30	6.58
2.25[1]	2.93	3.91	5.07	5.74	6.14	6.63	7.02
2.50[1]	2.96	3.98	5.19	5.89	6.34	6.92	7.41
3.00[1]	3.00	4.09	5.37	6.14	6.68	7.37	8.06
3.50[2]	3.04	4.19	5.55	6.37	6.98	7.79	8.63

[1]Laws J.O. 1941. Measurement of fall-velocity of water drops and rain drops. Transactions of the American Geophysical Union 22:709-721. From Wischmeier 1975.
[2]Extrapolation of values given by Laws (1941).
[3]Values in the last column are considered terminal velocities.

Figure IV.8 is based on a medium drop size of 2.5 mm for both the rain and droplets formed on the canopy. If the 3.35 mm droplets measured by Chapman (1948) on a red pine plantation are assumed to be characteristic for most tree canopies (Trimble and Witzman 1954), figure IV.8 should be modified. When modifying, subfactor values for complete canopy cover can be computed from the data in table IV.2 below for a given diameter using equation IV.10:

$$C_{100} = 0.169V - 0.356 \qquad \text{(IV.10)}$$

where:

C_{100} = factor for canopy effect at 100 percent ground cover, and

V = velocity, in meters/second, for a water drop of a given diameter, falling a given distance.

Values for less than complete canopy cover can be found by drawing a line on figure IV.8, from the point calculated for 100 percent cover to the upper left corner where other lines are converging.

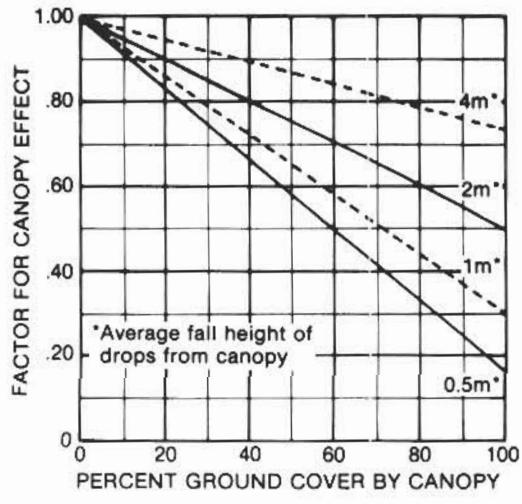


Figure IV.8.—Influence of vegetal canopy on effective EI, assuming bare soil beneath the canopy, and based on the velocities of free-falling waterdrops 2.5 mm in diameter (Wischmeier 1975).

Effects Of Mulch And Close Growing Vegetation, Type II

A mulch on the soil surface is much more effective than an equivalent percentage of canopy cover. There are two reasons for this: (1) raindrops intercepted by the mulch have very little remaining fall height to the ground, and their impact on the soil surface is essentially eliminated; and (2) a mulch that makes good contact with the ground also reduces the velocity of runoff. This, in turn, greatly reduces the runoff's potential to detach soil material.

Effectiveness of type II cover can be expressed on the basis of percent surface cover using the relationship in figure IV.9 (Wischmeier 1975). If

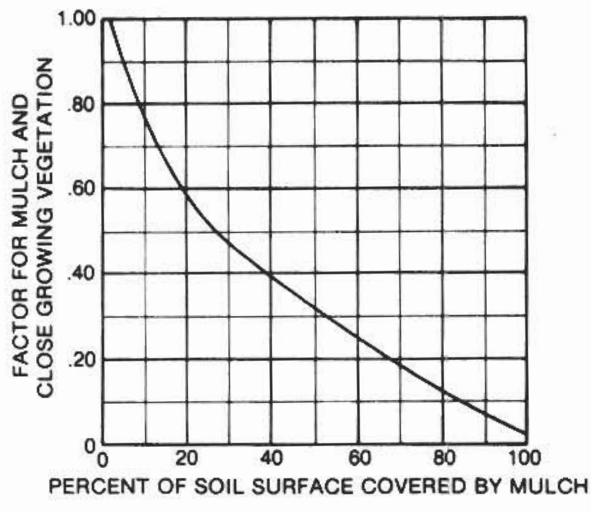


Figure IV.9—Effect of plant residues or close-growing stems at the soil surface on the VM factor *(does not include subsurface root effects)* (Wischmeier 1975).

the cover includes both canopy and surface mulch, the canopy and mulch factors overlap and the canopy factor can not be fully credited. Impact energy of a raindrop striking the mulch is dissipated at that point regardless of effects of canopy interception on its fall energy. The mulch factor is always taken at full value, and the canopy factor is reduced so that it applies only to the percentage of the soil surface not covered by mulch.

To illustrate this, assume a 30 percent mulch cover combined with a 60 percent canopy at a height of 1 m. From figure IV.9, the factor for mulch cover effect is 0.47. Because of the 30 percent mulch cover, the effective canopy cover is only 0.70 of the overall 60 percent cover, or 42 percent. Entering figure IV.8 with a 42 percent canopy cover, we obtain a factor of 0.70 for canopy effect. The factor for this combination of canopy and mulch cover is the product of the two subfactors (0.47 times 0.70), which equals 0.33.

Residual Effects Of Land Use, Type III

This category includes residual effects of the land use on soil structure, organic matter content, and soil density; effects of site preparation or lack of preparation on surface roughness and porosity; roots and subsurface stems; biological effects; and any other factors affected by land use.

Figure IV.10 (Wischmeier 1975) was developed for Type III effects on undisturbed pasture, range, forest, and idle land. The initial point (0.45) for the curves is an estimate of the long-term effect of no tillage and no vegetation. It was obtained from 10-year soil loss records on a 12 percent slope of silt loam soil that was not tilled after the first year but was kept free of vegetation and traffic. The rate of

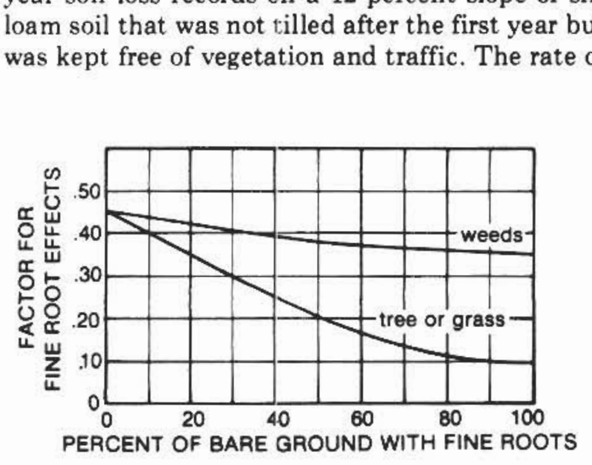


Figure IV.10.—Effects of fine roots in topsoil on the VM factor. These values do not apply to cropland and construction sites (Wischmeier 1975).

soil loss per unit of EI declined annually until it leveled off at about 45 percent of the rate for the first 2 years of the study. The curvature and end-points of the curves were based on comparisons of soil losses from meadow with those from plots having equivalent percentages of surface cover in the form of applied straw mulch.

If an area has been cultivated or totally scalped so that all of the fine roots from trees, grass, and weeds are destroyed, then the Type III effect as described does not exist.

Sediment Filter Strips

Sediment filter strips are areas of residue or other kinds of effective sediment traps. If surface areas that are completely open (having minimal amounts of residue and soil mixed with residue) are separated from each other by small filter strips, a factor of 0.5 should be included in the calculations (Wischmeier 1972). If the open areas are not separated by sediment filter strips, use a factor of 1.0 (see example in Chapter VIII).

Determining The Vegetation-Management Factor

Use either previously published values or estimate the VM factor using Type I, II and III subfactors.

Previously published tables (tables IV.3, IV.4, IV.5, and IV.6) and graphs (figs. IV.11 and IV.12) are reproduced in this chapter with specific VM values for use under some conditions. Table IV.3 applies only to construction sites (e.g., roads). Tables from other literature are usually expressed in terms of the C factor for the Universal Soil Loss Equation. The C factor is considered appropriate only if the forest situation and the situation represented in the published tables have the following in common: the management practice described in the table must have the same characteristics as the one to be used, the vegetative recovery rates must be the same, and all assumptions must be the same in practice as presented in the tables. In addition there will be significant errors if terminology used in the tables does not mean exactly the same thing from one part of the country to another.

Type I, II, and III values determined from figures IV.8, IV.9, and IV.10 are multiplied to obtain a VM value for use in equation IV.1. An example of this procedure is given in chapter VIII.

This estimation procedure for VM does not recognize the effects of time on fine root-density. It is recognized that some changes in soil characteristics which influence erodibility will occur due to various silvicultural activities. If these soil changes are for a short time (only a few years),

Table IV.3.—VM factor values for construction sites (Clyde et al. 1976).

Condition	VM factor
1. Bare soil conditions	
freshly disked to 6-8 inches	1.00
after one rain	0.89
loose to 12 inches smooth	0.90
loose to 12 inches rough	0.80
compacted buldozer scraped up and down	1.30
same except root raked	1.20
compacted bulldozer scraped across slope	1.20
same except root raked across	0.90
rough irregular tracked all directions	0.90
seed and fertilize, fresh	0.64
same after six months	0.54
seed, fertilize, and 12 months chemical	0.38
not tilled algae crusted	0.01
tilled algae crusted	0.02
compacted fill	1.24
undisturbed except scraped	0.66-1.30
scarified only	0.76-1.31
sawdust 2 inches deep, disked in	0.61
2. Asphalt emulsion	
1,250 gallons/acre	0.02
1,210 gallons/acre	0.01-0.019
605 gallons/acre	0.14-0.57
302 gallons/acre	0.28-0.60
151 gallons/acre	0.65-0.70
3. Dust binder	
605 gallons/acre	1.05
1,210 gallons/acre	0.29-0.78
4. Other chemicals	
1,000 lb fiber glass roving with 60-150 gallons/acre	0.01-0.05
Aquatain	0.68
Aerospray 70, 10 percent cover	0.94
Curasol AE	0.30-0.48
Petroset SB	0.40-0.66
PVA	0.71-0.90
Terra-Tack	0.66
5. Seedlings	
temporary, 0 to 60 days	0.40
temporary, after 60 days	0.05
permanent, 0 to 60 days	0.40
permanent, 2 to 12 months	0.05
permanent, after 12 months	0.01
6. Brush	0.35
7. Excelsior blanket with plastic net	0.04-0.10

they are accounted for by the VM factor. Long-term changes in soil erodibility, as a result of activities changing soil structure and permeability, should be evaluated by changing the K factor.

Adjustments for surface microrelief or roughness and adjustments for different contouring practices are also lacking from this presentation. More research needs to be directed toward these additional VM subfactors.

Seasonal Adjustments For VM

If necessary, the VM factor can be adjusted for seasonal changes using equation IV.11 to obtain an average annual VM value.

$$VM = \frac{(VM_g M_g + VM_d M_d)}{M_g + M_d} \qquad (IV.11)$$

where:

VM = weighted mean vegetation-management factor,

VM_g = VM factor for growing season,

M_g = number of growing season months with erosive rainfall,

VM_d = VM factor for dormant season,

M_d = number of dormant months with erosive rainfall and/or snowmelt runoff.

Estimated Soil Loss Per Unit Area

When all of the parameters of the MSLE (equation IV.1) have been assigned the proper values, the factors are multiplied to obtain an estimate of soil loss for a specific unit area. The answer generally will be expressed in tons/acre/year. If other units of area and time are chosen for use in the MSLE, they must be applied consistently throughout the equation.

Converting MSLE To Metric[1]

The rainfall intensity-energy equation in the metric system is: $E = 210.3 + 89 \log_{10} i$ where E is kinetic energy in metric-ton meters/hectare/centimeter of rain, and i is rainfall intensity in centimeter/hour. A logical counterpart to the English-system EI is the product: storm energy in metric-ton meters/hectare times the maximum 30-minute intensity in centimeter/hour. The magnitude of this product would be 1.735 times that of the EI as defined in English units. The factor for direct conversion of K to metric-tons/hectare/metric EI units is 0.2572.

[1]The equations used in this chapter usually require data to be in the English system (inches, feet, lbs., etc.) with the exception of equation IV.10. Substitution of metric data without making appropriate changes in equation coefficients will result in erroneous answers.

Table IV.4.—"C" factors for permanent pasture, rangeland, idle land, and grazed woodland[1] (Soil Conservation Service 1977)

Vegetal canopy: Type and height of raised canopy[2]	Canopy cover[3]	Type[4]	Cover that contacts the surface: 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
		W	.17	.12	.09	.067	.038	.011
Appreciable brush or bushes (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

[1]All values shown assume (1) random distribution of mulch or vegetation, and (2) mulch of appreciable depth where it exists. Idle land refers to land with undisturbed profiles for at least a period of three consecutive years. Also to be used for burned forest land and forest land that has been harvested less than 3 years ago.

[2]Average fall height of water drops from canopy to soil surface.

[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 at least 2 inches deep. W: Cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface), and/or undecayed residue.

Table IV.5.—"C" factors for undisturbed woodland (Soil Conservation Service 1977)

Effective canopy[1] % of area	Forest litter[2] % of area	"C"[3] factor
100-75	100-90	.0001-.001
70-40	85-75	.002-.004
35-20	70-40	.003-.009

[1]When effective canopy is less than 20 percent, the area will be considered as grassland or idle land for estimating soil loss. Where woodlands are being harvested or grazed, use table IV.4.

[2]Forest litter is assumed to be at least 2 inches deep over the percent ground surface area covered.

[3]The range in "C" values is due in part to the range in the percent area covered. In addition, the percent of effective canopy and its height has an effect. Low canopy is effective in reducing raindrop impact and in lowering the "C" factor. High canopy, over 13 m, is not effective in reducing raindrop impact and will have no effect on the "C" value.

Table IV.6.—"C" factors for mechanically prepared woodland sites (U.S. Department of Agriculture Soil Cons. Serv. 1977.)

Percent of soil covered with residue in contact with soil surface	Soil Condition and Weed Cover[4]							
	Excellent		Good		Fair		Poor	
	NC[5]	WC[5]	NC	WC	NC	WC	NC	WC
None								
A. Disked, raked or bedded[1 2]	.52	.20	.72	.27	.85	.32	.94	.36
B. Burned[3]	.25	.10	.26	.10	.31	.12	.45	.17
C. Drum chopped[3]	.16	.07	.17	.07	.20	.08	.29	.11
10% Cover								
A. Disked, raked or bedded[1 2]	.33	.15	.46	.20	.54	.24	.60	.26
B. Burned[3]	.23	.10	.24	.10	.26	.11	.36	.16
C. Drum chopped[3]	.15	.07	.16	.07	.17	.08	.23	.10
20% Cover								
A. Disked, raked or bedded[1 2]	.24	.12	.34	.17	.40	.20	.44	.22
B. Burned[3]	.19	.10	.19	.10	.21	.11	.27	.14
C. Drum choppd[3]	.12	.06	.12	.06	.14	.07	.18	.09
40% Cover								
A. Disked, raked or bedded[1 2]	.17	.11	.23	.14	.27	.17	.30	.19
B. Burned[3]	.14	.09	.14	.09	.15	.09	.17	.11
C. Drum chopped[3]	.09	.06	.09	.06	.10	.06	.11	.07
60% Cover								
A. Disked, raked or bedded[1 2]	.11	.08	.15	.11	.18	.14	.20	.15
B. Burned[3]	.08	.06	.09	.07	.10	.08	.11	.08
C. Drum chopped[3]	.06	.05	.06	.05	.07	.05	.07	.05
80% Cover								
A. Disked, raked or bedded[1 2]	.05	.04	.07	.06	.09	.08	.10	.09
B. Burned[3]	.04	.04	.05	.04	.05	.04	.06	.05
C. Drum chopped[3]	.03	.03	.03	.03	.03	.03	.04	.04

[1]Multiply A. values by following values to account for surface roughness:

Very rough, major effect on runoff and sediment storage, depressions greater than 6" 0.40
Moderate 0.65
Smooth, minor surface sediment storage, depressions less than 2" 0.90

[2]The "C" values for A. are for the first year following treatment. For A. type sites 1 to 4 years old, multiply "C" value by 0.7 to account for aging. For sites 4 to 8 years old, use table IV.4. For sites more than 8 years old, use table IV.5.

[3]The "C" values for B. and C. areas are for the first 3 years following treatment. For sites treated 3 to 8 years ago, use table IV.4. For sites treated more than 8 years ago, use table IV.5.

[4]Soil condition and weed cover descriptors.

Excellent—Highly stable soil aggregates in topsoil with litter and fine tree roots mixed in.

Good—Moderately stable soil aggregates in topsoil or highly stable soil aggregates in subsoil (topsoil removed during raking), only traces of litter mixed in.

Fair—Highly unstable soil aggregates in topsoil or moderately stable soil aggregates in subsoil, no litter mixed in.

Poor—No topsoil, highly erodible soil aggregates in subsoil, no litter mixed in.

[5]For each of the soil conditions, "C" factors are provided for no live vegetation (NC column) and for 75% cover of grass and weeds having about 0.5 meter fall height (WC column). For weed and grass cover other than 0% and 75%, "C" values may be interpolated.

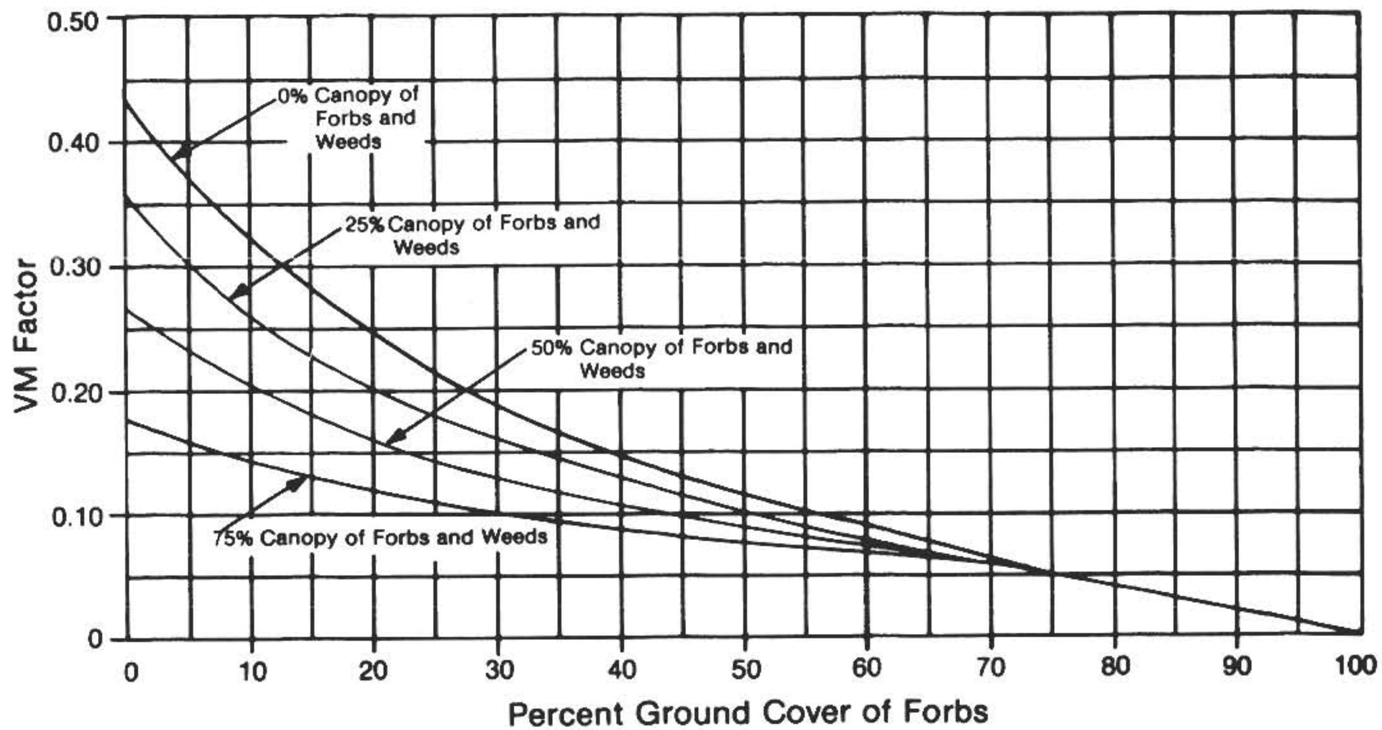


Figure IV.11—Relationship between grass density and the VM factor (Clyde and others 1976).

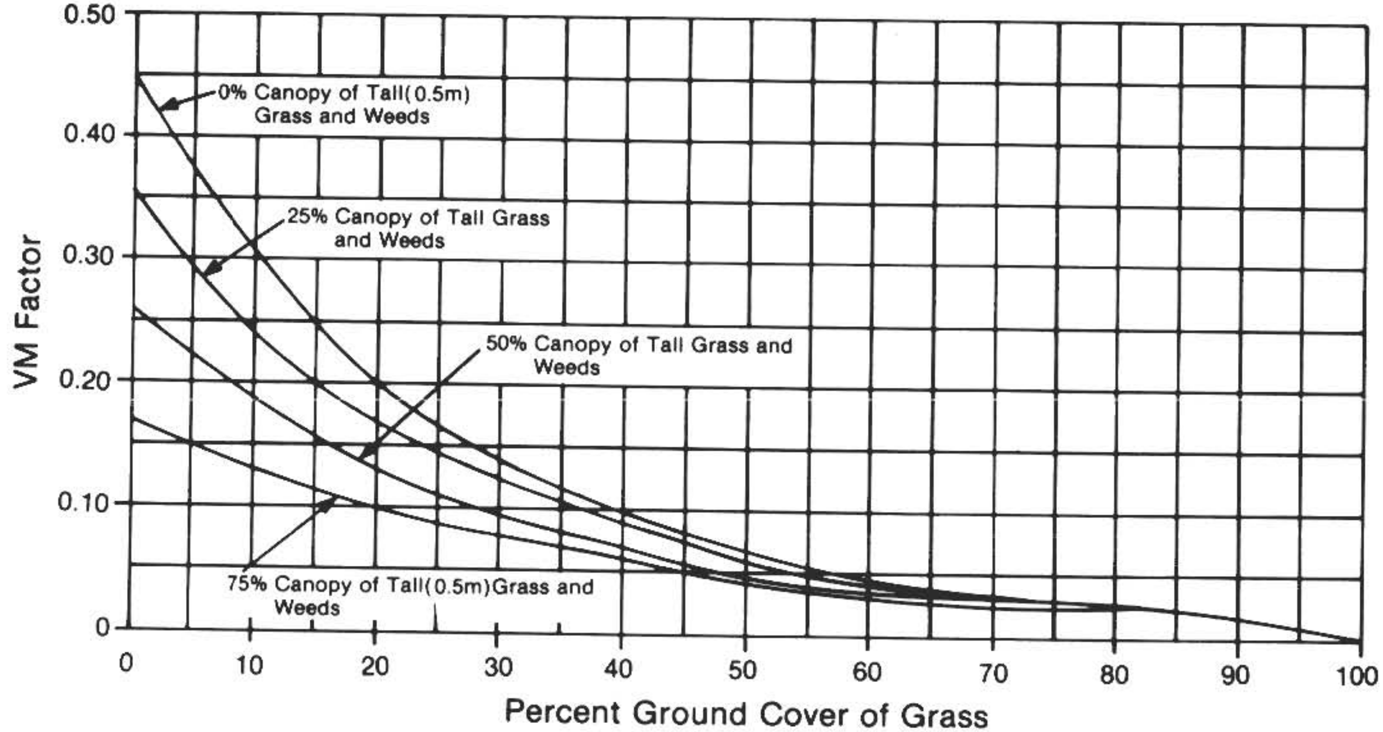


Figure IV.12—Relationship between forb density and the VM factor (Clyde and others 1976).

For practical purposes, it would be expedient to redefine the unit-plot as having a length of 25 meters and a slope of 10 percent, to derive K on the basis of those dimensions, and to recompute the slope-effect chart. The translated values would be:

L $= \lambda^{0.5}/_5$ where λ is slope length in meters; and $S = (0.43 + 0.30s + 0.043s^2)7.73$ where, s = percent slope. Combining the two,

LS $= \sqrt{\lambda}(0.00111s^2 + 0.00776s + 0.0111)$. (Wischmeier 1972).

Erosion Response Units

Potential sources of non-point pollution constitute site specific problems within an individual watershed. To estimate the magnitude of a specific onsite soil loss and to identify the particular drainageway where this erosion occurs, the watershed must be divided into homogeneous areas. Delineating erosion response units requires identification of individual activities such as roads, landings, cutting blocks, or skid trails, and the relative contribution of each activity to potential sediment yield.

Delineating Erosion Response Units

The following information needs to be shown on a series of maps or overlays in order to identify and delineate erosion response units:

1. Topographic information showing hydrographic areas and channel network.
2. Soil and vegetative resource information used for the quantification of surface erosion.
3. Project proposal showing the location of roads, trails, landings, cutting units, etc.

The procedure for compiling these data is explained by steps:

Step 1. — Obtain a topographic map (fig. IV.13) to show spatial relationships of the factors needed in the quantification process. The amount of detail desired and the amount that can be produced by the analysis will depend upon the scale and accuracy of the base map.

Step 2. — Extend the stream detail shown on the topographic base (fig. IV.14). Perennial streams, and in some cases intermittent streams, will be printed on the original topographic base; however, this does not completely define the stream channel network within that watershed. It is important that the displayed stream network be extended to include all intermittent channels that are definable on the basis of the contour lines. Each channel should be extended toward the watershed divide from channels originally identified on the base map. Field information, if available, should be used to verify the final channel network.

Step 3. — Delineate individual hydrographic areas (fig. IV.15). Draw the interior watershed boundaries or hydrographic divides separating the extended channel network that was identified in step 2. At this point, a series of sub-watersheds or hydrographic areas will have been delineated within the watershed of interest.

Step 4. — Since soils information is required for the evaluation of onsite erosion, soil mapping unit boundaries should be drawn (fig. IV.16). These soil units may come from a standard soil survey, a soil resource inventory, or a land systems inventory. The soils may be grouped so that the delineated map units represent soils that are homogenous with respect to texture (percent sand, silt, clay), organic matter, permeability, and structure. Vegetative cover information, if available, should be mapped to show the percent surface area occupied by vegetation, mulch, rock, litter, and debris. Sediment delivery, as well as surface erosion, is greatly influenced by these factors; having them mapped prior to initiating quantification of erosion is beneficial to the analysis.

For the purpose of bookkeeping, it is necessary to number these erosion response units consecutively. Begin near the mouth of the watershed with number "1" and proceed clockwise toward the head of the watershed and back around the mouth on the opposite side.

Step 5. — Stratify the problem as it relates to the proposed silvicultural activity by drawing roads, cutting blocks, log landings, skid trails, and other activities on an overlay for the topographic base (fig. IV.17). Placing this information on an overlay will make the maps more readable and will also facilitate making changes in a proposal without destroying the entire topographic base.

Delineate the transportation system first, including all existing and proposed roads, skid trails, and aircraft landing areas. Then delineate the cutting blocks as precisely as possible relative to the topographic base (fig. IV.18). Other items, such as decking areas and log landings, should also be shown on the topographic base whenever possible. Once again, the detail that is shown will partially determine the detail of the analysis.

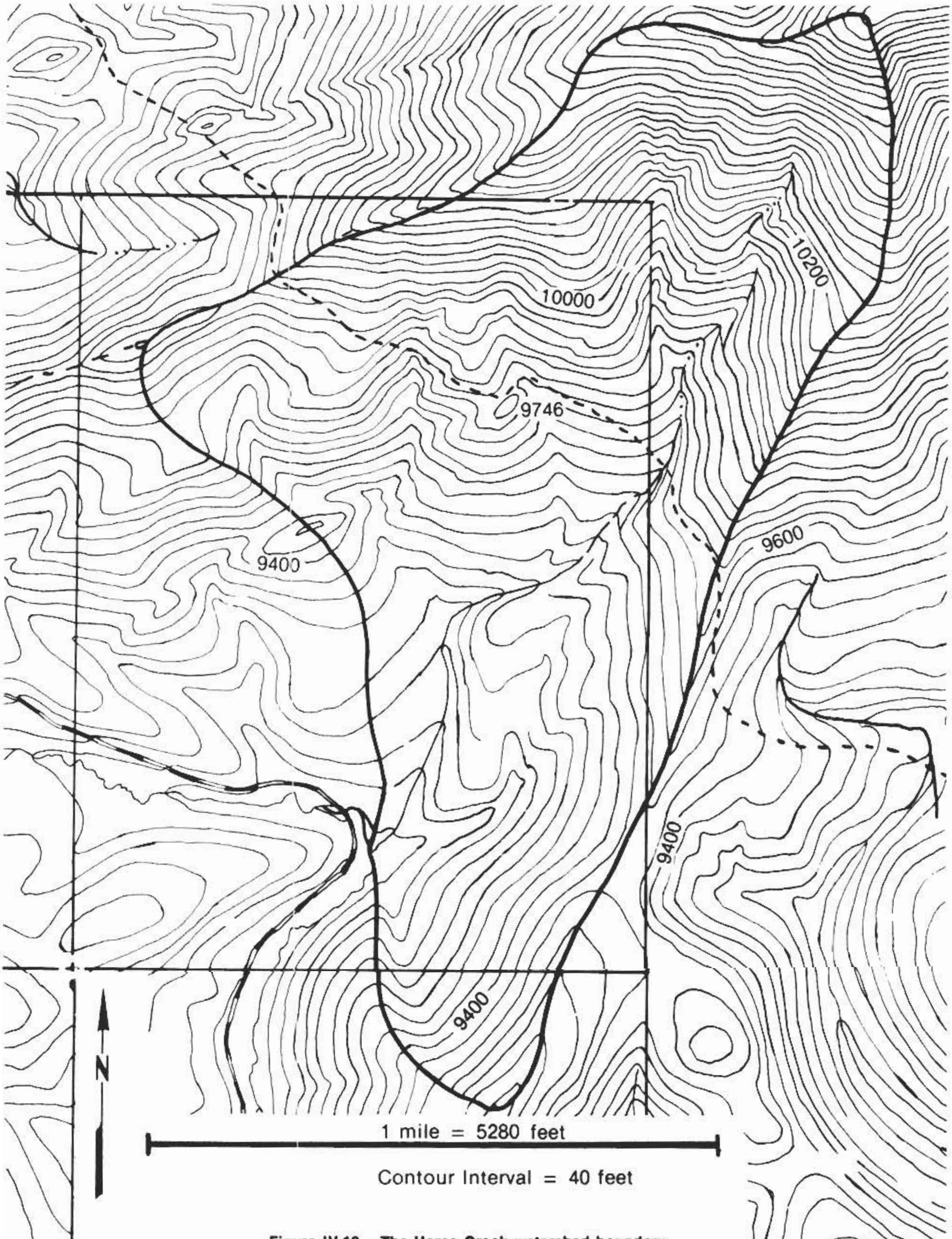


Figure IV.13.—The Horse Creek watershed boundary.

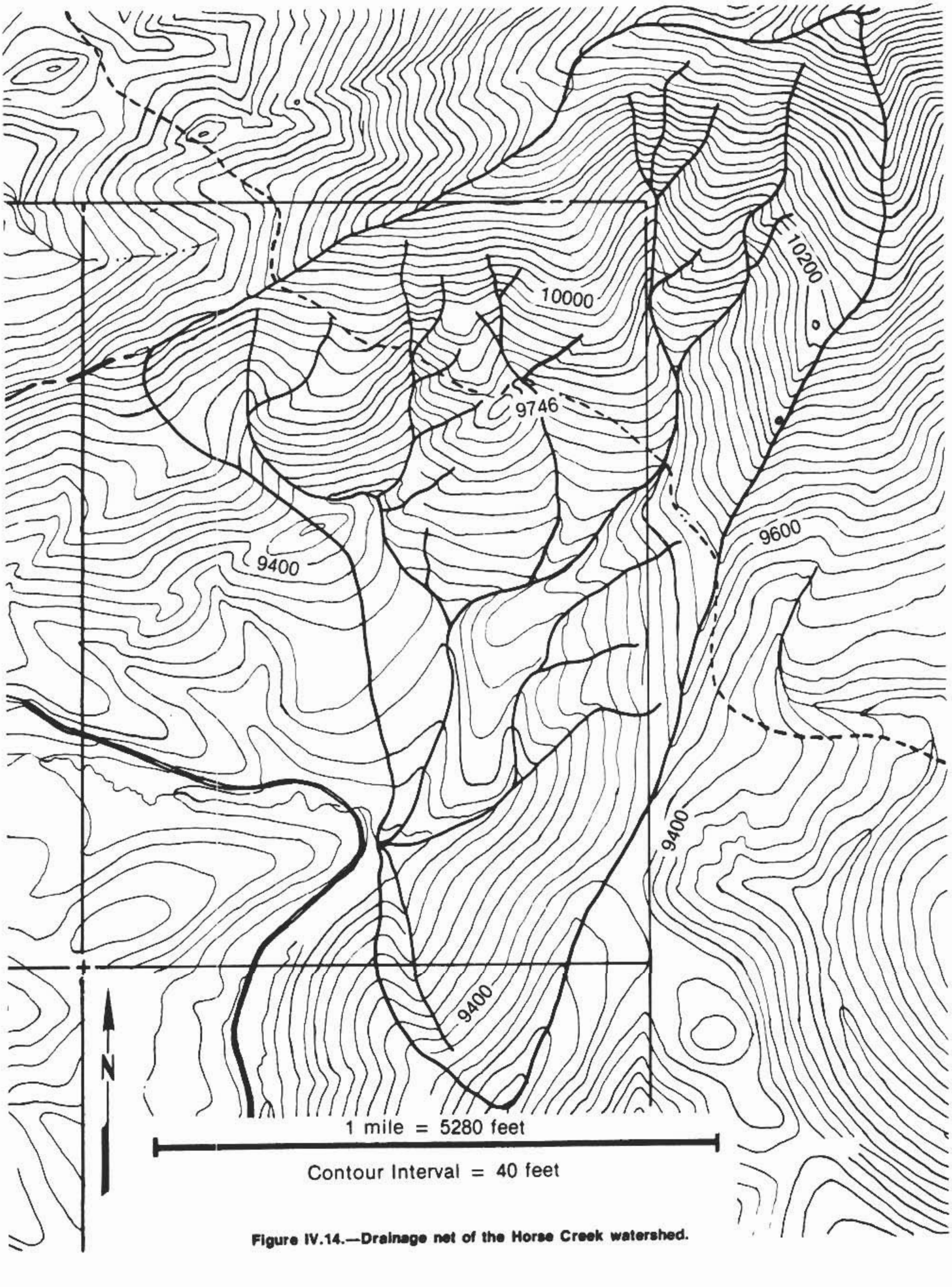


Figure IV.14.—Drainage net of the Horse Creek watershed.

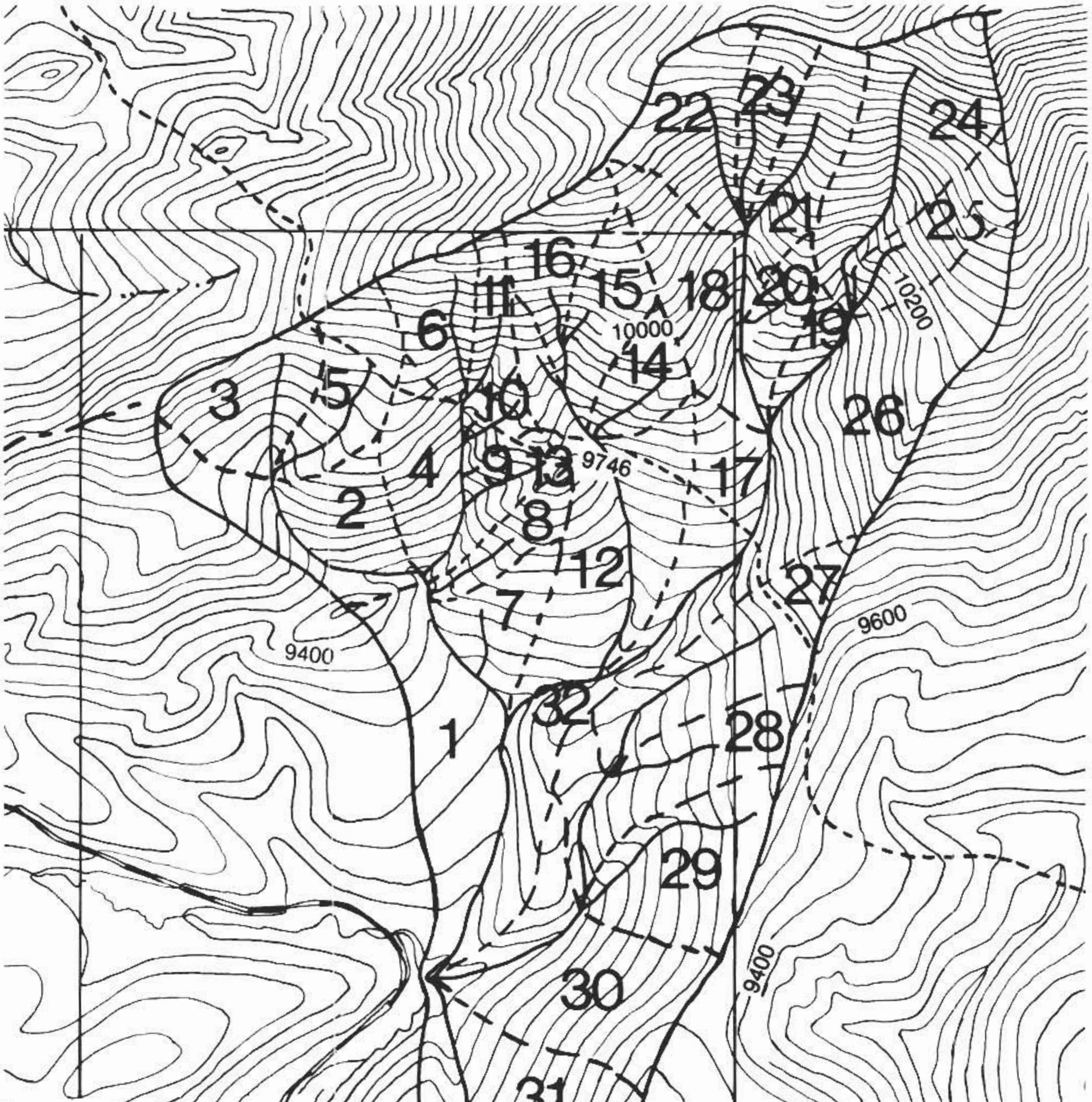


Figure IV.15.—Individual hydrographic areas of the Horse Creek watershed.

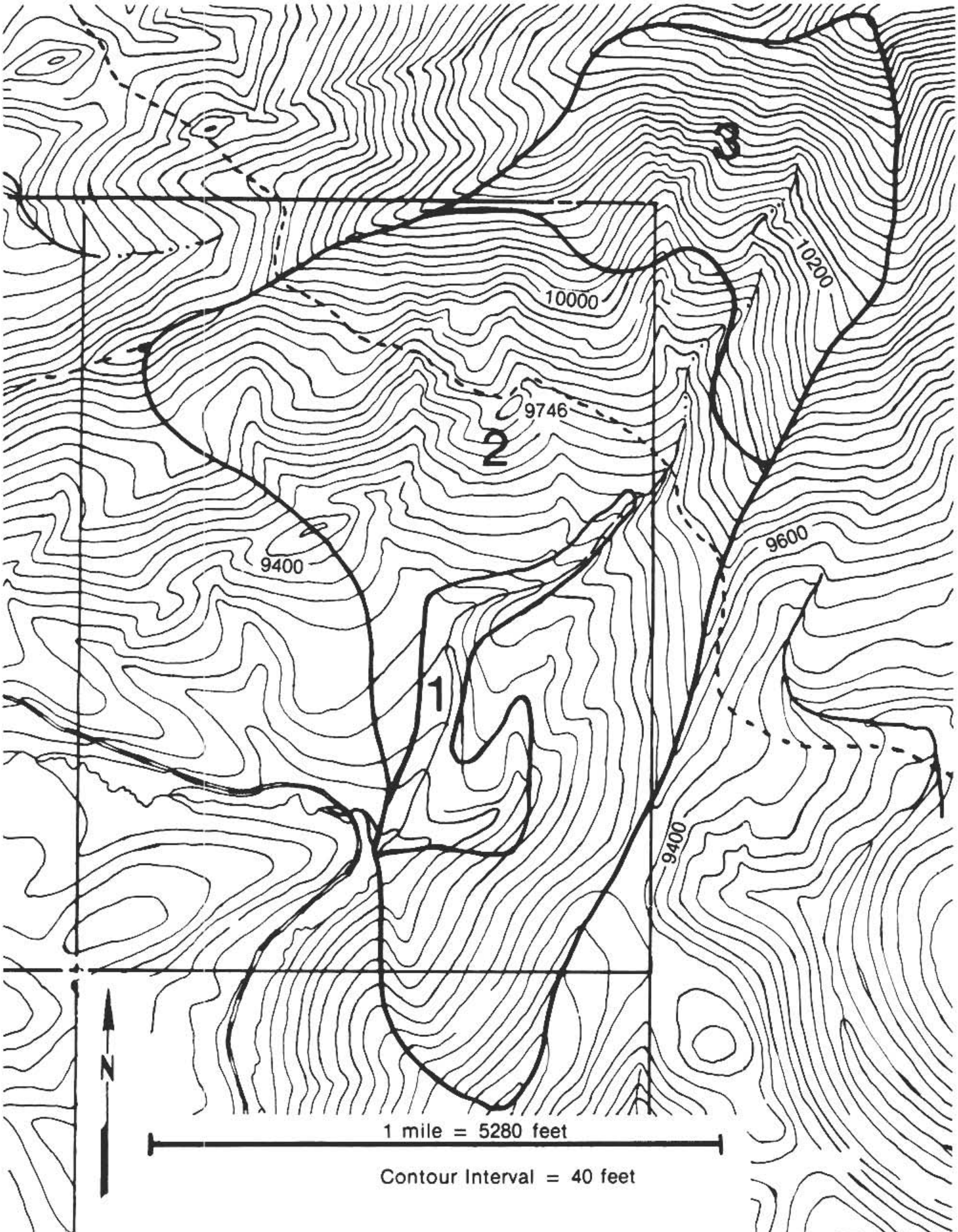


Figure IV.16.—Soil mapping unit boundaries for the Horse Creek watershed.

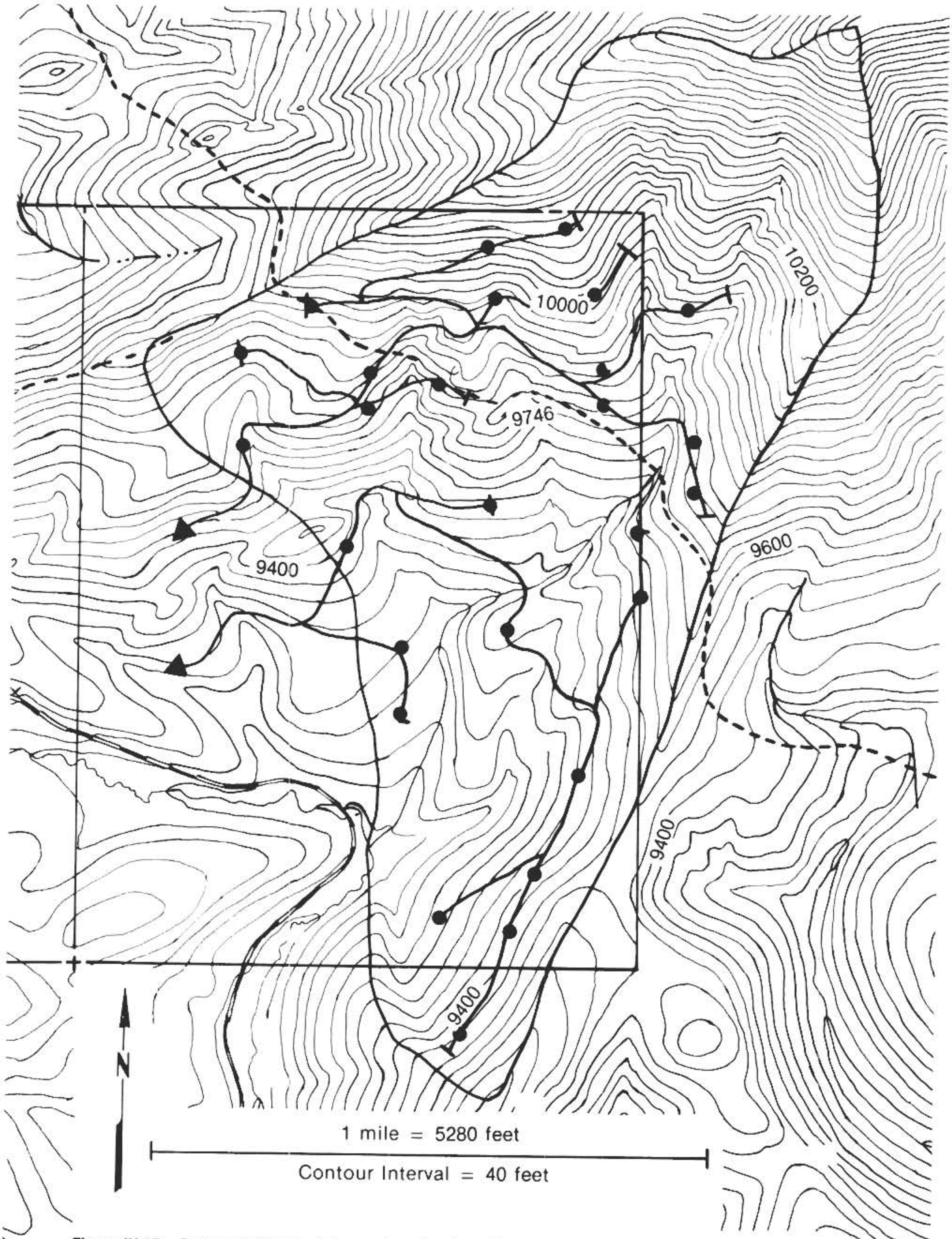


Figure IV.17.—Proposed transportation system (roads and log landings) for the Horse Creek watershed.

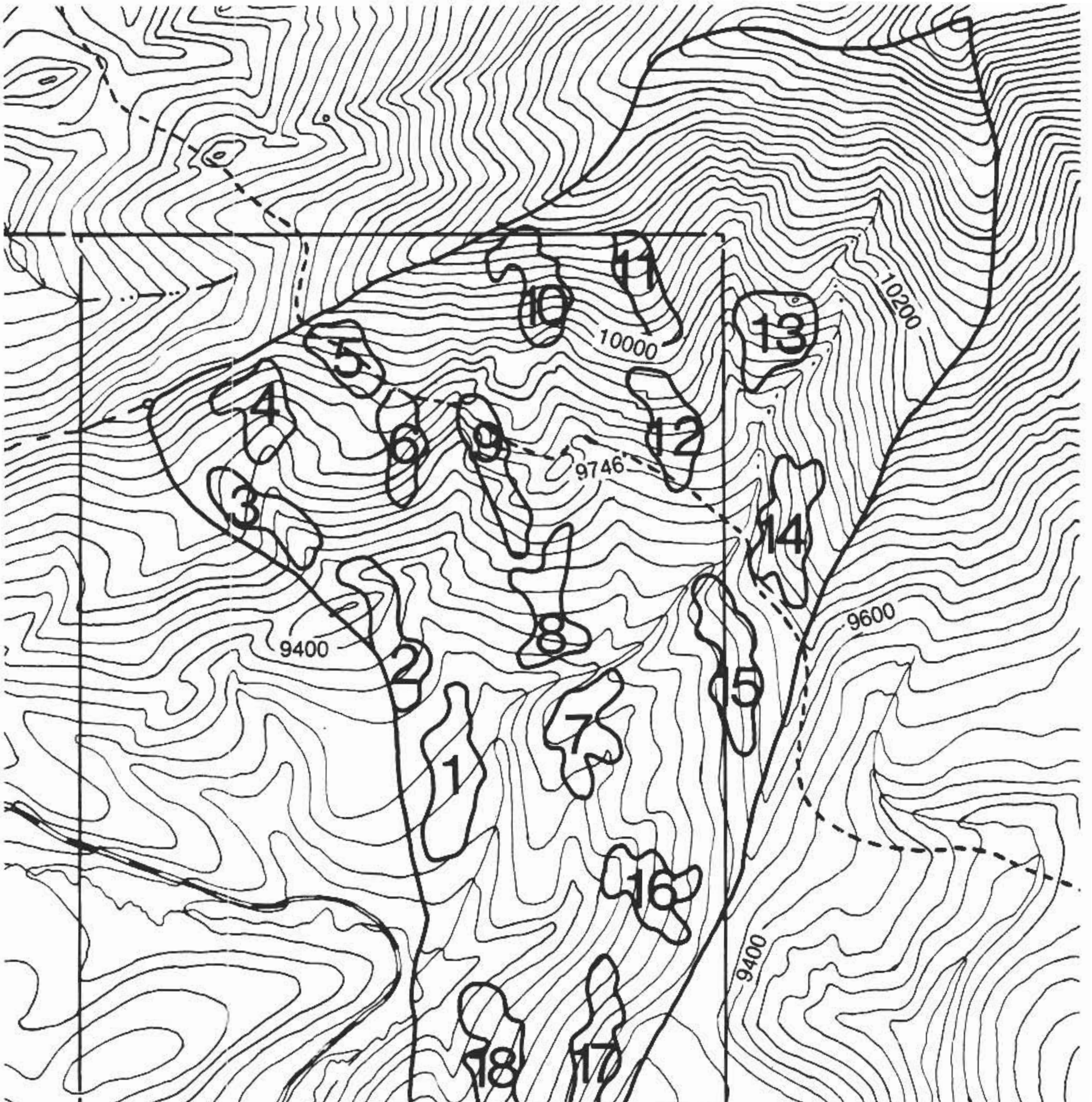


Figure IV.18.—Proposed cutting units for the Horse Creek watershed.

Step 6. — All of the preceding information should be incorporated onto a single map base or preferably onto overlays using the previous map scale (fig. IV.19). The information in its overlaid form should include the hydrographic areas, the soil and vegetation resources, and the proposed activities within each erosion response unit.

Step 7. — Further subdivisions of the proposed activities are possible to identify specific sources contributing eroded materials to the drainageway via separate delivery routes within each hydrographic area. The degree to which the silvicultural activities are subdivided is important to the final quantification process and may be useful in ultimately applying controls to specific parts of an area. The more detailed the subdivision of activities the more complex the accounting procedure and the more detailed the answer.

Step 8. — List the potential sediment source areas on worksheets (IV.1-IV.8) by activity types for each erosion response unit identified in step 4.

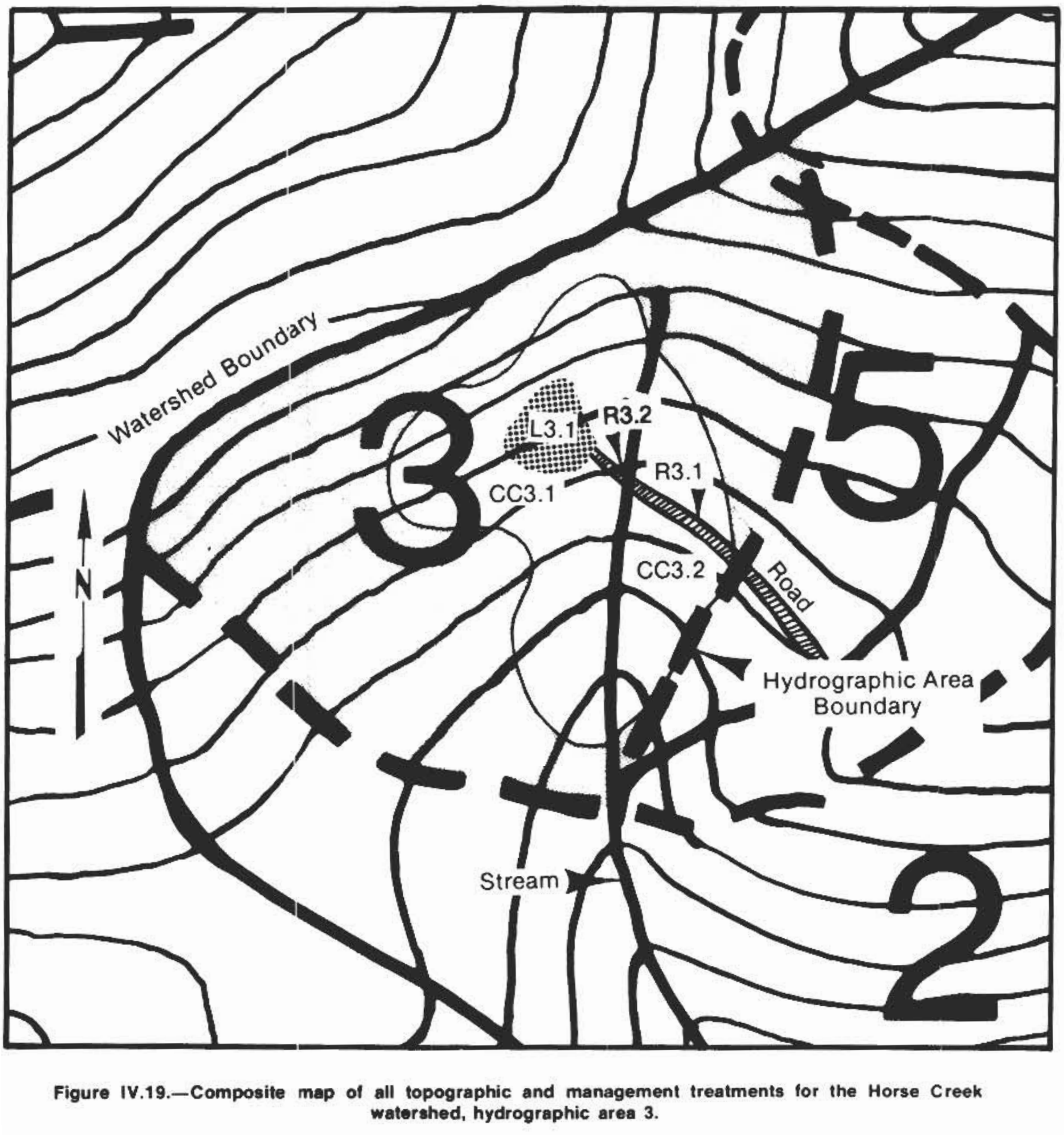


Figure IV.19.—Composite map of all topographic and management treatments for the Horse Creek watershed, hydrographic area 3.

WORKSHEET IV.1

Soil characteristics for the ____________________ watershed

Soil group		Percent sand 2.0-0.1 mm	Percent very fine sand 0.10-0.05 mm	Percent "coarse silt" 0.062-0.05 mm[1/]	Percent silt 0.05-0.002 mm	Percent clay 0.002 mm	Percent organic matter	Soil structure		Soil permeability	
								MSLE code	Descriptive	MSLE code	Inches per hour
1	Topsoil										
	Subsoil										
2	Topsoil										
	Subsoil										
3	Topsoil										
	Subsoil										

[1/] The "coarse silt" particle size group is not part of the USDA classification system, but 0.062 mm represents an upper limit of particle size that is used when estimating suspended sediment transport in streams. For this use only the "coarse silt" size within the USDA very fine sand classification is presented.

WORKSHEET IV.2

_______________ watershed erosion response unit management data for use in the MSLE and sediment delivery index, hydrographic area _______________

Erosion response unit	Slope length of disturbed area (ft)	Slope gradient of disturbed area (%)	Length of road section (ft)	Average width of disturbance (ft)	Area (sq.ft.)	Area (acres)
1.						
2.						
3.						
4.						
5.						
6.						
7.						
8.						
9.						
10.						
11.						
12.						
13.						
14.						
15.						
16.						
17.						
18.						
19.						
20.						
21.						
22.						
23.						
24.						
25.						

WORKSHEET IV.2--continued

Area with surface residues			Open area				
Percent of total area	Percent of surface with mulch	Percent of area with fine roots	Percent of total area	Percent of surface with mulch	Percent of area with fine roots	Are open areas separated by filter strips?	Percent of total area with canopy
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							
10.							
11.							
12.							
13.							
14.							
15.							
16.							
17.							
18.							
19.							
20.							
21.							
22.							
23.							
24.							
25.							

WORKSHEET IV.2--continued

Average minimum height of canopy (m)	Time for recovery (mo)	Average dist. from disturbance to stream channel (ft)	Overall slope shape between disturbance and channel	Percent ground cover in filter strip	Surface roughness (quali-tative)	Texture of eroded material (% silt + clay)	Percent slope between disturbance and channel
1.							
2.							
3.							
4.							
5.							
6.							
7.							
8.							
9.							
10.							
11.							
12.							
13.							
14.							
15.							
16.							
17.							
18.							
19.							
20.							
21.							
22.							
23.							
24.							
25.							

WORKSHEET IV.3

Estimates of soil loss and delivered sediment by erosion response unit for hydrographic area ________ of ______________________ watershed

Erosion response unit	Soil unit	R	K	LS	VM	Area (acres)	Surface soil loss (tons/yr)	SD_1	Delivered sediment (tons/yr)

WORKSHEET IV.4

Estimated VM factors for silvicultural erosion response units
________________ watershed, hydrographic area ________

	Logging residue area					Open area							
Erosion response unit	Fraction of total area	Mulch (duff & residue)	Canopy	Roots	Sub VM	Fraction percent of total area	Mulch (duff & residue)	Canopy	Roots	Filter strip	Sub VM	Total VM

WORKSHEET IV.5

Example of estimated monthly change in VM factor following construction for road cuts and fills in ________________ watershed, hydrographic area ____________________________

Month	Percent cover and VM subfactors						Monthly VM
	Mulch		Canopy		Roots		
	Percent	VM	Percent	VM	Percent	VM	
Sep.1/							
Oct.3/							
Nov.							
Dec.2/							
Jan.2/							
Feb.2/							
March2/							
April4/							
May4/							
June5/							
July5/							
Aug.							

1/ *Begin seeding, enough rain is assumed to ensure seed germination.*

2/ Snow cover with no erosive precipitation.

3/ Significant canopy effect developing.

4/ Snowmelt runoff occurs, some protective vegetative cover lost during winter.

5/ Significant root network developing from seeded grass.

WORKSHEET IV.6

Weighting of VM values for roads in
__________________ watershed, hydrographic area _____

Erosion response unit	Cut or fill: Fraction of total width	Cut or fill: VM	Roadbed: Fraction of total width	Roadbed: VM	Fill: Fraction of total width	Fill: VM	Weighted VM

WORKSHEET IV.7

Factors for sediment delivery index from erosion response units in

________________ watershed, hydrographic area ________

Erosion response unit	Water availability	Texture of eroded material	Percent ground cover between disturbance and channel	Slope shape code	Distance (edge of disturbance to channel) (ft)	Surface roughness code	Slope gradient (%)	Specific site factor	Percent of total area for polygon	SDI

WORKSHEET IV.8

Estimated tons of sediment delivered to a channel for each hydrographic area and type of disturbance for ____________ watershed

____

Hydro-graphic area	Cutting units					Landings			Roads					Total tons/yr	Per-cent
	CC_1	CC_2	CC_3	CC_4	CC_5	L_1	L_2	L_3	R_1	R_2	R_3	R_4	R_5		
Column total															
Distur-bance total															
Percent															

Summary

Once the data are accumulated, a specific estimate of surface soil loss can be made. To compute an estimate of total soil loss for a unit area (one acre), the MSLE must be applied to each activity within the area. The unit area soil loss is multiplied by the actual area that is disturbed by an activity to obtain an estimate of surface soil loss per activity. Soil loss for each activity is then added together to obtain estimated total soil loss. This overall procedure is further explained in "The Procedure" section of this chapter.

CONSIDERATIONS FOR REDUCING EROSION

Theoretically, it is possible to reduce soil loss by making appropriate changes in any of the MSLE factors. In actual practice, some factors are easier to change than others. The following tabulation describes the basic concepts underlying the variable changes brought about by controls for surface erosion. This conceptual presentation is to aid in understanding controls and determining which control practice to use. Details of specific control practices may be found in "Chapter II: Control Opportunities."

MSLE Factor	Preventive	Mitigative
R	Where soils have high erodibility factors, plan silvicultural activities so that snowmelt rates are not increased over natural conditions. Use management techniques which will not create significant increases in the amount of solar energy reaching the forest floor.	Reduce snowmelt runoff rates by intercepting the solar energy above the snow surface.
R	Control over the rainfall portion of the R factor is not likely to occur because it is a function of overall weather patterns.	
K	Use management practices that do not reduce long-term soil permeability, structure, or organic matter content. For example, avoid soil compaction or creation of conditions that destroy organic matter.	Increase long-term organic matter content in the soil by promoting good vegetative growth. This can lead to desirable soil structure and permeability. Obtaining desirable soil texture changes would be very difficult at best.
LS	Usually slope length and slope gradient effects must be considered together because a change in one also causes a change in the other.	
L	Control location and design of various types of construction to avoid creating long cut and/or fill slopes, large landings, and extensive activity areas.	Locate various types of diversions, such as terraces, to reduce the distance water can move over land.
S	Control location and design of various types of construction and other activities on steep slopes.	Reduce steep slopes, created by construction activities, by placing soil and rock at the base of a cut slope and removing it from a fill slope.
VM	Control and design forest activities to minimize forest floor destruction. Maintain adequate amounts of low understory canopy. This is important where surface residues are few or lacking. A high overstory canopy may accelerate raindrop splash erosion from storms in areas where the forest floor has been destroyed. An example might be a campground with little or no surface residue or understory canopy. Control the use and intensity of fire on coarse-textured soils to prevent hydrophobic conditions from developing.	Add mulch, or chemical binders, establish vegetation, or use other practices to change VM so that acceptable levels of soil loss are achieved. Use various mechanical methods of creating surface roughness or small diversions, e.g., perform final site preparation on the contour rather than up and down slope. Use wetting agents to reduce or reverse hydrophobic conditions enough to significantly reduce soil loss (Osborn and others 1964).

APPLICATIONS, LIMITATIONS AND PRECAUTIONS: SURFACE SOIL LOSS

The confidence limits on predictions by the Universal Soil Loss Equation are the narrowest (predictions are most accurate) for silt, silt loam, and loam textures on uniform slopes of 5 to 12 percent, and with slope lengths of less than 400 feet (122m) (Wischmeier 1972). **Beyond these limits, significant extrapolation errors become more likely.** However, the MSLE appears to have sufficient accuracy for comparing estimated soil loss from different silvicultural management practices on a given site over a wider range of forest environmental conditions. Predicting long-term (5- to 50-year) average soil loss for a given situation is limited by lack of available data needed to evaluate the individual terms rather than the overall model. The prediction accuracy for forest land may improve as research provides a more accurate evaluation of the critical site factors over a wider range of conditions within the forest environment.

Specific limitations of the MSLE are as follows:

1. The MSLE is empirical; it indexes the quantity of soil loss under various forest conditions and does not always show the factors in correct relationships with actual erosion processes. There are limitations due to the use of empirical coefficients and fitted curves.
2. The MSLE only estimates an amount of soil loss, but does not deal with the probability or chance of soil loss occurring.
3. The MSLE was developed to predict soil loss on an average annual basis. Soil loss predictions on a storm-by-storm basis often are erroneous because of the complicated interaction between forces governing soil loss rates that are not accounted for by the MSLE. On any given site, these interactions may tend to average out over long periods of time so that their effect on long-term soil loss may be minimal. The soil loss equation has been rewritten in several attempts to develop techniques to handle storm-by-storm losses (Foster and others 1977, Williams 1975c, Williams and LaSeur 1976). The accuracy and reliability of such techniques is questionable, and it is not recommended that they be used for quantification.
4. It is assumed in the MSLE that the K factor is a constant, average value throughout a given analysis time period. However, changes in surface particle size distribution (texture) due to freeze-thaw or ongoing erosion processes will affect the value of K. Some of these effects, if they are short-term, are provided for by the VM factor. Long-term changes in the K factor due to soil compaction which occurs on roads, from equipment operations, or by animal traffic needs further study.
5. The LS factor has a low level of sensitivity to potential errors in the estimation of slope length because it is raised to a fractional power. However, an error in slope gradient, particularly on steep slopes, can result in a large error in LS because of the parabolic form of the equation.
6. The MSLE is most accurate for VM values above 0.2. As VM approaches 0.01 and below, the errors in the absolute estimate of soil loss increase greatly; the smaller VM becomes, the larger the potential absolute error.
7. The rainfall erosion index (R) measures only the erosive force of rainfall and associated runoff. The equation does not predict soil loss that is due solely to thaw, snowmelt, or wind.
8. Relationships of a given MSLE parameter to soil loss are often appreciably influenced by the levels of all other MSLE parameters (Wischmeier 1976). Graphs in figure IV.20 illustrate one example of this interrelationship for the K factor. Table IV.7 shows values used as constants in this example. Using figure IV.20 and table IV.7 together it is shown how changing one parameter, while holding all others constant (either at high, moderate, or low levels), affects erodibility, the K factor. For example, Figure IV.20a illustrates the effects upon the K factor when organic matter is varied from 0 to 6 percent and all other parameters are held constant. When all other parameters are at low or moderate levels, changes in organic matter do not appreciably affect erodibility. However, when all other parameters are held

Table IV.7.—Values of organic matter, fine sand + silt, clay, structure, and permeability used as constants when calculating K factor over a range of each parameter for low, moderate, and high values of K.

	Relative Level of K		
	Low	Moderate	High
% organic matter	6	3	0
% fine sand + silt	10	35	70
% clay	90	65	30
structure	4	3	1
permeability	1	3	6

at high levels, changes in organic matter do have an appreciable influence on the K factor. There is a similar graph for each of the K factor parameters showing the changes in K due to a change in a parameter.

9. There are additional erosion processes not accounted for in the MSLE that are important in making accurate predictions of soil loss. On steep slopes wind is an important erosion factor and may increase rainstorm erosion by up to one order of magnitude. Fall freeze-thaw processes cause a change in the median particle size of eroded material (Megahan 1978).

10. No adjustments are made for timing of rainfall relative to vegetative growth periods. Intuitively, the amount of soil loss would be different if most of the rainfall occurred during a vegetative dormant season rather than a growing period.

11. The MSLE does not separate runoff and rainfall components of erosion. If this could be done, the accuracy of estimated soil losses might be improved in situations where one factor is more important than the other.

12. There does not appear to be any acceptable method to account for the influence of rock and stone on the soil surface. A suggestion is to view the rock or stone as a non-erodible part of the surface; however, because of the runoff from the surface of a rock, there might be more soil loss than would occur without any rock.

13. Coarse-textured soils that are exposed to an intense fire may become hydrophobic, thus promoting more surface runoff after a fire than might have occurred under natural vegetation. It is not known if adjusting the K factor for a change in permeability will provide a satisfactory estimate of this effect on runoff-induced erosion.

14. The equation does not account for sediment deposition that occurs in depressions within a field, at the toe of a slope, along disturbance boundaries, or in terrace channels on a slope (Wischmeier 1976).

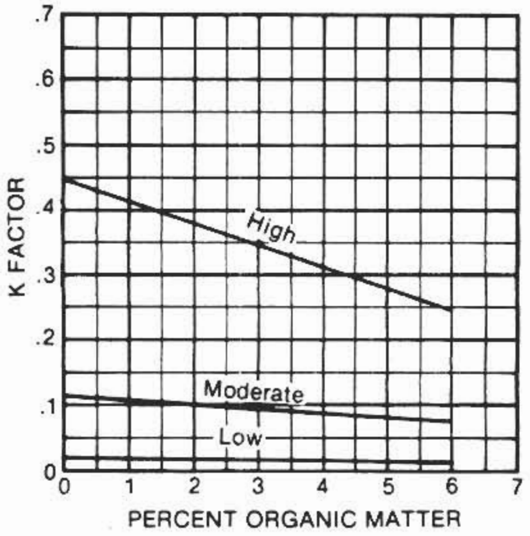
15. Gully erosion cannot be accounted for by the Modified Soil Loss Equation. (See appendix IV.A). The use of the soil loss equation is confined to sheet and rill erosion.

16. The relationships of factors influencing erosion on soils that are high in organic matter, that have developed from volcanic ash, or that have permafrost are not well understood. Use of the soil loss equation for these soils may result in significant errors in the amount of predicted soil loss.

17. The MSLE estimates average soil loss for 1 year only. Using MSLE for periods of over a year is briefly discussed in appendix IV.B.

18. Accurate soil loss estimates from roads and skid trails may not be obtained where they intercept surface and subsurface runoff in addition to precipitation. The MSLE does not estimate soil loss by concentrated water flow, such as in a road ditch. (See Appendix IV.C: Controlling Ditch Erosion).

19. In forest areas with a dense overstory canopy, there is a limit to map accuracy. When a topographic map is prepared from aerial photographs, the technician making the map cannot see the actual ground surface on the photograph — only the canopy top. The map maker is usually not acquainted with the area, but must still estimate the canopy height. Anything that would cause some trees to grow taller than others will cause errors in delineating contour lines. For example, a small first-order stream channel with its additional moisture may cause trees to grow so that the tops are level with tree tops on the drier interflueves between channels, and thus be mapped as a uniform ground surface.



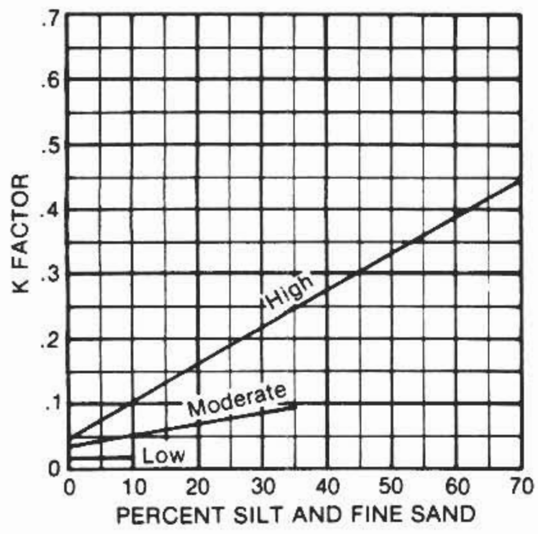


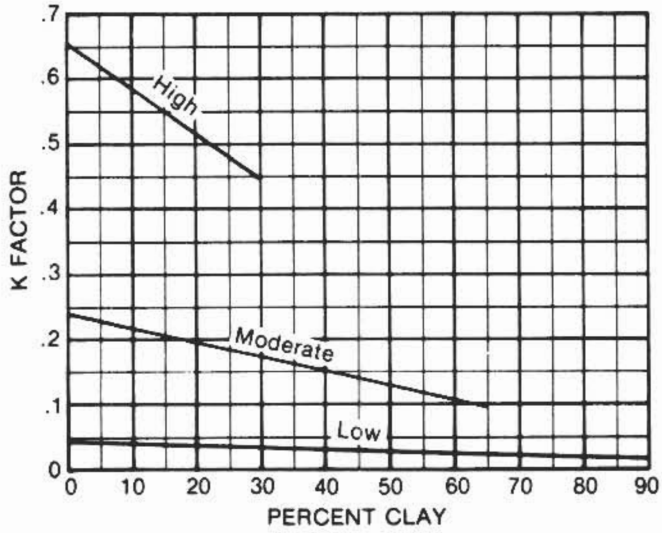
Figure IV.20a.—Effect of organic matter content on K factor when other parameters are at low, moderate, or high values.

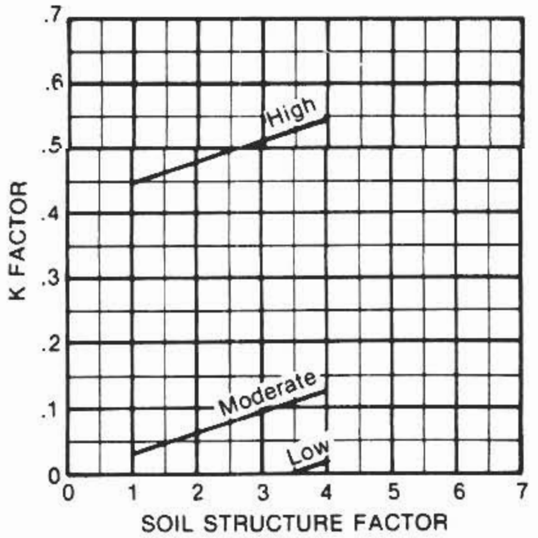
Figure IV.20b.—Effect of silt and fine sand on K factor when other parameters are at low, moderate, or high values.

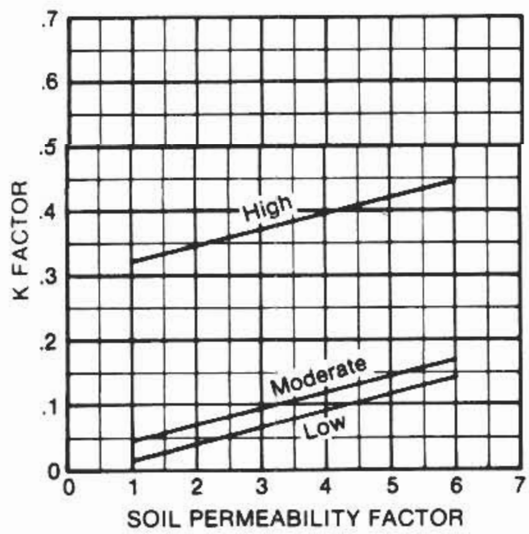
Figure IV.20c.—Effect of clay on K factor when other parameters are at low, moderate, or high values.

Figure IV.20d.—Effect of soil structure on K factor when other parameters are at low, moderate, or high values.

Figure IV.20e.—Effect of soil permeability on the K factor when other parameters are at low, moderate, or high values.







DISCUSSION: SEDIMENT DELIVERY

GENERAL CONCEPTS OF SEDIMENT DELIVERY

To evaluate the effects of surface erosion on water quality, it is necessary to estimate the amount of eroded material that might be moved from the eroding site into a receiving stream channel system. Unfortunately, the processes which describe the delivery of eroded materials are less well understood than those for erosion, and data for sediment delivery are scarce.

Historically, the determination of the amount of sediment that reached a stream channel revolved around the concept of delivery ratios (Gottschalk and Brune 1950, Maner 1958, Maner and Barnes 1953, Roehl 1962, Williams and Berndt 1972). A delivery ratio is the volume of material delivered to a point in the watershed, divided by the gross erosion estimated for the slopes in the watershed above that point. Values range from zero to one.

Apparently, a characteristic relationship of sediment yield to erosion does not exist. Many factors influence a sediment delivery ratio; if these factors are not uniform from one watershed to another, the relationship between sediment yield and erosion shows considerable variation (Renfro 1975).

Factors Influencing Sediment Delivery

Sediment delivery from a disturbed site to a stream channel is influenced to varying degrees by the following factors (Foster and Meyer 1977, Megahan 1974, Renfro 1975). (There may be other factors, not listed here, that are also important in given situations.)

Sediment Sources

In terms of effects upon a sediment delivery index, there are at least three ways to describe sediment sources:

1. Type of disturbance — Materials originating from logging areas, skid trails, landings, and roads seem to have a range of delivery ratios that are characteristic of each disturbance type.
2. Type of erosion — Sheet, rill, gully, and soil mass movement have one or more sediment delivery parameters that are unique to that particular form of erosion.
3. Mineralogy of the source area — Delivery ratios are influenced by various physical characteristics of sediment materials. Size, shape, and density of individual particles and their tendency to form stable aggregates are usually reflected by their mineralogy. Wettability of particles may be a function of mineralogy or of unique biological systems both of which influence the efficiency of sediment delivery.

Amount Of Sediment

When the amount of potential sediment exceeds the runoff delivery capability, deposition occurs and the amount of sediment delivered to a stream channel is closely controlled by the amount of runoff energy. If the amount of sediment is less than the runoff delivery capability, then no deposition will occur between the disturbed area and a stream channel.

Proximity Of Sediment Source

The distance that sediment must move and the shape and surface area of the transport path all affect the amount of material that may be lost from the transport system.

Transport Agents

Surface runoff from rainfall and snowmelt is the main agent for transporting eroded material. Sediment transport is dependent on the volume and velocity of water as well as the character and amount of material to be transported.

Texture Of Eroded Material

Individual particles of fine-textured material can be moved easier than particles of coarse-textured material because the finer the particle, the less transport energy required. If a watershed is dominated by fine-textured material, it is likely to have more material delivered to a stream channel by surface runoff than an equivalent situation with coarse-textured material — assuming that soil aggregates are not involved.

Deposition Areas

Microrelief that results in surface depressions or other irregularities will deliver less sediment than a smooth, flat surface. Decreases in slope gradient also promote deposition of large size fractions of transported material.

Watershed Topography

Size of the drainage area, overall shape of the land surface, (concave to convex), slope gradient, slope length, and stream channel density all affect the sediment delivery ratio by varying amounts.

Sediment Delivery Model

From the previous discussion concerning factors that influence sediment delivery over an area of land, it can be seen that the amount of eroded material deposited between a disturbed site and a drainage channel is due to a variety of interacting factors. To aid understanding overland sediment transport, the process can be divided conceptually into two parts.

The first requirement is a transporting agent with sufficient energy to move the sediment. In this case, surface runoff is the transporting agent. Its energy is a function of the amount and velocity of waterflow passing over a given area in a given time period.

The second part deals with factors which tend to stop or slow the movement of sediment and waterflow over a slope. Microrelief, slope gradient, slope length, slope shape, vegetation, and surface residues all play a part in reducing the amount of sediment that will actually reach a delivery point (Neibling and Foster 1977, Zingg 1940).

The shape of the area over which sediment is transported (fig. IV.21) also influences the amount actually delivered to a drainage channel. In one case, sediment entering delivery area A is funneled so that a given amount passes over progressively less surface during transit. This reduces the opportunities for deposition and also increases the energy of the transporting agent, thus resulting in increased sediment delivery efficiency. At the other extreme, delivery area C spreads material and water over progressively more area thus reducing the transporting energy and increasing opportunities for in-transit deposition. Delivery area B represents an intermediate situation between A and C. A relative comparison of the three areas would have A delivering more sediment than B, which delivers more than C.

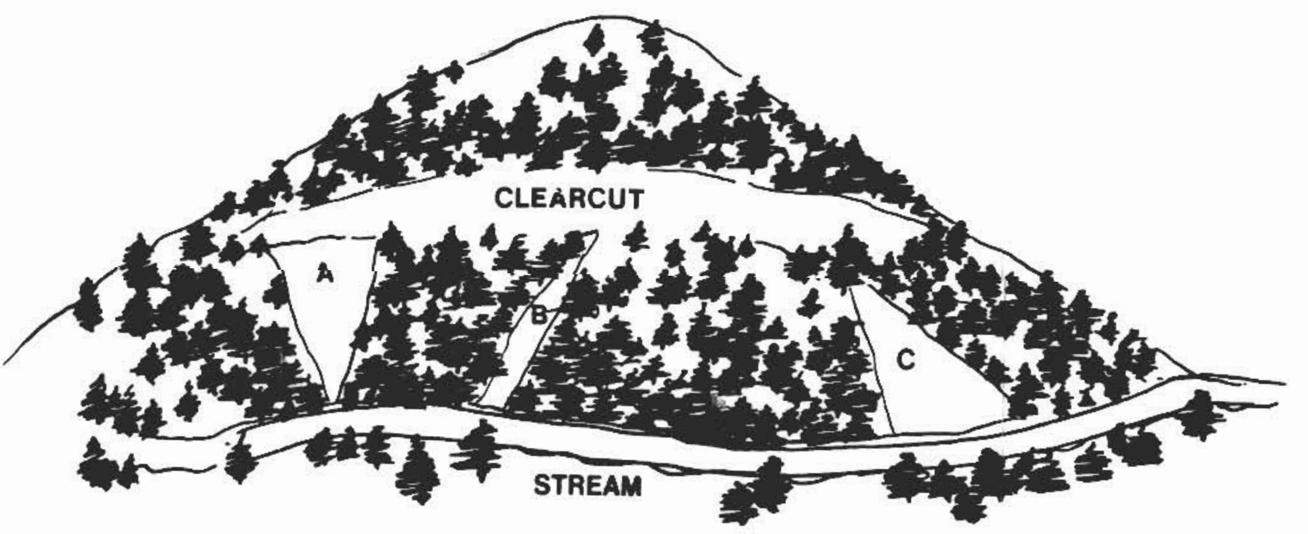


Figure IV.21.—Potential sediment transport paths (A,B, and C) for different parts of a slope.

Any working sediment delivery model must have clearly defined factors which represent the amount of surface runoff available for transporting sediment, the length of the transport path, the gradient of the path, the shape and changes in surface area of the path, a measure of surface microrelief, and a measure of ground cover. All of these factors should have measurable parameters and be combined together with the proper coefficients. To date, there is no accurate way to estimate the amount of surface runoff that might be available for sediment delivery in the forest environment, the actual shape and location of sediment delivery paths, degree of surface roughness, or characteristics of slope shape. An understanding of how to combine these factors or what coefficients to use is not known for most situations.

PROCEDURAL CONCEPTS: ESTIMATING SEDIMENT DELIVERY

This section discusses the concepts necessary for estimating sediment delivery and for evaluating the individual parameters involved. It is organized according to a conceptual perception of sediment delivery and corresponds with the flow chart of figure IV.1. An outline of the overall procedure for estimating sediment delivery to a stream from surface erosion sources is presented in "The Procedure" section of this chapter. A detailed example for using the procedure is provided in "Chapter VIII: Procedural Examples." All concepts discussed here are necessary for using the overall procedure.

The Sediment Delivery Index

An index approach is recommended to help bridge the gap between the need to estimate how much sediment reaches a stream channel and the lack of a working sediment delivery model to provide such estimates. This approach provides a relative evaluation of seven generally accepted environmental factors and one site specific factor that are considered important in the sediment delivery process. These eight factors are not necessarily the only ones that may be needed in all situations. This indexing procedure has not been validated by research. Therefore, the computed quantities may be different from measured quantities of sediment delivered to a stream channel. Use of the index is only an aid in evaluating the relative effects of different management practices on sediment delivery from a given forest area.

Evaluation Factors

For this discussion, each of the following eight factors is considered as though it acts independently of any other factor. In reality, these factors interact with each other in complex ways.

1. **Transport agent (e.g., water availability).** — Surface runoff from rainfall and snowmelt is an important factor in the movement of eroded material. It is estimated that overland flow rates from sheet and rill erosion rarely exceed 1 cfs on agricultural land and generally are less than 0.1 cfs on forest lands in the United States.
2. **Texture of eroded material.** — Assuming that aggregates do not form, individual particles of fine-textured soil material require less energy for delivery than particles of coarse-textured material. Sediment delivery efficiencies are higher on an area dominated by fine-textured material than on an area dominated by coarse-textured materials if the other factors influencing sediment delivery are equal.
3. **Ground cover.** — Ground cover (forest floor litter, vegetation, and rocks) creates a tortuous pathway for eroded particles to travel which allows time for the eroded material to settle from surface runoff water (Tollner and others 1976). Protective ground cover may also prevent raindrop impact energy from creating increased flow turbulance which would increase the carrying capacity of the runoff flow.
4. **Slope shape.** — Concave slopes between the source area and the stream channel promote deposition of the larger size fraction of the transported material (Neibling and Foster 1977). Convex slopes create more favorable conditions for increasing the material carrying capacity of the transporting agent. Slope shape is a difficult factor to quantify, but it seems to play an important role in sediment delivery.
5. **Slope gradient.** — Slope gradient, along with the volume of water available for sediment delivery, provides the necessary energy to deliver the eroded material. The efficiency of

the sediment delivery process increases with increasing slope gradient.

6. **Delivery distance.** — Increasing the distance from a sediment source to a stream channel or diversion ditch increases the effect that other factors have on the amount of sediment actually delivered. On the other hand, if a sediment source is very close to a stream channel, the other factors affecting sediment delivery have proportionally less opportunity to reduce the amount of sediment delivered.
7. **Surface roughness.** — Roughness of the soil surface affects sediment delivery similarly to that of ground cover. Rougher surfaces create more tortuous pathways for eroded particles to pass over and more surface area for water infiltration than smooth surfaces for a given area (Meeuwig 1970).
8. **Site specific factors.** — In many parts of the United States, unique forest environments and/or soil factors influence the sediment delivery efficiency. For example, soil nonwettability (DeBano and Rice 1975), mineralogy such as the Idaho batholith described by Megahan (1974), biological activity, or fire can change the sediment delivery efficiency of some forest lands. Within forested areas of the southeast United States, microrelief adjacent to stream channels may cause concentrated water flows, thus having a large effect on sediment delivery efficiency. Some soils have a greater tendency than others to form stable aggregates, hence reducing the sediment delivery efficiency.

Determining The Sediment Delivery Index

The stiff diagram shown in figure IV.22 uses vectors to display the magnitude and scale of each major factor identified as influencing sediment delivery. The area of the polygon created by connecting the observed, anticipated, or measured value for each factor is determined and related to the total possible area (the polygon formed by connecting the outer limits of each vector) of the graph. The percentage of area inside the polygon is coupled to the delivery index through the use of skewed probit transformations (Bliss 1935). Small polygonal areas surrounding the midpoint indicate a low probability of efficient sediment delivery, or, in other words, a very low sediment delivery index. Sediment delivery indexes will be low in most forest ecosystems managed by the best forest practices. Polygons approaching the outer limits of the stiff diagram indicate a high probability of efficient sediment delivery. The fraction of the total stiff diagram area formed by a given polygon is adjusted using figure IV.23, to give the sediment delivery index.

The scale and magnitude of the vectors in figure IV.22 have been defined as follows:

1. The magnitude of the transport agent is determined by the equation:

$$F = CRL \qquad \text{(IV.12)}$$

where:

F = water availability,

C = $2.31 \times 10^{-5} \frac{ft^2\ hr}{in\ sec}$ (a conversion constant)

R = maximum anticipated precipitation and/or snowmelt rate minus infiltration in units of in/hr from local records, and

L = slope length in feet of the sediment source area (perpendicular to contours).

Values of F for given values of R and L are in table IV.8.

The maximum scale value in figure IV.22 is 0.1 cfs. If the flow is calculated to exceed 0.1 cfs, use the scale factor of 0.1 for water availability. This model assumes that the precipitation input exceeds the site infiltration capacity causing overland flow conditions at the lower boundary of the eroded material source area. If no water is available then the sediment delivery index is zero (0.0).

2. Texture of eroded material is expressed as percent of eroded material that is finer than 0.05 mm (silt size). A particle diameter less than 0.05 mm was shown to be highly transportable for sediment movement (Neibling and Foster 1977). A scale factor of zero indicates that the eroded material contains no material less than 0.05 mm diameter, and a factor of 100 percent indicates that all of the eroded material is 0.05 mm or less in diameter.
3. Ground cover that is in actual contact with the soil surface, is expressed in percent cover between 0 (bare soil surface) and 100 (mineral soil surface completely covered). This factor is scaled based on unpublished data by Dissmeyer[2] which relates relative ground cover

[2]Personal communication of unpublished material from G. Dissmeyer, USDA Forest Service, State and Private Forestry, Atlanta, Ga.

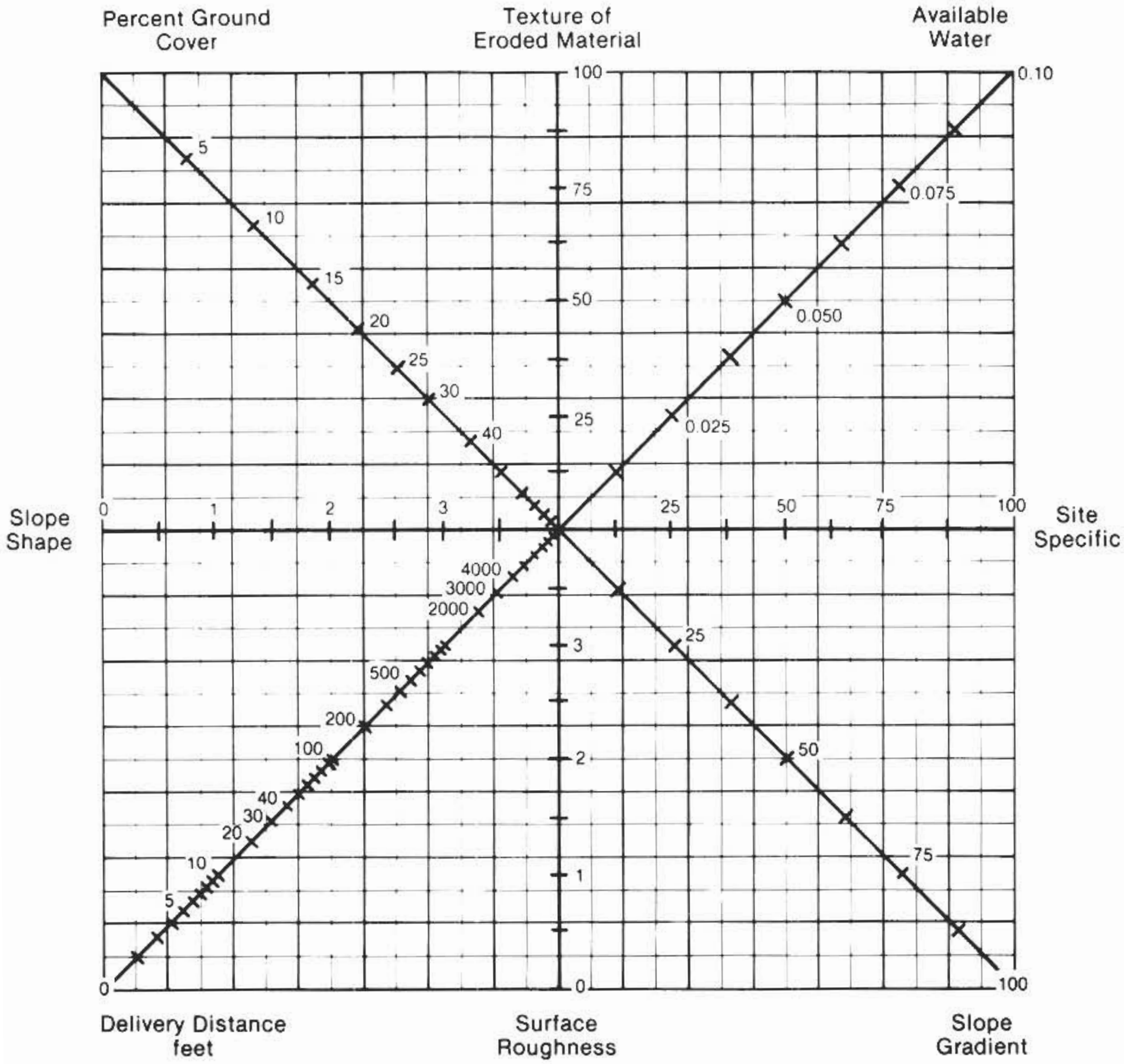


Figure IV.22—Stiff diagram for estimating sediment delivery.

density influence to overland water flow.

4. Slope shape is scaled in magnitude between 0 and 4, with 4 being a slope that is convex from the boundary of the source area to the stream channel. A scale factor of 0 describes a slope concave from the boundary of the source area to the stream channel, while a factor of 2 shows that one-half of the slope is concave and the other half is convex or that the entire slope is uniformly straight. A factor of 3 indicates that a larger percentage of the slope is convex in shape.
5. The slope gradient is the vertical elevation difference between the lower boundary of the source area and the stream channel divided by the horizontal distance and expressed as a percent between 0 and 100.
6. The distance factor is the $\log_{10}$ of the distance in feet from the boundary of the source area to a stream channel or ditch. Distances greater than 10,000 feet (3,050 m) are considered infinite. The distance vector is marked using a $\log_{10}$ scale so that distances are entered directly onto the vector in figure IV.22.

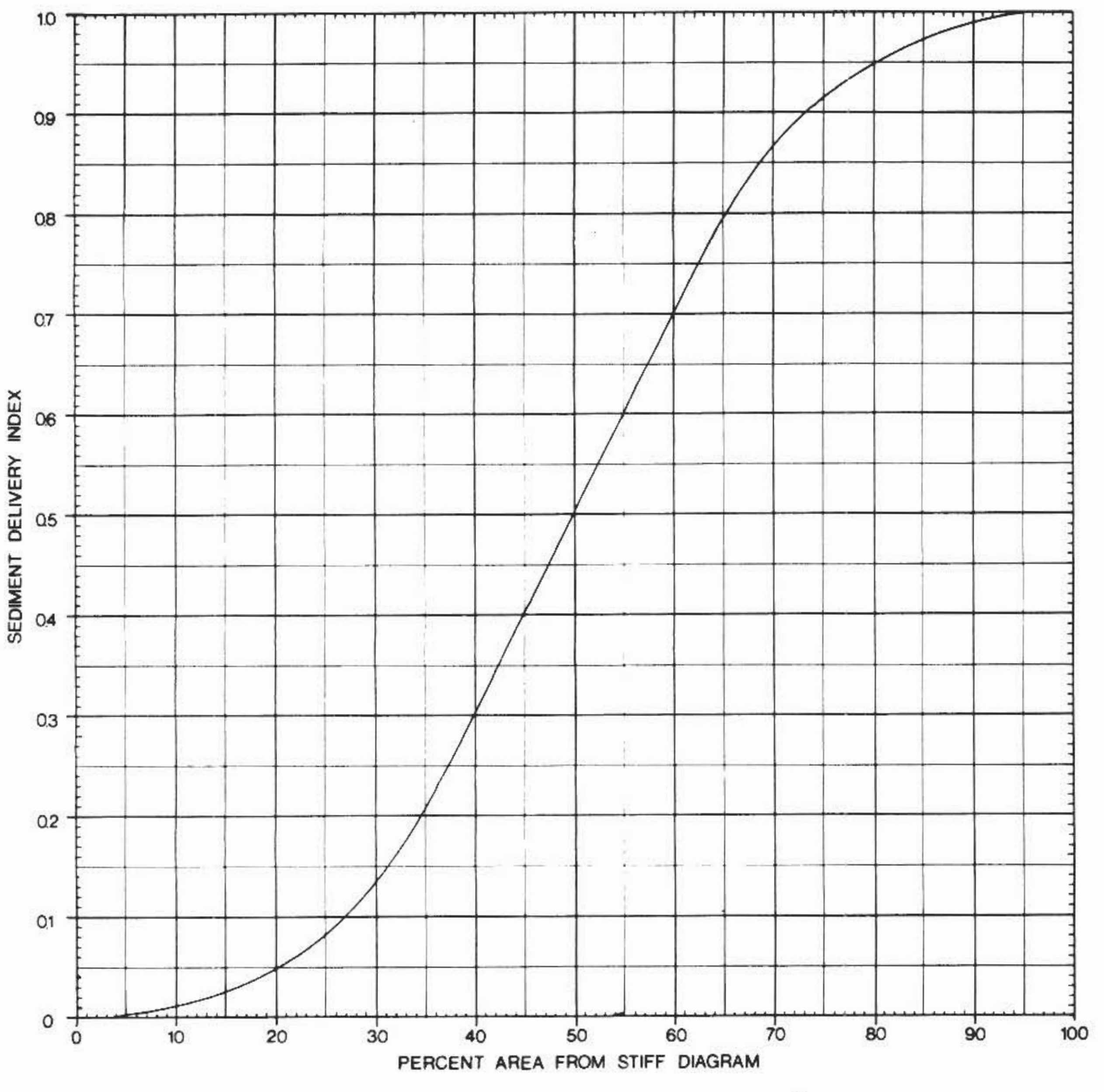


Figure IV.23.—Relationship between polygon area on stiff diagram and sediment delivery index.

7. The roughness factor is scaled in magnitude between 0 and 4 with 0 being an extremely smooth forest floor surface condition and 4 being a very rough surface. This is a subjective evaluation of soil surface conditions.

8. The site specific factor influencing delivery ratios is scaled between 0 and 100 and must be **assigned** its effective magnitude by a user familiar with the unique condition of the site.

Appropriate factor values are plotted on each vector of the graphic sediment delivery model (fig. IV.24). Lines are drawn to connect all plotted points to form an enclosed, irregular polygon. If a site specific factor is not used, draw a line directly between plotted points on the slope gradient and available water vectors. Determine the area inside the polygon by: measuring with a planimeter, estimating with a dot grid, or calculating and summing the areas of the individual triangles. Determine the percent of the total graph area that is

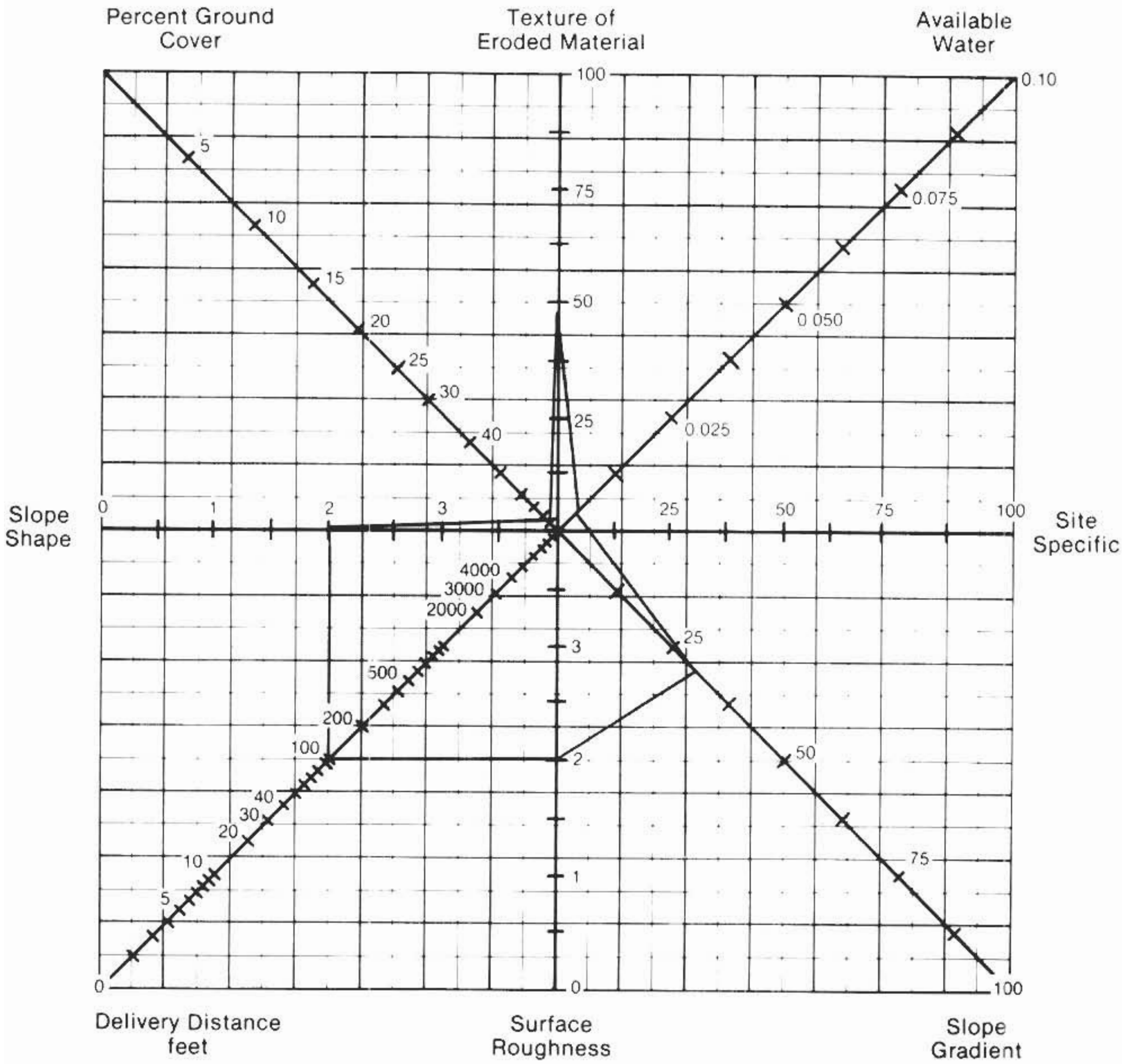


Figure IV.24.—Example of graphic sediment delivery model for road R3.1.

within the polygon. Using the S-shaped probit curve in figure IV.23, determine the sediment delivery index by using the percent area of the polygon from figure IV.24.

Table IV.8.—Water availability values for given source area slope length (ft) and runoff (in/hr)[1]

Surface slope length	Runoff															
	.025	.05	0.75	1.0	1.25	1.5	1.75	2.0	2.25	2.5	2.75	3.0	3.25	3.5	3.75	4.0
10	.00006	.00012	.00017	.00023	.00029	.00035	.00040	.00046	.00052	.00058	.00064	.00069	.00075	.00081	.00087	.00092
20	.00012	.00023	.00035	.00046	.00058	.00069	.00081	.00092	.0010	.0012	.0013	.0014	.0015	.0016	.0017	.0018
30	.00017	.00035	.00052	.00069	.00087	.0010	.0012	.0014	.0016	.0017	.0019	.0021	.0023	.0024	.0026	.0028
40	.00023	.00046	.00069	.00092	.0012	.0014	.0016	.0018	.0021	.0023	.0025	.0028	.0030	.0032	.0035	.0037
50	.00029	.00058	.00087	.0012	.0014	.0017	.0020	.0023	.0026	.0029	.0032	.0035	.0038	.0040	.0043	.0046
75	.00043	.00087	.0013	.0017	.0022	.0026	.0030	.0035	.0039	.0043	.0048	.0052	.0056	.0061	.0065	.0069
100	.00058	.0012	.0017	.0023	.0029	.0035	.0040	.0046	.0052	.0058	.0064	.0069	.0075	.0081	.0087	.0092
150	.00087	.0017	.0026	.0035	.0043	.0052	.0061	.0069	.0078	.0087	.0095	.010	.011	.012	.013	.014
200	.0012	.0023	.0035	.0046	.0058	.0069	.0081	.0092	.010	.012	.013	.014	.015	.016	.017	.018
250	.0014	.0029	.0043	.0058	.0072	.0087	.010	.012	.013	.014	.016	.017	.019	.020	.022	.023
300	.0017	.0035	.0052	.0069	.0087	.010	.012	.014	.016	.017	.019	.021	.023	.024	.026	.028
350	.0020	.0040	.0061	.0081	.010	.012	.014	.016	.018	.020	.022	.024	.026	.028	.030	.032
400	.0023	.0046	.0069	.0092	.012	.014	.016	.018	.021	.023	.025	.028	.030	.032	.035	.037
450	.0026	.0052	.0078	.010	.013	.016	.018	.021	.023	.026	.029	.031	.034	.036	.039	.042
500	.0029	.0058	.0087	.012	.014	.017	.020	.023	.026	.029	.032	.035	.038	.040	.043	.046
1000	.0058	.012	.017	.023	.029	.035	.040	.046	.052	.058	.064	.069	.075	.081	.087	.092

[1]The table values were obtained by the formula:

$$F = \left(2.31 \times 10^{-5} \frac{ft^2\,hr}{in\ sec}\right)\left(\text{Runoff in/hr}\right)(\text{slope length ft.})$$

Estimating Sediment Delivery By Activity

Each land-disturbing activity should have an estimate of soil loss for the location where it occurs and a delivery index based on site characteristics. An estimate of the amount of sediment which might reach a stream channel can be obtained by multiplying the surface soil loss (tons/year) by the sediment delivery index for each erosion response unit.

All of the procedures used to arrive at an estimate of surface soil loss and sediment delivered to a stream channel only provide a way to evaluate alternative management practices. Only on-the-ground monitoring can verify if the objectives have been met by the management strategy.

CONSIDERATIONS FOR REDUCING SEDIMENT DELIVERY

Theoretically it is possible to reduce sediment delivered to a stream channel by making appropriate changes in any of the index factors. In actual practice, some factors are easier to change than others. The following tabulation describes the basic concepts underlying each factor and the changes brought about by controls for sediment delivery. This conceptual presentation is to aid understanding of controls and determining which control practice to use. Details of specific control practices may be found in "Chapter II: Control Opportunities."

Sediment delivery factors	Preventive	Mitigative
Water availability	Control over the rainfall rate is not likely to occur because it is a function of overall weather patterns.	
	Use management practices that maintain high infiltration rates. Avoid such things as soil compaction which changes soil structure and permeability. Control of soil moisture content by high consumptive use promotes infiltration.	Increase infiltration rates by breaking surface crusts, and incorporating organic matter or other soil amendments to improve aggregation of soil particles. Promote vegetative growth for high consumptive water use and desirable soil structure development.
	Where snowmelt is influential, use management practices which will not create significant increases in the amount of solar energy reaching the snow pack.	Reduce snowmelt runoff rates by increasing the interception of solar energy above the snow surface.
Texture of eroded material	Soil texture is controlled by soil-forming factors that are generally related to mineralogy and weathering.	
	Maintain natural, stable soil aggregates which will act as a coarse-textured material in response to sediment delivery forces.	Use soil amendments which promote floculation and development of aggregates.

Sediment delivery factors	Preventive	Mitigative
Ground cover	Control and design forest management activities to minimize forest floor disturbance.	Add mulch, establish vegetation, distribute residues, or use other practices to create long tortuous pathways for water flow and sediment delivery.
Slope shape	Control location and design of various types of construction and other activities that would create adverse slope shapes.	Design concave slope segments for sediment delivery control on construction sites or with other activities.
Slope gradient	Control location and design of various types of construction activities to minimize the cıeation of steep slopes.	Reduce slope gradients created by construction and other activities wherever possible.
Delivery distance	Locate activities well away from stream channels to maintain long delivery paths.	Relocate activity sites to increase overall delivery distance to a stream channel.
Surface roughness	Design activities to maintain natural surface roughness. Avoid creating channels that shortcut natural tortuous pathways.	Create ridges and depressions on the surface to trap sediment and increase water infiltration.
Site specific factors	This will depend upon the characteristics of the chosen site factor.	

APPLICATIONS, LIMITATIONS AND PRECAUTIONS: SEDIMENT DELIVERY

Very few attempts have been made to verify the reliability of sediment delivery models due to the difficulty of obtaining sufficient data for testing. The following limitations attributed to this model are not based on actual data but are deduced as being important. Future research may add to or change ideas about these limitations.

1. Only sheet flow surface runoff is addressed with the sediment delivery index. If channeled flow develops, other approaches must be used to describe sediment delivery.
2. The choice of factors used to describe sediment delivery is thought to apply in all cases; however, these may vary with future research.
3. The scaling of each factor on the stiff diagram is based on the best available information; however, new research information will probably show a need for some changes
4. Many factors work together in various ways to influence sediment delivery. These interactions have not been studied extensively and may not be expressed correctly by the model.
5. The model assumes that the only water used to move the sediment is generated on the sediment delivery path. It does not consider the potential for additional water from other sources on the slope. Solution of this problem depends on the development of a satisfactory water routing model.
6. Individual sediment delivery routes have various shapes and overall surface areas which are not accounted for by the model.
7. Infiltration rates may be different on disturbed areas than in sediment filter strips. Only the infiltration rate for the disturbed site is used.
8. Antecedent soil moisture conditions are not incorporated into the model. If sediment delivery is most likely to occur during certain time periods with particular soil moisture characteristics, then some adjustments could be made in the infiltration rate.

THE PROCEDURE

ESTIMATING SEDIMENT DELIVERY FROM SURFACE EROSION SOURCES

The following steps outline the overall procedure for estimating sediment delivery to a stream from surface erosion sources. Steps 1 through 11 represent the procedure for estimating surface soil loss, and steps 12 through 15 represent the procedure for estimating sediment delivery. A complete example for using the procedure is provided in "Chapter VIII: Procedural Examples." Most of the steps are self explanatory; however, the specific concepts, parameters and computations involved in the procedure were discussed earlier in this chapter under "Procedural Concepts: Estimating Soil Surface Loss" and "Procedural Concepts: Estimating Sediment Delivery."

Step 1. — Identify the watershed of interest and obtain the necessary materials and information.

Step 2. — Delineate the drainage network in as much detail as the topographic base will allow.

Step 3. — Delineate the hydrographic divides relative to the drainage network identified in Step 2 above.

Step 4. — Delineate soil and vegetative ground cover units based on appropriate data.

Step 5. — Show the proposed land use activity in detail, delineating cutting units, roads, landings and skid trails, etc.

Step 6. — Using overlays, incorporate all map-related information onto a single map base.

Step 7. — Show the direction of water flow for each hydrographic source area.

Step 8. — Set up worksheets for estimating potential sediment load (wkshts. IV.1—IV.8).

Step 9. — List each source area that is delineated, and number by erosion response unit.

Step 10. — Working in individual hydrographic areas, determine for each erosion response unit the values for the variables R, K, LS, and VM.

Step 11. — Using the values from step 10, calculate the estimated surface soil loss (tons/year).

Step 12. — Working by erosion response units, determine for each treatment source the sediment delivery index (SD_1).

Step 13. — Calculate the estimated tons per year of sediment input to the stream system by each erosion response unit.

Step 14. — Arrange erosion response unit sediment values in matrix by treatment type.

Step 15. — Evaluate results.

LITERATURE CITED

Adams, G. E., D. Kirkham, and W. H. Scholtes. 1958. Soil erodibility and other physical properties of some Iowa soils. J. Sci., Iowa State Coll. 32:485-540.

Barnett, A. P., and J. S. Rogers. 1966. Soil physical properties related to runoff and erosion from artificial rainfall. Trans. Am. Soc. Agric. Eng. 9:123-125.

Bekey, G. A. 1977. Models and reality: Some reflections on the art and science of simulation. Simulation 29(5):161-164.

Bennett, H. H. 1934. Dynamic action of rains in relation to erosion in the humid region. Trans. Am. Geophys. Union, Fifteenth meeting. p. 474-488.

Bennett, J. P. 1974. Concepts of mathematical modeling of sediment yield. Water Resour. Res. 10(3):485-492.

Bliss, C. I. 1935. The calculation of the dosage mortality curve. Ann. Appl. Biol. 22(1):134-167.

Browning, G. M., C. L. Parish, and J. A. Glass. 1947. A method for determining the use and limitation of rotation and conservation practices in control of soil erosion in Iowa. J. Am. Soc. Agron. 39:65-73.

Chapman, Gordon. 1948. Size of raindrops and their striking force at the soil surface in a red pine plantation. Trans. Am. Geophys. Union 29:664-670.

Clyde, Calvin F., C. Earl Israelsen, and Paul E. Packer. 1976. Erosion control during highway construction, Vol. II. Manual of erosion control principles and practices. Utah Water Res. Lab., Utah State Univ., Logan.

Cruse, R. M., and W. E. Larson. 1977. Effect of soil shear strength on soil detachment due to raindrop impact. Soil Sci. Soc. of Am. J. 41(4):777-781.

DeBano, L. F., and R. M. Rice. 1975. Water-repellant soils: Their implications in forestry. J. For. 71(4):222-223.

Dohrenwend, R. E. 1977. Raindrop erosion in the forest. Res. Note No. 4, Mich. Technol. Univ., Ford For. Cent., Lanse, Mich. 49946. 19 p.

Ellison, W. D. 1947. Soil erosion studies — part I. Agric. Eng. 28(4):145-146.

Foster, G. R., and W. H. Wischmeier. 1973. Evaluating irregular slopes for soil loss prediction. ASAE, Pap. No. 73-227, Am. Soc. Agric. Eng., St. Joseph, Mich.

Foster, G. R., L. D. Meyer, and C. A. Onstad. 1977. A runoff erosivity factor and variable slope length exponent for soil loss estimates. Trans. Am. Soc. Agric. Eng. 20(4):683-687.

Foster, G. R., and L. D. Meyer. 1977. Soil erosion and sedimentation by water — an overiew. *In:* Proc. Natl. Symp. on Soil Erosion and Sedimentation by Water. ASAE, publ. 4-77, Am. Soc. Agric. Eng., St. Joseph, Mich. p. 1-13.

Fredrikson, R. L. 1972. Nutrient budget of a Douglas-fir forest on an experimental watershed in western Oregon. *In:* Proc. res. on coniferous for. ecosyst. p. 115-131. J. F. Franklin, L. P. Dempster, and R. H. Waring, eds. US/IBP, USDA, For. Serv., Pac. Northwest For. and Range Exp. Stn., Portland, Ore.

Gottschalk, L. C., and G. M. Brune. 1950. Sediment design criteria for the Missouri Basin loess hills. USDA Soil Conserv. Serv. Tech. Pap. No. 97.

Gunn, R., and G. D. Kinzer. 1949. The terminal velocity of fall for water droplets. J. Meteorol. 6:243-248.

Horton, R. E. 1975. Erosional development of streams and their drainage basins, hydrophysical approach to quantitative morphology. Geol. Soc. Am. Bull. 56:275-370.

Laws, J. O. 1941. Measurement of fall-velocity of water drops and rain drops. Trans., Am. Geophys. Union 22:709-721.

Laws, J. O., and D. A. Parsons. 1943. Relation of raindrop size to intensity. Trans., Am. Geophys. Union 24:452-460.

Lillard, J. H., H. T. Rogers, and J. Elson. 1941. Effects of slope, character of soil, rainfall, and cropping treatments on erosion losses from dunmore silt loam. Va. Agric. Exp. Stn. Tech. Bull. 72. 32 p.

Maner, S.B. 1958. Factors affecting sediment delivery rates in the Red Hills physiographic area. Trans. Am. Geophys. Union 39:669-675.

Maner, S.B. and L.H. Barnes. 1953. Suggested criteria for estimating gross sheet erosion and sediment delivery rates for the Blackland Prairies problem area in soil conservation. U.S. Dep. Agric., Soil Conserv. Serv., Western Gulf Region, Fort Worth, Texas. Mimeograph.

Meeuwig, R. D. 1970. Infiltration and soil erosion as influenced by vegetation and soil in northern Utah. J. Range Manage. 23(3):185-188.

Megahan, W. F. 1974. Erosion over time on severely disturbed granitic soil: A model. USDA For. Serv. Res. Pap. INT-156. 14 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Megahan, W. F. 1978. Erosion processes on steep granitic roadfills in Central Idaho. Soil Sci. Soc. Am. J. 42(2):350-357.

Meyer, L. D., G. R. Foster, and M. J. M. Romkens. 1975. Origin of eroded soil from upland slopes. *In:* Present and Prospective Tech. for Predict. Sediment Yields and Sour. U.S. Dep. Agric., Agric. Res. Serv. Rep. ARS-S-40:177-189.

Meyer, L. D., D. G. DeCoursey, and M. J. M. Romkens. 1976. Soil erosion concepts and misconceptions. Proc. Third Fed. Inter-agency Sedimentation Conf.

Middleton, H. E., C. S. Slater, and H. G. Byers. 1932. Physical and chemical characteristics of the soils from the erosion experiment stations. U.S. Dep. Agric. Tech. Bull. 316. 51 p.

Musgrave, G. W. 1947. The quantitative evaluation of factors in water erosion, a first approximation. J. Soil and Water Conserv. 2:133-138.

Neibling, W. H., and G. R. Foster. 1977. Estimating deposition and sediment yield from overland flow processes. Proc. of Int. Symp. on Urban Hydrol., Hydraul., and Sediment Contr., Univ. Kentucky, Lexington, Ky. p. 75-86.

Olson, T. C., and W. H. Wischmeier. 1963. Soil-erodibility evaluations for soils on the runoff and erosion stations. Soil Sci. Soc. Am. Proc. 27:590-592.

Osborn, J. F., R. E. Pelishek, and J. S. Krammes. 1964. Soil wettability as a factor in erodibility. Soil Sci. of Am. Proc. 28(2):294-295.

Peele, T. C., E. E. Latham, and O. W. Beale. 1945. Relation of the physical properties of different soil types to erodibility. S. C. Agric. Exp. Stn. Bull. 357.

Renfro, G. W. 1975. Use of erosion equations and sediment delivery ratios for predicting sediment yield. *In:* Proc. Sedimentation Yield Workshop, Oxord, Miss. U.S. Dep. Agric., Agric. Res. Serv. Rep. ARS-S-40:33-45.

Roehl, J. W. 1962. Sediment source areas, delivery ratios and influencing morphological factors. Int. Assoc. Sci. Hydrol. Publ. No. 59.

Roth, C. B., D. W. Nelson, and M. J. M. Romkens. 1974. Prediction of subsoil erodibility using chemical, mineralogical and physical parameters. U.S. Environ. Protect. Agency Rep. EPA-660/2-74-043. USGPO, Washington D.C. 111 p.

Simons, D. B., R. M. Li, and M. A. Stevens 1975. Development of models for predicting water and sediment routing and yield from storms on small watersheds. Colo. State Univ. Rep. CER 74-75-DBS-RML-MAS24.

Smith, D. D., and W. H. Wischmeier. 1957. Factors affecting sheet and rill erosion. Trans. Am. Geophys. Union 38(6):889-896.

Smith, D. D., and W. H. Wischmeier. 1962. Rainfall erosion. Adv. Agron. 14:109-148.

Swank, W. T., N. B. Goebel, and J. D. Helvey. 1972. Interception loss in loblolly pine stands of the South Carolina Piedmont. J. Soil and Water Conserv. 27(4):160-164.

Tollner, E. W., B. J. Barfield, C. T. Haan, and T. Y. Kao. 1976. Suspended sediment filtration capacity of simulated vegetation. Trans. Am. Soc. Agric. Eng. 19(4):678-682.

Trimble, G. R., Jr., and S. Weitzman. 1954. Effect of a hardwood forest canopy on rainfall intensities. Trans. Am. Geophys. Union, 35(2);226-234.

U.S. Army Engineer School. 1973. Open channel design, student pamphlet, U.S. Army Eng. Sch., Ft. Belvoir, Va. Stock No. E.004-C1-SP-003.

U.S. Department of Agriculture, Soil Conservation Service 1977. Procedure for computing sheet and rill erosion on project areas. U.S. Dep. Agric. Soil Conserv. Serv., Tech. Release No. 41, (Rev. 2). 17 p.

U.S. Department of Agriculture, Soil Survey Staff. 1951. Soil survey manual. U.S. Dep. Agric., Agric. Handb. No. 18, U.S. Gov. Print. Off., Wash., D.C., 503 p.

Williams, J. R., H. D. Berndt. 1972. Sediment yield computed with universal equation. J. Hydraul. Div. Am. Soc. Civ. Eng. 98(HY12):2087-2098.

Williams, J. R., and W. V. LaSeur. 1976. Water yield model using SCS curve numbers. J. Hydraul. Div. Am. Soc. Div. Eng. 102(HY9):1241-1253.

Wischmeier, W. H. 1972. Upslope erosion analysis. *In*: Environmental impact on rivers. p 15-1 — 15-26. Colo. St. Univ., Fort Collins.

Wischmeier, W. H. 1975. Estimating the soil loss equation's cover and management factor for undisturbed areas. p. 118-124. *In:* Present and prospective technology for predicting sediment yields and sources. Proc. Sediment-Yield Workshop, U.S. Dep. Agric. Sediment Lab., Oxford, Miss. Nov. 28-30, 1972. 285 p. MS, ARS-S-40.

Wischmeier, W.H. 1976. Use and misuse of the Universal Soil Loss Equation. J. Soil and Water Conserv. 31:5-9.

Wischmeier, W. H., and D. D. Smith. 1958. Rainfall energy and its relation to soil loss. Trans. Am. Geophys. Union 39(2):285-291.

Wischmeier, W. H., and D. D. Smith. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. U.S. Dep. Agric., Agric. Handb. 282, USGPO, Washington, D.C.

Wischmeier, W. H. and D. D. Smith. 1968. A universal soil-loss equation to guide conservation farm planning. Trans. Int. Congr. Soil Sci. 1:418-425.

Wischmeier, W. H., and J. V. Mannering. 1969. Relation of soil properties to its erodibility. Soil Sci. Soc. Am. Proc. 33:131-137.

Wischmeier, W. H., C. B. Johnson, and B. V. Cross. 1971. A soil erodibility nomograph for farmland and construction sites. J. Soil and Water Conserv. 26:189-193.

Wischmeier, W. H., and D. D. Smith. Predicting rainfall-erosion losses as a guide to conservation planning. U.S. Dep. Agric. Sci. and Educ. Adm., Agric. Handb. 282, (rev.). [In press.]

Zingg, A. W. 1940. Degree and length of land slope as it affects soil loss in runoff. Agric. Eng. 21:59-64.

APPENDIX IV.A.:
GULLY EROSION

A gully is a channel created by concentrated but intermittent flow of water, usually during and immediately following heavy rains; however, concentration of snowmelt runoff may also be a factor. Gullies are deep enough to interfere with, and usually are not obliterated by, normal tillage or silvicultural activities.

Quantitative estimates of soil loss and sediment produced by gully erosion must be based on professional judgment about the overall erosional processes in a particular location. Changes in the geometry of a gully can provide an estimate of the amount of material being eroded. Rates of headward cutting, final average width, and depth of each cycle of cutting can be used to compute the volume of soil material removed from the gully. The mass of soil material is calculated by multiplying the volume by an appropriate bulk density factor for the particular soil.

Bulk density is usually expressed in grams per cubic centimeter or pounds per cubic foot. Conversion factors are:

$$g/cm^3 = (0.016)\ (lb/ft^3)$$
$$lb/ft^3 = (62.43)\ (g/cm^3)$$

An estimate of the proportion of eroded material actually delivered to a stream channel may be needed if the gully does not connect directly to a stream system.

APPENDIX IV.B.:

EROSION OVER TIME

To predict long-term, onsite soil losses, changes in the various parameters in the soil loss equation must be estimated and redefined for each year. The most important is the VM factor. The K factor needs to be changed if management causes long-term changes in soil characteristics to occur. Future changes in VM and K factors become, at best, an educated guess about what might happen in any given year. Time trend analysis should be based on both best condition and worst condition parameters in order to show a range of possible outcomes.

The part of the equation which is most likely to change with time is the VM factor. The effects of roughness and vegetation change with time either as the surface roughness is broken down or as the vegetation becomes healthier and covers more of the surface. Estimates of VM changes must be made relative to the time period of interest.

Fine materials in the surface soil tend to erode away, leaving the heavier material, which is less erosive to protect the surface (Clyde and others 1976, Megahan 1974, Wischmeier and Mannering 1969). Other long-term changes due to management must also be evaluated.

APPENDIX IV.C.:
CONTROLLING DITCH EROSION

The simulation procedures in Chapter IV, "Surface Erosion" do not consider road ditch erosion. There is no technique to estimate the amount of sediment delivered to the stream from road ditches. Because some controls are designed to affect road ditch erosion, the Manning formula (U.S. Army Engineering School 1973) is used to estimate the effect of various controls on road ditch stability and water velocity. Manning's formula is:

$$V = \left(\frac{1.49}{n}\right)(R^{0.66})(S^{0.5}) \qquad \text{(IV.C.1)}$$

where:

V = velocity of flow in ft/sec,

R = hydraulic radius, = $\dfrac{\text{cross-section area of the channel}}{\text{wetted perimeter (ft)}}$ (from tables IV.C.2 through IV.C.5)

S = slope of the channel in ft/ft, and

n = friction factor which depends on the material comprising the channel from Table IV.C.1

Manning formula limitations: (1) It will not predict amounts of sediment delivered to the stream from a road ditch. (2) The formula is based on the amount of energy necessary to move particles of given size, and does not account for detachment. Soils with strong structure are likely to be more resistant than soils with weak structure. (3) The maximum recommended velocity figures are based on energy/particle size relationships.

An Example For Use Of The Manning Formula

Problem — Determine whether the water velocity for a given road ditch will be below critical levels for erosion. If velocities are too high, make and evaluate changes.

Solution

1. Obtain hydraulic radius for channel. Assume that the road ditch is a symmetrical, triangular channel 1.3 feet deep with 2½:1 slopes. Check table IV.C.2 for hydraulic radius which is 0.60 feet for this size channel.
2. Obtain slope of channel. (Slope of the road ditch is measured and found to be 0.003 feet per feet.)
3. Obtain roughness coefficient from table IV.C.1.(The channel sides, in this case, are sand and have a friction factor (n) of 0.020.)
4. Obtain maximum allowable velocity. (For a sandy channel, the maximum velocity is 1-2 feet per second (table IV.C.1).)
5. Obtain V (velocity) for the specified channel by using the nomograph (fig. IV.C.1). (Velocity for the specified ditch is 2.9 feet per second.)
6. Compare the predicted velocity for the specified ditch with the maximum recommended velocity for sandy channels.

specified ditch	maximum velocity
2.9 ft/sec	1-2 ft/sec

If the specified ditch has too great a velocity, it will erode. Therefore, controls must be chosen that will reduce the water velocity in the road ditch.

7. Water velocities in ditches can be reduced by protecting the channel with vegetation, rock, or by changing the channel shape. (With vegetative protection, the friction factor (n) becomes 0.030-0.050 and the maximum recommended velocity becomes 3-4 feet per second.)
8. Obtain velocity for specified ditch with vegetative protection by referring to the nomograph (fig. IV.C.1). Velocity is 1.9 feet per second.
9. Compare the predicted velocity for the specified ditch with the maximum recommended velocity for vegetation protected channels (average turf) with easily eroded soil.

specified ditch	maximum velocity
1.9 ft/sec	3-4 ft/sec

10. If the specified ditch has a lower velocity than the recommended maximum velocities, it should be stable as long as the vegetation remains intact.

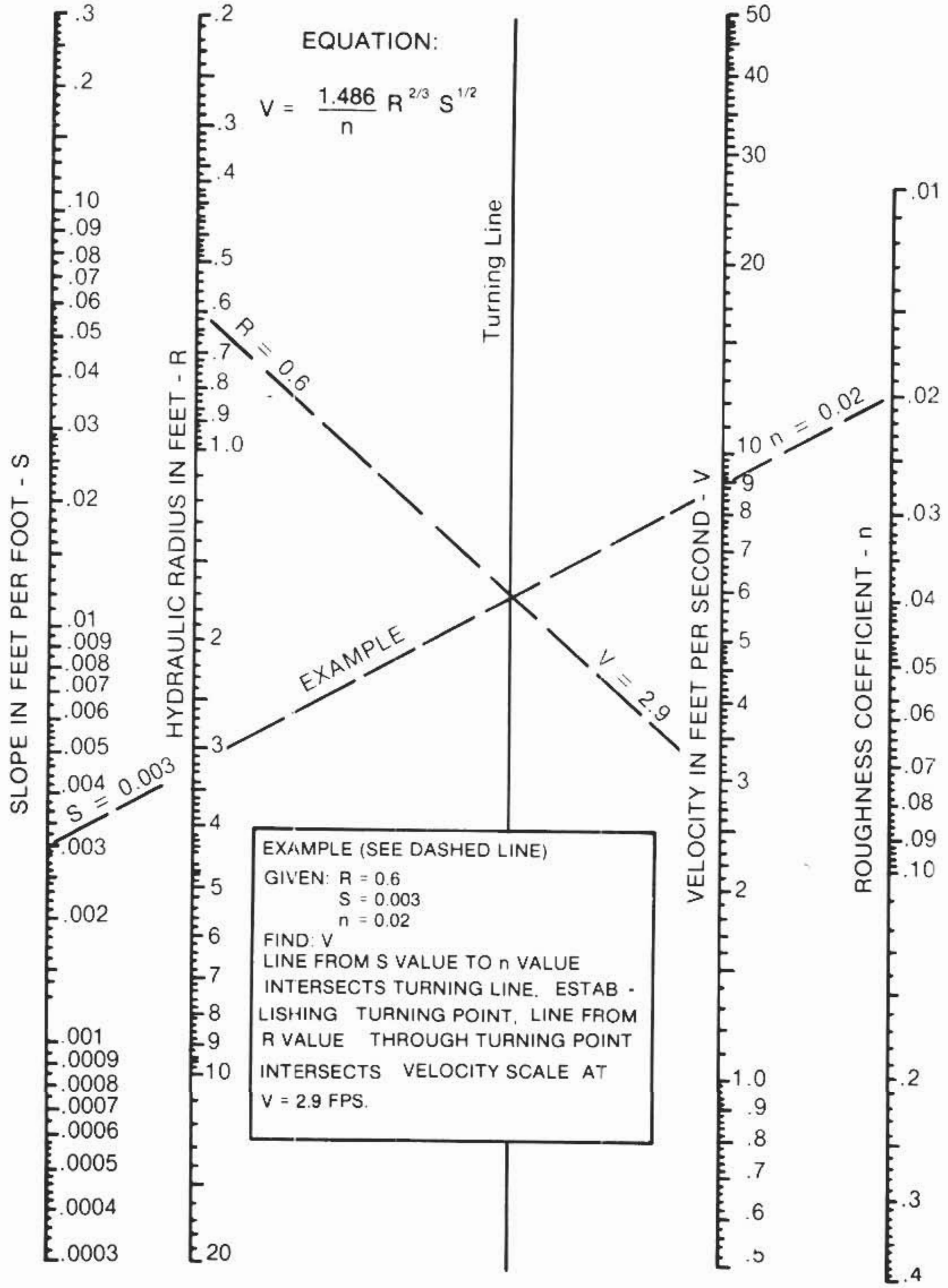


Figure IV.C.1 Nomograph for Manning formula.

Table IV.C.1—Values for Manning's n and maximum permissible velocity of flow in open channels

Ditch lining						Manning's n	V_{max} fps[1]
1. Natural earth							
a. Without vegetation							
(1) Rock							
(a) Smooth and uniform						0.035 - 0.040	20
(b) Jagged & irregular						0.040 - 0.045	15 - 18
(2) Soils							
			Unified	USDA			
Coarse grained	Gravel and gravelly soils		GW	Gravel		0.022 - 0.024	6 - 7
Coarse grained	Gravel and gravelly soils		GP	Gravel		0.023 - 0.026	7 - 8
Coarse grained	Gravel and gravelly soils		GM	Loamy Gravel	d	0.023 - 0.025	3 - 5
Coarse grained	Gravel and gravelly soils		GM	Loamy Gravel	u	0.022 - 0.020	2 - 4
Coarse grained	Gravel and gravelly soils		GC	Gravelly Loam Gravelly Clay		0.024 - 0.026	5 - 7
Coarse grained	Sand and sandy soils		SW	Sand		0.020 - 0.024	1 - 2
Coarse grained	Sand and sandy soils		SP	Sand		0.022 - 0.024	1 - 2
Coarse grained	Sand and sandy soils		SM	Loamy Sand	d	0.020 - 0.023	2 - 3
Coarse grained	Sand and sandy soils		SM	Loamy Sand	u	0.021 - 0.023	2 - 3
Coarse grained	Sand and sandy soils		SC	Sandy Loam		0.023 - 0.025	3 - 4
Fine grained	Silts and clays	LL 50	CL	Clay Loam Sandy Clay Loam Silty Clay		0.022 - 0.024	2 - 3
Fine grained	Silts and clays	LL 50	ML	Silt Loam Very Fine Sand Silt		0.023 - 0.024	3 - 4
Fine grained	Silts and clays	LL 50	OL	Mucky Loam		0.022 - 0.024	2 - 3
Fine grained	Silts and clays	LL 50	CH	Clay		0.022 - 0.023	2 - 3
Fine grained	Silts and clays	LL 50	MH	Silty Clay		0.023 - 0.024	3 - 5
Fine grained	Silts and clays	LL 50	OH	Mucky Clay		0.022 - 0.024	2 - 3
Highly Organic			PT	Peat		0.022 - 0.025	2 - 3

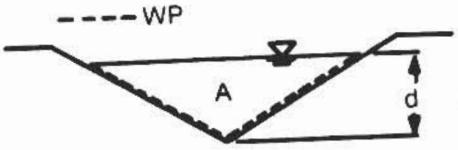
[1]Maximum recommended velocities

Table IV.C.1—Continued

Ditch lining	Manning's n	V_{max} fps[1]
b. With vegetation		
(1) Average turf		
(a) Erosion resistant soil	0.050 - 0.070	4 - 5
(b) Easily eroded soil	0.030 - 0.050	3 - 4
(2) Dense turf		
(a) Erosion resistant soil	0.070 - 0.090	6 - 8
(b) Easily eroded soil	0.040 - 0.050	5 - 6
(3) Clean bottom with bushes on sides	0.050 - 0.080	4 - 5
(4) Channel with tree stumps		
(a) No sprouts	0.040 - 0.050	5 - 7
(b) With sprouts	0.060 - 0.080	6 - 8
(5) Dense weeds	0.080 - 0.120	5 - 6
(6) Dense brush	0.100 - 0.140	4 - 5
(7) Dense willows	0.150 - 0.200	8 - 9
2. Paved	(Construction)	
a. Concrete, w/all surfaces:	**Good Poor**	
(1) Trowel finish	0.012 - 0.014	20
(2) Float finish	0.013 - 0.015	20
(3) Formed, no finish	0.014 - 0.016	20
b. Concrete bottom, float finished, w/sides of:		
(1) Dressed stone in mortar	0.015 - 0.017	18 - 20
(2) Random stone in mortar	0.017 - 0.020	17 - 19
(3) Dressed stone or smooth concrete rubble (riprap)	0.020 - 0.025	15
(4) Rubble or random stone (riprap)	0.025 - 0.030	15
c. Gravel bottom, sides of:		
(1) Formed concrete	0.017 - 0.020	10
(2) Random stone in mortar	0.020 - 0.023	8 - 10
(3) Random stone or rubble (riprap)	0.023 - 0.033	8 - 10
d. Brick	0.014 - 0.017	10
e. Asphalt	0.013 - 0.016	18 - 20

[1]Maximum recommended velocities

Table IV.C.2. Hydraulic radius (R) and area (A) of symmetrical triangular channels.

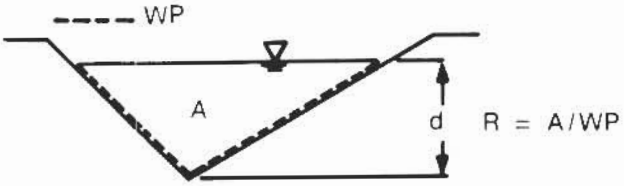


R = A/WP

Depth, d (feet)	1:1 A	1:1 R	1½:1 A	1½:1 R	2:1 A	2:1 R	2½:1 A	2½:1 R	3:1 A	3:1 R	4:1 A	4:1 R
0.5	0.25	0.18	0.38	0.21	0.50	0.22	0.63	0.23	0.75	0.24	1.00	0.24
0.6	0.36	0.21	0.54	0.25	0.72	0.27	0.90	0.28	1.08	0.28	1.44	0.29
0.7	0.49	0.25	0.74	0.29	0.98	0.31	1.23	0.32	1.47	0.33	1.96	0.34
0.8	0.64	0.28	0.96	0.33	1.28	0.36	1.60	0.37	1.92	0.38	2.56	0.39
0.9	0.81	0.32	1.21	0.37	1.62	0.40	2.03	0.42	2.43	0.43	3.24	0.44
1.0	1.00	0.35	1.50	0.42	2.00	0.45	2.50	0.46	3.00	0.47	4.00	0.49
1.1	1.21	0.39	1.82	0.46	2.42	0.49	3.03	0.51	3.63	0.52	4.84	0.53
1.2	1.44	0.42	2.16	0.50	2.88	0.54	3.60	0.56	4.32	0.57	5.76	0.58
1.3	1.69	0.46	2.54	0.54	3.38	0.58	4.23	0.60	5.07	0.62	6.76	0.63
1.4	1.96	0.50	2.94	0.58	3.92	0.63	4.90	0.65	5.88	0.66	7.84	0.68
1.5	2.25	0.53	3.38	0.62	4.50	0.67	5.63	0.70	6.75	0.71	9.00	0.73
1.6	2.56	0.57	3.84	0.67	5.12	0.72	6.40	0.74	7.68	0.76	10.24	0.78
1.7	2.89	0.60	4.34	0.71	5.78	0.76	7.23	0.79	8.67	0.80	11.56	0.83
1.8	3.24	0.64	4.86	0.75	6.48	0.80	8.10	0.84	9.72	0.85	12.96	0.87
1.9	3.61	0.67	5.42	0.79	7.22	0.85	9.03	0.88	10.83	0.90	14.44	0.92
2.0	4.00	0.71	6.00	0.83	8.00	0.90	10.00	0.93	12.00	0.95	16.00	0.97
2.5	6.25	0.88	9.38	1.04	12.50	1.12	15.63	1.16	18.75	1.19	25.00	1.21
3.0	9.00	1.06	13.50	1.25	18.00	1.34	22.50	1.39	27.00	1.42	36.00	1.46
3.5	12.25	1.24	18.38	1.45	24.50	1.56	30.62	1.62	36.75	1.66	49.00	1.70
4.0	16.00	1.41	24.00	1.66	32.00	1.78	40.00	1.85	48.00	1.90	64.00	1.94

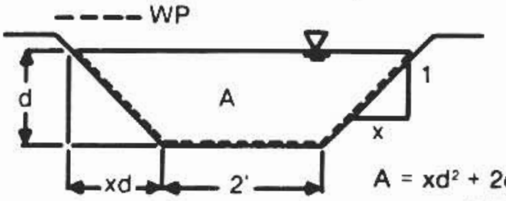
Depth, d (feet)	5:1 A	5:1 R	6:1 A	6:1 R	7:1 A	7:1 R	8:1 A	8:1 R	9:1 A	9:1 R	10:1 A	10:1 R
0.5	1.25	0.25	1.50	0.25	1.75	0.25	2.00	0.25	2.25	0.25	2.50	0.25
0.6	1.80	0.29	2.16	0.30	2.52	0.30	2.88	0.30	3.24	0.30	3.60	0.30
0.7	2.45	0.34	2.94	0.35	3.43	0.35	3.92	0.35	4.41	0.35	4.90	0.35
0.8	3.20	0.39	3.84	0.39	4.48	0.40	5.12	0.40	5.76	0.40	6.40	0.40
0.9	4.05	0.44	4.86	0.44	5.67	0.45	6.48	0.45	7.29	0.45	8.10	0.45
1.0	5.00	0.49	6.00	0.49	7.00	0.49	8.00	0.50	9.00	0.50	10.00	0.50
1.1	6.05	0.54	7.26	0.54	8.47	0.55	9.68	0.55	10.89	0.55	12.10	0.55
1.2	7.20	0.59	8.64	0.59	10.08	0.59	11.52	0.60	12.96	0.60	14.40	0.60
1.3	8.45	0.64	10.14	0.64	11.83	0.64	13.52	0.64	15.21	0.65	16.90	0.65
1.4	9.80	0.69	11.76	0.69	13.72	0.69	15.68	0.69	17.64	0.70	19.60	0.70
1.5	11.25	0.74	13.50	0.74	15.75	0.74	18.00	0.74	20.25	0.75	22.50	0.75
1.6	12.80	0.78	15.36	0.79	17.92	0.79	20.48	0.79	23.04	0.80	25.60	0.80
1.7	14.45	0.83	17.34	0.84	20.23	0.84	23.12	0.84	26.01	0.84	28.90	0.85
1.8	16.20	0.88	19.44	0.89	22.68	0.89	25.92	0.89	29.16	0.89	32.40	0.90
1.9	18.05	0.93	21.66	0.94	25.27	0.94	28.88	0.94	32.49	0.94	36.10	0.95
2.0	20.00	0.98	24.00	0.99	28.00	0.99	32.00	0.99	36.00	0.99	40.00	1.00
2.5	31.25	1.23	37.50	1.23	43.75	1.24	50.00	1.24	56.25	1.24	62.50	1.24
3.0	45.00	1.47	54.00	1.48	63.00	1.48	72.00	1.49	81.00	1.49	90.00	1.49
3.5	61.25	1.72	73.50	1.72	85.75	1.73	98.00	1.74	110.25	1.74	122.50	1.74
4.0	80.00	1.96	96.00	1.97	112.00	1.98	128.00	1.98	144.00	1.98	160.00	1.99

Table IV.C.3. Hydraulic radius (R) and area (A) of nonsymmetrical triangular channels.



Depth, d (feet)	Slope ratio 1:1 - 3:1 A	1:1 - 3:1 R	1½:1 - 3:1 A	1½:1 - 3:1 R	2:1 - 3:1 A	2:1 - 3:1 R	2½:1 - 3:1 A	2½:1 - 3:1 R	4:1 - 3:1 A	4:1 - 3:1 R	5:1 - 3:1 A	5:1 - 3:1 R
0.5	0.50	0.22	0.56	0.23	0.63	0.23	0.69	0.23	0.88	0.24	1.00	0.24
0.6	0.72	0.26	0.81	0.27	0.90	0.28	0.99	0.28	1.26	0.29	1.44	0.29
0.7	0.98	0.31	1.10	0.32	1.23	0.32	1.35	0.33	1.72	0.34	1.96	0.34
0.8	1.28	0.35	1.44	0.36	1.60	0.37	1.76	0.38	2.24	0.38	2.56	0.39
0.9	1.62	0.39	1.82	0.41	2.03	0.42	2.23	0.42	2.84	0.43	3.24	0.44
1.0	2.00	0.44	2.25	0.45	2.50	0.46	2.75	0.47	3.50	0.48	4.00	0.48
1.1	2.42	0.48	2.72	0.50	3.03	0.51	3.33	0.52	4.24	0.53	4.84	0.53
1.2	2.88	0.52	3.24	0.54	3.60	0.56	3.96	0.56	5.04	0.58	5.76	0.58
1.3	3.38	0.57	3.80	0.59	4.23	0.60	4.65	0.61	5.92	0.63	6.76	0.63
1.4	3.92	0.61	4.41	0.63	4.90	0.65	5.39	0.66	6.86	0.67	7.84	0.68
1.5	4.50	0.66	5.06	0.68	5.63	0.69	6.19	0.70	7.88	0.72	9.00	0.73
1.6	5.12	0.70	5.76	0.73	6.40	0.74	7.04	0.75	8.96	0.77	10.24	0.77
1.7	5.78	0.74	6.50	0.77	7.23	0.79	7.95	0.80	10.12	0.82	11.56	0.82
1.8	6.48	0.79	7.29	0.82	8.10	0.83	8.91	0.85	11.34	0.86	12.96	0.87
1.9	7.22	0.83	8.12	0.86	9.03	0.88	9.93	0.89	12.64	0.91	14.44	0.92
2.0	8.00	0.87	9.00	0.91	10.00	0.93	11.00	0.94	14.00	0.96	16.00	0.97
2.1	8.82	0.92	9.92	0.95	11.03	0.97	12.13	0.99	15.44	1.00	17.64	1.02
2.2	9.68	0.96	10.89	1.00	12.10	1.02	13.31	1.03	16.94	1.06	19.36	1.07
2.3	10.58	1.01	11.90	1.04	13.23	1.07	14.55	1.08	18.52	1.10	21.16	1.11
2.4	11.52	1.05	12.96	1.09	14.40	1.11	15.84	1.13	21.16	1.15	23.04	1.16
2.5	12.50	1.09	14.06	1.13	15.63	1.16	17.19	1.17	21.87	1.20	25.00	1.21
2.6	13.52	1.14	15.21	1.18	16.90	1.20	18.59	1.22	23.66	1.25	27.04	1.26
2.7	14.58	1.18	16.40	1.22	18.23	1.25	20.05	1.27	25.52	1.30	27.16	1.31
2.8	15.68	1.22	17.64	1.27	19.60	1.30	21.56	1.32	27.44	1.35	31.36	1.36
2.9	16.82	1.27	18.92	1.31	21.03	1.34	23.13	1.36	29.44	1.39	33.64	1.40
3.0	18.00	1.31	20.25	1.36	22.50	1.39	24.75	1.41	31.50	1.44	36.00	1.45

Table IV.C.4. Hydraulic radius (R) and area (A) of symmetrical trapezoidal channels [2′ bottom width].



$$A = xd^2 + 2d$$

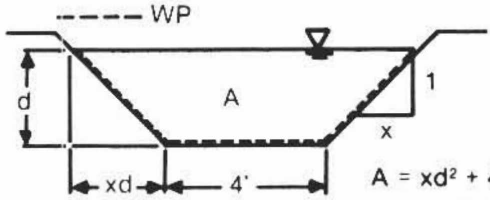
$$WP = 2d\sqrt{1 + x^2} + 2$$

$$R = A/WP$$

Depth, d (feet)	Slope ratio 1:1		1½:1		2:1		2½:1		3:1		4:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	1.25	0.37	1.38	0.36	1.50	0.35	1.63	0.35	1.75	0.34	2.00	0.33
0.6	1.56	0.42	1.74	0.42	1.92	0.41	2.10	0.40	2.28	0.39	2.64	0.38
0.7	1.89	0.47	2.14	0.47	2.28	0.44	2.63	0.46	2.87	0.45	3.36	0.43
0.8	2.24	0.53	2.56	0.52	2.88	0.52	3.20	0.51	3.52	0.50	4.16	0.48
0.9	2.61	0.51	3.01	0.57	3.42	0.57	3.83	0.56	4.23	0.55	5.04	0.54
1.0	3.00	0.62	3.50	0.62	4.00	0.62	4.50	0.61	5.00	0.60	6.00	0.59
1.1	3.41	0.67	4.02	0.67	4.63	0.67	5.23	0.66	5.84	0.65	7.05	0.64
1.2	3.84	0.71	4.56	0.72	5.28	0.72	6.00	0.71	6.72	0.70	8.16	0.69
1.3	4.29	0.76	5.14	0.77	5.98	0.77	6.83	0.76	7.67	0.75	9.36	0.74
1.4	4.76	0.80	5.74	0.81	6.72	0.81	7.70	0.81	8.68	0.80	10.64	0.79
1.5	5.25	0.84	6.38	0.86	7.50	0.86	8.63	0.86	9.75	0.85	12.00	0.84
1.6	5.76	0.88	7.04	0.91	8.32	0.91	9.60	0.90	10.88	0.90	13.44	0.88
1.7	6.29	0.92	7.74	0.95	9.18	0.96	10.63	0.95	12.07	0.95	14.96	0.93
1.8	6.84	0.96	8.46	1.00	10.08	1.00	11.70	1.00	13.32	1.00	16.56	0.98
1.9	7.41	1.00	9.22	1.04	11.02	1.05	12.83	1.05	14.63	1.04	18.24	1.03
2.0	8.00	1.04	10.00	1.09	12.00	1.10	14.00	1.10	16.00	1.09	20.00	1.08
2.5	11.25	1.24	14.38	1.30	17.50	1.33	20.63	1.33	23.75	1.33	30.00	1.33
3.0	15.00	1.43	19.50	1.52	24.00	1.56	28.30	1.57	33.00	1.57	42.00	1.57

	5:1		6:1		7:1		8:1		9:1		10:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	2.25	0.32	2.50	0.31	2.75	0.30	3.00	0.30	3.25	0.29	3.50	0.29
0.6	3.00	0.37	3.36	0.36	3.72	0.35	4.08	0.35	4.44	0.34	4.80	0.34
0.7	3.85	0.42	4.34	0.41	4.83	0.41	5.32	0.40	5.81	0.39	6.30	0.39
0.8	4.80	0.47	5.44	0.46	6.08	0.46	6.72	0.45	7.36	0.45	8.00	0.44
0.9	*5.85*	*0.52*	*6.66*	*0.51*	*7.47*	*0.51*	*8.28*	*0.50*	*9.09*	*0.50*	*9.90*	*0.49*
1.0	7.00	0.51	8.00	0.56	9.00	0.56	10.00	0.55	11.00	0.55	12.00	0.54
1.1	8.25	0.62	9.47	0.62	10.68	0.61	11.89	0.60	13.10	0.60	14.31	0.59
1.2	9.60	0.67	11.04	0.67	12.48	0.66	13.92	0.65	15.36	0.65	16.80	0.64
1.3	11.05	0.72	12.74	0.72	14.43	0.71	16.12	0.70	17.81	0.70	19.50	0.69
1.4	12.60	0.77	14.50	0.77	16.52	0.76	18.48	0.75	20.44	0.75	22.40	0.74
1.5	14.25	0.82	16.50	0.81	18.75	0.81	21.00	0.80	23.25	0.80	25.50	0.79
1.6	16.00	0.87	18.56	0.86	21.12	0.86	23.68	0.85	26.24	0.85	28.80	0.84
1.7	17.85	0.92	20.74	0.91	23.63	0.91	26.52	0.90	29.41	0.90	32.30	0.89
1.8	19.80	0.97	23.04	0.96	26.28	0.96	29.52	0.95	32.76	0.95	36.00	0.94
1.9	21.85	1.02	25.46	1.01	29.07	1.01	32.68	1.00	36.29	1.00	39.90	0.99
2.0	24.00	1.07	28.00	1.06	32.00	1.06	36.00	1.05	40.00	1.05	44.00	1.04
2.5	36.25	1.32	42.50	1.31	48.75	1.30	55.00	1.30	61.25	1.30	67.50	1.29
3.0	51.00	1.56	60.00	1.56	69.00	1.55	78.00	1.55	87.00	1.54	96.00	1.54

Table IV.C.4.—Continued



$A = xd^2 + 4d$

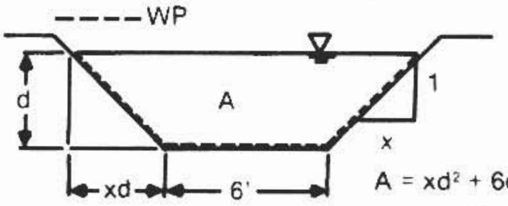
$WP = 2d\sqrt{1 + x^2} + 4$

$R = A/WP$

Depth, d (feet)	Slope ratio 1:1 A	1:1 R	1½:1 A	1½:1 R	2:1 A	2:1 R	2½:1 A	2½:1 R	3:1 A	3:1 R	4:1 A	4:1 R
0.5	2.25	0.41	2.38	0.41	2.50	0.40	2.63	0.39	2.75	0.39	3.00	0.37
0.6	2.76	0.48	2.94	0.48	3.12	0.47	3.30	0.46	3.48	0.45	3.84	0.43
0.7	3.29	0.55	3.54	0.54	3.78	0.53	4.03	0.52	4.27	0.50	4.76	0.49
0.8	3.84	0.61	4.16	0.60	4.48	0.59	4.80	0.58	5.12	0.57	5.76	0.54
0.9	4.41	0.67	4.82	0.66	5.22	0.65	5.63	0.64	6.03	0.62	6.84	0.60
1.0	5.00	0.73	5.50	0.72	6.00	0.71	6.50	0.69	7.00	0.68	8.00	0.65
1.1	5.61	0.79	6.22	0.78	6.82	0.76	7.43	0.75	8.03	0.73	9.24	0.71
1.2	6.24	0.84	6.96	0.84	7.68	0.82	8.40	0.80	9.12	0.79	10.56	0.76
1.3	6.89	0.90	7.74	0.89	8.58	0.87	9.43	0.86	10.27	0.84	11.96	0.81
1.4	7.56	0.95	8.54	0.94	9.52	0.93	10.50	0.91	11.48	0.89	13.44	0.86
1.5	8.25	1.00	9.38	1.00	10.50	0.98	11.63	0.96	12.75	0.94	15.00	0.92
1.6	8.96	1.05	10.24	1.05	11.52	1.03	12.80	1.01	14.08	1.00	16.64	0.97
1.7	9.69	1.10	11.14	1.10	12.58	1.08	14.03	1.07	15.47	1.05	18.36	1.02
1.8	10.44	1.15	12.06	1.15	13.68	1.14	15.30	1.12	16.92	1.10	20.16	1.02
1.9	11.21	1.20	13.02	1.20	14.82	1.19	16.63	1.17	18.43	1.15	22.04	1.12
2.0	12.00	1.24	14.00	1.25	16.00	1.24	18.00	1.22	20.00	1.20	24.00	1.17
2.5	16.25	1.47	19.38	1.48	22.50	1.48	25.63	1.47	28.75	1.45	35.00	1.42
3.0	21.00	1.68	25.50	1.72	30.00	1.72	34.50	1.71	39.00	1.70	48.00	1.67

	5:1 A	5:1 R	6:1 A	6:1 R	7:1 A	7:1 R	8:1 A	8:1 R	9:1 A	9:1 R	10:1 A	10:1 R
0.5	3.25	0.36	3.50	0.35	3.75	0.34	4.00	0.33	4.25	0.32	4.50	0.32
0.6	4.20	0.42	4.56	0.40	4.92	0.39	5.28	0.38	5.64	0.38	6.00	0.37
0.7	5.25	0.47	5.74	0.46	6.23	0.45	6.72	0.44	7.21	0.43	7.70	0.43
0.8	6.40	0.53	7.04	0.51	7.68	0.50	8.32	0.49	8.96	0.49	9.60	0.48
0.9	7.65	0.58	8.46	0.56	9.27	0.55	10.08	0.55	10.89	0.54	11.70	0.53
1.0	9.00	0.64	10.00	0.62	11.00	0.61	12.00	0.60	13.00	0.59	14.00	0.58
1.1	10.45	0.69	11.66	0.67	12.87	0.66	14.08	0.65	15.29	0.64	16.50	0.63
1.2	12.00	0.74	13.44	0.72	14.88	0.71	16.32	0.70	17.76	0.69	19.20	0.68
1.3	13.65	0.79	15.34	0.77	17.03	0.76	18.72	0.75	20.41	0.74	22.10	0.73
1.4	15.40	0.84	17.36	0.83	19.32	0.81	21.28	0.80	23.24	0.79	25.20	0.78
1.5	17.25	0.89	19.50	0.88	21.75	0.86	24.00	0.85	26.25	0.84	28.50	0.83
1.6	19.20	0.94	21.76	0.93	24.32	0.91	26.88	0.90	29.44	0.89	32.00	0.89
1.7	21.25	1.00	24.14	0.98	27.03	0.96	29.92	0.95	32.81	0.94	35.70	0.94
1.8	23.40	1.05	26.64	1.03	29.88	1.01	33.12	1.00	36.36	0.99	39.60	0.99
1.9	25.65	1.10	29.26	1.08	32.87	1.06	36.48	1.05	40.09	1.04	43.70	1.04
2.0	28.00	1.15	32.00	1.14	36.00	1.12	40.00	1.10	44.00	1.09	48.00	1.09
2.5	41.25	1.40	47.50	1.38	53.75	1.37	60.00	1.35	66.25	1.34	72.50	1.34
3.0	57.00	1.65	66.00	1.64	75.00	1.63	84.00	1.62	93.00	1.62	102.00	1.61

Table IV.C.4. —Continued



$A = xd^2 + 6d$

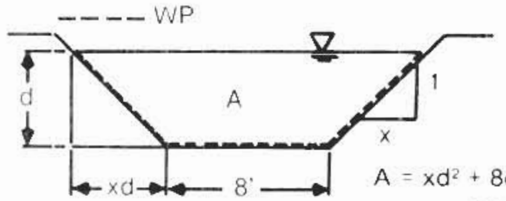
$WP = 2d\sqrt{1 + x^2} + 6$

$R = A/WP$

Depth, d (feet)	Slope ratio											
	1:1		1½:1		2:1		2½:1		3:1		4:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	3.25	0.44	3.38	0.43	3.50	0.42	3.63	0.42	3.50	0.41	4.00	0.40
0.6	3.96	0.51	4.14	0.51	4.32	0.50	4.50	0.49	4.68	0.48	5.04	0.46
0.7	4.69	0.59	4.94	0.58	5.18	0.57	5.43	0.56	5.67	0.54	6.16	0.52
0.8	5.44	0.66	5.76	0.65	6.08	0.63	6.40	0.62	6.72	0.61	7.36	0.58
0.9	6.21	0.73	6.62	0.72	7.02	0.70	7.43	0.68	7.83	0.67	8.64	0.64
1.0	7.00	0.79	7.50	0.78	8.00	0.76	8.50	0.75	9.00	0.73	10.00	0.70
1.1	7.81	0.86	8.42	0.85	9.02	0.83	9.63	0.80	10.23	0.79	11.44	0.76
1.2	8.64	0.92	9.36	0.91	10.08	0.89	10.80	0.87	11.52	0.85	12.96	0.82
1.3	9.49	0.98	10.34	0.97	11.18	0.95	12.03	0.93	12.87	0.91	14.56	0.87
1.4	10.36	1.04	11.34	1.03	12.32	1.00	13.30	0.98	14.28	0.96	16.24	0.93
1.5	11.25	1.10	12.38	1.08	13.50	1.06	14.63	1.04	15.75	1.01	18.00	0.98
1.6	12.16	1.16	13.44	1.14	14.72	1.12	16.00	1.09	17.28	1.07	19.84	1.03
1.7	13.09	1.22	14.54	1.20	15.98	1.17	17.43	1.15	18.87	1.13	21.76	1.09
1.8	14.04	1.27	15.66	1.25	17.28	1.23	18.90	1.20	20.52	1.18	23.76	1.14
1.9	15.01	1.32	16.82	1.30	18.62	1.28	20.43	1.25	22.23	1.24	25.84	1.19
2.0	16.00	1.37	18.00	1.36	20.00	1.34	22.00	1.31	24.00	1.29	28.00	1.24
2.5	21.25	1.61	24.38	1.61	27.50	1.60	30.63	1.58	33.75	1.55	40.00	1.50
3.0	27.00	1.86	31.50	1.87	36.00	1.85	40.50	1.83	45.00	1.80	54.00	1.76

	5:1		6:1		7:1		8:1		9:1		10:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	4.25	0.38	4.50	0.37	4.75	0.36	5.00	0.36	5.25	0.35	5.50	0.34
0.6	5.90	0.45	5.76	0.43	6.12	0.42	6.48	0.41	6.84	0.41	7.20	0.40
0.7	6.65	0.51	7.14	0.49	7.63	0.48	8.12	0.47	8.61	0.46	9.10	0.45
0.8	8.00	0.56	8.64	0.55	9.28	0.54	9.92	0.53	10.56	0.49	11.20	0.51
0.9	9.45	0.62	10.26	0.61	11.07	0.59	11.88	0.58	12.69	0.57	13.50	0.55
1.0	11.00	0.68	12.00	0.66	13.00	0.65	14.00	0.63	15.00	0.62	16.00	0.61
1.1	12.65	0.73	13.86	0.72	15.07	0.70	16.28	0.69	17.49	0.67	18.70	0.67
1.2	14.40	0.79	15.84	0.77	17.28	0.75	18.72	0.74	20.16	0.75	21.60	0.72
1.3	16.25	0.85	17.94	0.82	19.63	0.80	21.32	0.79	23.01	0.78	24.70	0.77
1.4	18.20	0.90	20.16	0.87	22.12	0.85	24.08	0.84	26.04	0.83	28.00	0.82
1.5	20.25	0.95	22.50	0.92	24.75	0.91	27.00	0.90	29.25	0.88	31.50	0.87
1.6	22.40	1.00	24.96	0.98	27.52	0.96	30.08	0.95	32.64	0.93	35.20	0.92
1.7	24.45	1.06	27.54	1.03	30.43	1.01	33.32	1.00	36.21	0.97	39.10	0.97
1.8	27.00	1.11	30.24	1.08	33.48	1.06	36.72	1.08	39.96	1.04	43.20	1.02
1.9	29.45	1.16	33.06	1.14	36.67	1.12	40.28	1.10	43.89	1.09	47.50	1.07
2.0	32.00	1.21	36.00	1.19	40.00	1.17	44.00	1.15	48.00	1.13	52.00	1.12
2.5	46.25	1.47	52.50	1.45	58.75	1.46	65.00	1.40	71.25	1.39	77.50	1.38
3.0	63.00	1.72	72.00	1.70	81.00	1.71	90.00	1.65	99.00	1.66	108.00	1.65

Table IV.C.4.—Continued



$A = xd^2 + 8d$

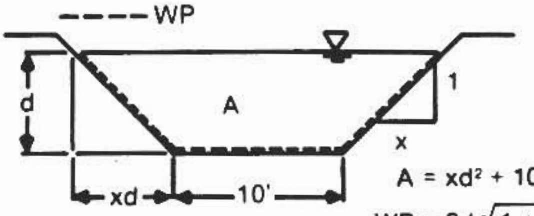
$WP = 2d\sqrt{1 + x^2} + 8$

$R = A/WP$

Depth, d (feet)	Slope ratio 1:1 A	R	1½:1 A	R	2:1 A	R	2½:1 A	R	3:1 A	R	4:1 A	R
0.5	4.25	0.45	4.38	0.45	4.50	0.44	4.63	0.43	4.75	0.43	5.00	0.41
0.6	5.16	0.53	5.34	0.53	5.52	0.52	5.70	0.51	5.88	0.50	6.24	0.48
0.7	6.09	0.61	6.34	0.60	6.58	0.59	6.83	0.58	7.07	0.57	7.56	0.55
0.8	7.04	0.69	7.36	0.68	7.68	0.66	8.00	0.65	8.32	0.64	8.96	0.61
0.9	8.01	0.76	8.42	0.75	8.82	0.73	9.22	0.72	9.63	0.70	10.44	0.68
1.0	9.00	0.83	9.50	0.82	10.00	0.80	10.50	0.78	11.00	0.77	12.00	0.74
1.1	10.01	0.90	10.62	0.89	11.22	0.87	11.83	0.85	12.43	0.83	13.64	0.80
1.2	11.04	0.97	11.76	0.95	12.48	0.93	13.20	0.91	13.92	0.89	15.36	0.86
1.3	12.09	1.04	12.94	1.02	13.78	1.00	14.63	0.98	15.97	0.95	17.16	0.92
1.4	13.16	1.10	14.14	1.08	15.12	1.06	16.10	1.04	17.08	1.01	19.04	0.97
1.5	14.25	1.16	15.38	1.14	16.50	1.12	17.63	1.10	18.75	1.07	21.00	1.03
1.6	15.36	1.23	16.64	1.21	17.92	1.18	19.20	1.16	20.48	1.13	23.04	1.09
1.7	16.49	1.29	17.44	1.27	19.38	1.24	20.83	1.22	22.27	1.19	25.16	1.14
1.8	17.64	1.35	19.26	1.33	20.88	1.30	22.50	1.27	29.12	1.24	27.36	1.20
1.9	18.81	1.41	20.63	1.40	22.42	1.36	24.23	1.33	26.03	1.30	29.64	1.25
2.0	20.00	1.46	22.00	1.45	24.00	1.42	26.00	1.39	28.00	1.36	32.00	1.31
2.5	26.25	1.76	29.38	1.72	32.50	1.69	35.63	1.66	38.75	1.63	45.00	1.57
3.0	33.00	2.00	37.50	1.99	42.00	1.96	46.50	1.93	51.00	1.89	60.00	1.83

	5:1 A	R	6:1 A	R	7:1 A	R	8:1 A	R	9:1 A	R	10:1 A	R
0.5	5.25	0.40	5.50	0.39	5.75	0.38	6.00	0.37	6.25	0.36	6.50	0.36
0.6	6.00	0.47	6.96	0.44	7.32	0.44	7.68	0.43	8.04	0.43	8.40	0.42
0.7	8.05	0.53	8.54	0.52	9.03	0.50	9.52	0.49	10.01	0.48	10.50	0.48
0.8	9.60	0.59	10.24	0.58	10.88	0.56	11.20	0.54	12.16	0.54	12.80	0.53
0.9	11.25	0.65	12.06	0.64	12.87	0.63	13.68	0.61	14.49	0.60	15.30	0.59
1.0	13.00	0.71	14.00	0.70	15.00	0.68	16.00	0.66	17.00	0.65	18.00	0.64
1.1	14.85	0.77	16.06	0.75	17.27	0.73	18.48	0.72	16.96	0.71	20.90	0.69
1.2	16.80	0.83	18.24	0.81	19.68	0.79	21.12	0.77	22.56	0.76	24.00	0.74
1.3	18.85	0.88	20.54	0.86	22.23	0.84	23.92	0.83	25.61	0.81	27.30	0.79
1.4	21.00	0.92	22.96	0.91	24.92	0.90	26.88	0.88	28.84	0.86	30.80	0.84
1.5	23.25	1.00	25.50	0.97	27.75	0.95	30.00	0.93	32.25	0.92	34.50	0.90
1.6	25.60	1.05	28.16	1.03	30.72	1.00	33.28	0.98	35.84	0.97	38.40	0.96
1.7	28.25	1.11	30.94	1.08	33.85	1.06	36.72	1.04	39.61	1.02	42.50	1.01
1.8	30.60	1.16	33.84	1.13	37.08	1.11	40.32	1.08	43.56	1.07	46.80	1.06
1.9	33.25	1.22	36.86	1.18	40.47	1.16	44.08	1.14	47.69	1.12	51.30	1.11
2.0	36.00	1.28	40.00	1.24	44.00	1.21	48.00	1.19	52.00	1.18	56.00	1.16
2.5	57.25	1.54	57.50	1.50	63.75	1.48	70.00	1.45	76.25	1.43	82.50	1.42
3.0	69.00	1.80	78.00	1.77	87.00	1.74	96.00	1.70	105.00	1.70	114.00	1.69

Table IV.C.4.—Continued



$A = xd^2 + 10d$

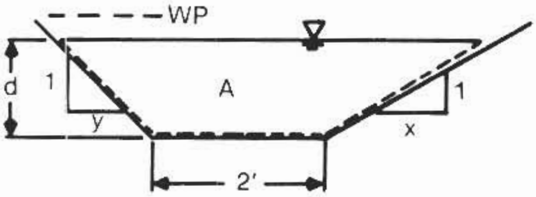
$WP = 2d\sqrt{1 + x^2} + 10$

$R = A/WP$

Depth, d (feet)	Slope ratio 1:1		1½:1		2:1		2½:1		3:1		4:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	5.25	0.46	5.38	0.46	5.50	0.45	5.63	0.44	5.75	0.44	6.00	0.42
0.6	6.36	0.54	6.54	0.54	6.72	0.53	6.90	0.52	7.08	0.51	7.44	0.50
0.7	7.49	0.63	7.74	0.62	7.98	0.61	8.23	0.60	8.47	0.59	8.96	0.57
0.8	8.64	0.71	8.96	0.70	9.28	0.68	9.60	0.67	9.92	0.66	10.56	0.64
0.9	9.81	0.78	10.22	0.77	10.62	0.76	11.03	0.74	11.43	0.73	12.24	0.70
1.0	11.00	0.86	11.50	0.85	12.00	0.83	12.50	0.81	13.00	0.80	14.00	0.77
1.1	12.21	0.93	12.82	0.92	13.42	0.90	14.03	0.88	14.63	0.86	15.84	0.83
1.2	13.44	1.00	14.16	0.99	14.88	0.97	15.60	0.95	16.32	0.93	17.76	0.89
1.3	14.69	1.07	15.54	1.06	16.38	1.04	17.23	1.01	18.07	0.99	19.76	0.95
1.4	15.96	1.14	16.94	1.13	17.92	1.10	18.90	1.08	19.88	1.05	21.84	1.01
1.5	17.25	1.21	18.38	1.19	19.50	1.17	20.63	1.14	21.75	1.12	24.00	1.07
1.6	18.56	1.28	19.84	1.26	21.12	1.23	22.40	1.20	23.68	1.18	26.24	1.13
1.7	19.89	1.34	21.34	1.32	22.78	1.29	24.23	1.26	25.67	1.24	28.56	1.19
1.8	21.24	1.41	22.86	1.39	24.48	1.36	26.10	1.33	27.72	1.30	30.96	1.25
1.9	22.61	1.47	24.42	1.45	26.22	1.42	28.03	1.39	29.83	1.35	33.44	1.30
2.0	24.00	1.53	26.00	1.51	28.00	1.48	30.00	1.44	32.00	1.41	36.00	1.36
2.5	31.25	1.83	34.38	1.81	37.50	1.77	40.63	1.73	43.75	1.69	50.00	1.63
3.0	39.00	2.11	43.50	2.09	48.00	2.05	52.50	2.01	57.00	1.97	66.00	1.90

	5:1		6:1		7:1		8:1		9:1		10:1	
	A	R	A	R	A	R	A	R	A	R	A	R
0.5	6.25	0.41	6.50	0.40	6.75	0.40	7.00	0.39	7.25	0.38	7.50	0.37
0.6	7.80	0.48	8.16	0.47	8.52	0.46	8.88	0.45	9.24	0.44	9.60	0.44
0.7	9.45	0.55	9.94	0.54	10.43	0.52	10.92	0.51	11.41	0.50	11.90	0.49
0.8	11.20	0.62	11.84	0.60	12.48	0.59	13.12	0.57	13.76	0.56	14.40	0.55
0.9	13.05	0.68	13.86	0.66	14.67	0.65	15.48	0.63	16.29	0.62	17.10	0.61
1.0	15.00	0.74	16.00	0.72	17.00	0.70	18.00	0.69	19.00	0.68	20.00	0.66
1.1	17.05	0.80	18.26	0.78	19.47	0.76	20.68	0.75	21.89	0.73	23.00	0.72
1.2	19.20	0.86	20.64	0.84	22.08	0.82	23.52	0.80	24.96	0.79	26.40	0.77
1.3	21.45	0.92	23.14	0.90	24.83	0.87	26.52	0.86	28.21	0.84	29.90	0.83
1.4	23.80	0.98	25.76	0.95	27.72	0.93	29.68	0.91	31.64	0.89	33.60	0.88
1.5	26.25	1.04	28.50	1.01	30.75	0.99	33.00	0.97	35.25	0.95	37.50	0.93
1.6	28.80	1.10	31.36	1.06	33.92	1.04	36.48	1.02	39.04	1.00	41.60	0.99
1.7	31.45	1.15	34.34	1.12	37.23	1.09	40.12	1.07	43.01	1.05	45.90	1.04
1.8	34.20	1.21	37.44	1.17	40.68	1.15	43.92	1.13	47.16	1.11	50.40	1.09
1.9	37.05	1.26	40.66	1.23	44.27	1.20	47.88	1.18	51.49	1.16	55.10	1.14
2.0	40.00	1.32	44.00	1.28	48.00	1.25	52.00	1.23	56.00	1.21	60.00	1.20
2.5	56.25	1.58	62.50	1.55	68.75	1.52	75.00	1.49	81.25	1.47	87.50	1.45
2.0	75.00	1.85	84.00	1.81	93.00	1.77	102.00	1.75	111.00	1.73	120.00	1.71

Table IV.C.5. Hydraulic radius (R) and area (A) of nonsymmetrical trapezoidal channels [2′ bottom width].



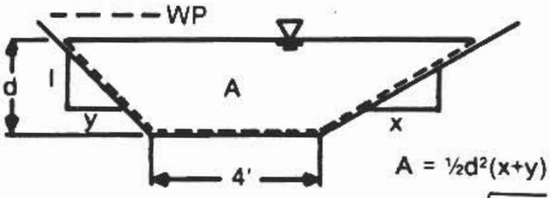
$$A = \tfrac{1}{2}d^2(x+y) + 2d$$

$$WP = d(\sqrt{1+y^2} + \sqrt{1+x^2}) + 2$$

$$R = A/WP$$

Depth, d (feet)	Slope ratio 1:1 - 3:1 A	R	1½:1 - 3:1 A	R	2:1 - 3:1 A	R	2½:1 - 3:1 A	R	4:1 - 3:1 A	R	5:1 - 3:1 A	R
1.0	4.00	0.61	4.25	0.61	4.50	0.61	4.75	0.61	5.50	0.59	6.00	0.58
1.1	4.62	0.66	4.92	0.66	5.23	0.66	5.53	0.66	6.44	0.64	7.04	0.63
1.2	5.28	0.70	5.64	0.71	6.00	0.71	6.36	0.70	7.44	0.68	8.16	0.68
1.3	5.98	0.75	6.40	0.76	6.83	0.76	7.25	0.75	8.52	0.73	9.36	0.74
1.4	6.72	0.80	7.21	0.80	7.70	0.81	8.19	0.81	9.66	0.79	10.64	0.79
1.5	7.50	0.85	8.06	0.85	8.63	0.85	9.19	0.85	10.88	0.84	12.00	0.84
1.6	8.32	0.89	8.96	0.91	9.60	0.91	10.24	0.90	12.16	0.90	13.44	0.88
1.7	9.18	0.94	9.90	0.95	10.63	0.95	11.35	0.95	13.52	0.94	14.96	0.93
1.8	10.08	0.99	10.89	1.00	11.90	1.01	12.51	1.00	14.94	0.98	16.56	0.98
1.9	11.02	1.03	11.92	1.04	12.83	1.05	13.73	1.05	16.44	1.03	18.24	1.03
2.0	12.00	1.07	13.00	1.09	14.00	1.10	15.00	1.10	18.00	1.09	20.00	1.08
2.2	14.08	1.17	15.29	1.19	16.50	1.19	17.71	1.19	21.34	1.19	23.76	1.18
2.4	16.32	1.26	17.76	1.28	19.20	1.28	20.64	1.29	24.96	1.28	27.84	1.27
2.6	18.72	1.35	20.41	1.37	22.10	1.37	23.79	1.38	28.86	1.38	32.24	1.37
2.8	21.28	1.43	23.24	1.46	25.20	1.48	27.16	1.48	33.04	1.48	36.76	1.48
3.0	24.00	1.52	26.25	1.54	28.50	1.57	30.75	1.57	37.50	1.57	42.00	1.57
3.5	31.50	1.76	34.57	1.78	37.63	1.80	40.70	1.81	49.88	1.81	56.01	1.81
4.0	40.00	1.97	44.00	2.00	48.00	2.02	52.00	2.03	64.00	2.04	72.00	2.04

Table IV.C.5.—Continued



Depth, d (feet)	Slope ratio 1:1 - 3:1 A	R	1½:1 - 3:1 A	R	2:1 - 3:1 A	R	2½:1 - 3:1 A	R	4:1 - 3:1 A	R	5:1 - 3:1 A	R
1.0	6.00	0.70	6.25	0.69	6.50	0.69	6.75	0.68	7.50	0.66	8.00	0.65
1.1	6.82	0.75	7.12	0.75	7.43	0.75	7.73	0.74	8.64	0.72	9.24	0.70
1.2	7.68	0.80	8.04	0.80	8.40	0.81	8.76	0.79	9.84	0.78	10.56	0.76
1.3	8.58	0.86	9.00	0.86	9.43	0.85	9.85	0.85	11.12	0.81	11.96	0.81
1.4	9.52	0.91	10.01	0.91	10.59	0.92	10.99	0.90	12.46	0.88	13.44	0.87
1.5	10.50	0.97	11.06	0.97	11.63	0.96	12.19	0.95	13.88	0.93	15.00	0.92
1.6	11.52	1.02	12.16	1.02	12.80	1.01	13.44	1.00	15.36	0.98	16.64	0.96
1.7	12.58	1.06	13.30	1.07	14.03	1.07	14.75	1.06	16.92	1.04	18.36	1.01
1.8	13.38	1.10	14.49	1.12	15.50	1.13	16.11	1.11	18.54	1.08	20.16	1.07
1.9	14.82	1.17	15.72	1.17	16.63	1.17	17.53	1.16	20.24	1.13	22.04	1.12
2.0	16.00	1.22	17.00	1.22	18.00	1.22	19.00	1.21	22.00	1.18	24.00	1.17
2.2	18.48	1.31	19.69	1.32	20.90	1.32	22.11	1.31	25.74	1.29	28.16	1.27
2.4	21.12	1.41	22.56	1.42	24.00	1.41	25.44	1.41	29.76	1.38	32.64	1.37
2.6	23.92	1.51	25.61	1.51	27.30	1.51	28.99	1.51	34.06	1.49	37.44	1.47
2.8	26.88	1.60	28.84	1.61	30.80	1.62	32.76	1.61	38.64	1.59	42.36	1.57
3.0	30.00	1.69	32.25	1.71	34.50	1.71	36.75	1.71	43.50	1.68	48.00	1.66
3.5	38.50	1.93	41.57	1.94	44.63	1.95	47.70	1.95	56.88	1.93	63.07	1.92
4.0	48.00	2.15	52.00	2.17	56.00	2.18	60.00	2.18	72.00	2.16	80.00	2.15