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16. Abstract

This manual provides design information for four groups of sediment control structures and treatments which are suitable for use on small areas in surface coal mining. A detailed design procedure is given for each group which will estimate the total amount of settleable solids from a small area with a sediment control structure or treatment for a specific design storm. A procedure is also given for estimating the mean annual sediment yield from a small area. Information on design, installation, maintenance and cost is given for each sediment control measure. Methods for determining the maximum allowable area for each sediment control measure and for design of combined sediment control systems are presented. The design procedures contain numerous nomographs, graphs, and worksheets to facilitate the use of the design procedure. The sediment control measures, design procedures, and materials in this manual are applicable to coal bearing regions of the continental United States.

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DESIGN of SEDIMENT CONTROL MEASURES for SMALL AREAS in SURFACE COAL MINING

Prepared for

Office of Surface Mining
Washington, DC
Contract No.: J5110061

by

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LIST OF SYMBOLS

A . . . . . Area

A_b . . . . . Bare soil area, acres

A_{maxd} . . . . Maximum area for the diversion and conveyance, acre

A_{maxs} . . . . Maximum area above the structure, acres

A_{maxt} . . . . Maximum area for treatments, acre

b . . . . . Rainfall ratio exponent

C . . . . . Constant

C_f . . . . . Structure length coefficient

C_g . . . . . Decimal percent cover

C_l . . . . . Overland flow length coefficient

C_r . . . . . Mean annual sediment yield factor

C_{rT} . . . . . Total mean annual sediment yield factor

C_s . . . . . Mean concentration of settleable solids, ppm

C_w . . . . . Settling parameter

CN . . . . . Curve number

CN_H . . . . . High value of CN in the given range

CN_L . . . . . Low value of CN in the given range

d . . . . . depth, feet

d_c . . . . . design depth, feet

d_d . . . . . deposition depth, feet

d_f . . . . . additional freeboard exceeding 5 feet

d_h . . . . . hydraulic depth, feet

d_{max} . . . . maximum allowable ponded depth for the structure, feet

d_{sw} . . . . . ponded depth of water and sediment, feet

D_c . . . . . critical particle size, mm

LIST OF SYMBOLS (continued)

D_f . . . . . Overland flow detachment coefficient

D_s . . . . . Particle size distribution, inches

e_s . . . . . Trap efficiency

FE . . . . . Filtering efficiency, %

q_t . . . . . Sediment transport rate, tons/foot/hour

G_d . . . . . Sediment trapped, tons

G_f . . . . . Flow detachment, tons

G_r . . . . . Total raindrop detachment, tons

G_s . . . . . Sediment supply capacity, tons

G_t . . . . . Sediment transport capacity, tons

G_y . . . . . Actual sediment yield for a storm, tons

$\overline{G}_y$ . . . . . Mean annual sediment yield, tons

H . . . . . Head

H_d . . . . . Structure height, feet

I . . . . . Rainfall intensity, inches/hour

K_a . . . . . Flow rate per unit area, feet/second

K_2 . . . . . Critical shear stress on sides/critical shear

K' . . . . . Weighted mean erodibility

K_d . . . . . Soil erodibility during dry season

K_e . . . . . Soil erodibility index

K_f . . . . . Detention parameter

K_g . . . . . Roughness coefficient

K_w . . . . . Soil erodibility during wet season

L . . . . . Length, feet

L_a . . . . . Length of the drop slope

LIST OF SYMBOLS (continued)

L_b . . . . . Length of downstream apron

L_d . . . . . Structure length, feet

L_f . . . . . Rock outlet length, feet

L_{max} . . . . . Maximum overland flow length, feet

L_{min} . . . . . Minimum structure length, feet

L_u . . . . . Length of upstream transition channel

M_d . . . . . Number of dry months with erosive rainfall and/or snowmelt runoff

M_w . . . . . Number of wet months with erosive rainfall and/or snowmelt runoff

n . . . . . Mannings' roughness coefficient

q . . . . . Unit overland flow discharge, cfs/foot/hour

Q . . . . . Discharge runoff rate, cfs (Chapter IV, V)

p . . . . . Decimal percent of a particular sediment size

p_1 . . . . . Silt (0.002-0.05 mm), decimal percent

p_2 . . . . . Very find sand (0.05-0.1 mm), decimal percent

p_3 . . . . . Fine, medium, coarse sand (0.1-1.0 mm), decimal percent

p_4 . . . . . Very coarse sand (1.0-2.0 mm), decimal percent

p_f . . . . . Percentage of material finer than the critical size

P . . . . . Rainfall, inches

P_e . . . . . Rainfall excess, inches

P_o . . . . . Initial abstraction, inches

P_p . . . . . Total expected water yield, inches

P_t . . . . . Total rainfall at 24 hours

P_w . . . . . Mean annual water yield, inches

R . . . . . Hydraulic radius, feet

LIST OF SYMBOLS (continued)

R_p . . . . . Rainfall excess ratio

S . . . . . Slope, decimal percent

S . . . . . Maximum potential abstraction, inches (used only in Equations 4.2, 4.3, and 4.4)

S_d . . . . . Spacing of dams

S_x . . . . . Upland slope, decimal percent

SS_{after} . . . Suspended solids value after filtration

SS_{bg} . . . . . Suspended solids value of background level

t . . . . . Time, hours

t_a . . . . . Thickness of the lining

t_e . . . . . Duration of rainfall excess

T . . . . . Topwidth, feet

V . . . . . Velocity, fps

V_c . . . . . Critical velocity, fps

$\forall_s$ . . . . . Deposited volume, cubic feet

$\forall_{sw}$ . . . . . Volume of sedient and water, cubic feet

w . . . . . Fall velocity, feet/second

W . . . . . Width, feet

W_p . . . . . Weighting factor

z . . . . . Side slope, horizontal unit per one vertical unit

I. INTRODUCTION

This design manual gives a series of four design procedures for estimating the performance of a wide variety of erosion control structures which are presently used to control sediment from small areas subjected to surface coal mining. The design procedures give quantitative estimates of the sediment reduction achieved by utilizing a type of structure and the amount of sediment passing the structure. The design procedures are suitable for determining if effluent water quality standards can be met by a structure. The procedures can predict sediment yield from a specific site on an event-by-event basis or can be used to predict sediment yield on an average annual basis. This allows personnel to specify structures capable of meeting regulatory requirements for infrequent events such as the 10-year, 24-hour storm. The procedures also predict annual sediment accumulation and maintenance requirements.

The design procedures follow known physical processes which produce or control the yield of sediment from a small catchment. All erosion control structures in this manual are grouped into one of four categories based on the dominant physical process by which they control sediment yield. These categories are:

1. Surface Protection Measures. This group includes mulches, vegetation, and erosion control products such as hydraulic mulch, netting and mulch binders.

2. Mechanical Treatment Measures. This group includes mechanical treatments such as contour furrowing, imprinting, ripping and pitting the soil surface.

3. Diversion and Conveyance Structures. This group includes terraces, diversions and small conveyance channels.

4. Detention and Filtering Structures. This group includes filter fence, permeable and impermeable berms, and vegetative buffer strips.

The water quality objective for the sediment control structures and measures presented in this manual is to limit the volume of settleable solids carried in the runoff to a specified concentration. The maximum area which can be treated and meet the water quality requirement will be a function of several important factors. First, the type of soil and particularly the amount of fine material in the soil has a great deal of influence on the size of the area which can be controlled. Fine soil sizes, called silt, are the

most difficult to control. The allowable size of an area will decrease as the percentage of silt increases in the soil. The second important factor governing the maximum area size is the amount of rainfall for the design storm and the resulting runoff. The allowable size of an area will decrease as the volume of runoff increases. Areas in regions with large design storms or areas with soils having poor infiltration rates will have a smaller allowable size than areas with lower design storm volumes or areas with soils having good infiltration rates. The third set of factors are the shape, slope and roughness of the area. Areas which are wide and have short overland flow lengths will have a larger allowable size than narrow areas with long overland flow lengths. Areas with a steep slope will have a smaller allowable area than areas with a mild slope. Areas with a high surface roughness will have a larger allowable size than areas which are smoother.

The maximum area can be computed directly for various types of treatments with information and procedures presented in this manual. Chapter VIII gives a procedure for determining maximum allowable area based on information presented in Chapters IV, V, VI and VII. The design procedures developed in Chapters IV through VII can be used to predict sediment yield from various sediment control measures for larger areas if this information is required. The procedures can be used to predict sediment yield to sediment ponds.

The physical processes active in small catchments (small area) are discussed in detail in Chapter II. Chapter III gives data requirements and sources of data used in preparing this manual. The manual is self contained in terms of data required to conduct a design of any structure introduced in the manual. If better data are available for a particular mine site, they can be easily incorporated into the design procedures and the designer is encouraged to do so. Chapter III documents numerous references that identify where these data can be located and methods for obtaining them. Chapters IV through VII include the design procedure for each structure group, design information for specific design types, planning considerations, design specifications, and maintenance requirements. Each design procedure chapter contains all worksheets, charts, tables, and nomographs necessary to carry out a design. Also, a complete design example is presented in these chapters. Chapter VIII provides an overview of sediment control structures with a guide toward planning for a cost effective erosion control system. The manual also contains four appendices providing information on procedures by which other

data sources can be used in conjunction with the manual (Appendices A and B), basic equations used in the manual (Appendix C), and 1980 materials costs (Appendix D). A glossary of key terms and phrases used in this manual is given in Appendix E.

II. BASIC CONCEPTS

2.1 Physical Processes Governing Sediment Yield from Small Areas

The four sediment control design procedures presented in this manual are all based on known physical processes which cause erosion. Figure 2.1 illustrates four dominant physical processes which control the production of sediment. The first source of sediment supply is raindrop impact, which detaches soil from the soil surface and makes it available for transport by overland flow. The amount of soil detached by raindrop impact depends on the energy of the rainfall; as rainfall intensity increases, the amount of soil detachment increases.

The second dominant physical process is the transport of the sediment supply by overland flow. The sediment transport capacity of overland flow depends on its velocity and depth. These two hydraulic conditions, velocity and flow depth, depend on the amount of rainfall excess (i.e., the amount of the rainfall which has not infiltrated, been intercepted by vegetation, or been caught in depressions), the overland slope, and the slope roughness. The roughness of a slope will depend on erodibility of the soil and the ground cover on the slope. Rills and gullies easily form on erodible soils, thereby reducing the slope roughness. Ground cover increases slope roughness by adding roughness elements to the slope such as leaves, roots and small branches. Ground cover will also decrease the amount of rainfall excess by increasing the amount of infiltration and interception. If the sediment transport capacity of a flow exceeds the supply of sediment from raindrop detachment, then overland flow will attempt to erode additional sediments from the soil surface.

The third dominant physical process is overland flow detachment. If the sediment transport capacity of the overland flow exceeds the supply of sediment, then it is possible for an additional sediment supply to be derived from flow detachment of the soil surface. Some soils are bound together by cohesive forces (dominant in the clay particle sizes), such soils resist detachment. For soils that are very cohesive flow detachment will be small. Conversely, noncohesive soil will erode easily and will provide an additional sediment supply which approaches the transport capacity of the overland flow.

If the supply of sediment from raindrop detachment and overland flow detachment remains below the transport capacity of the flow, then sediment

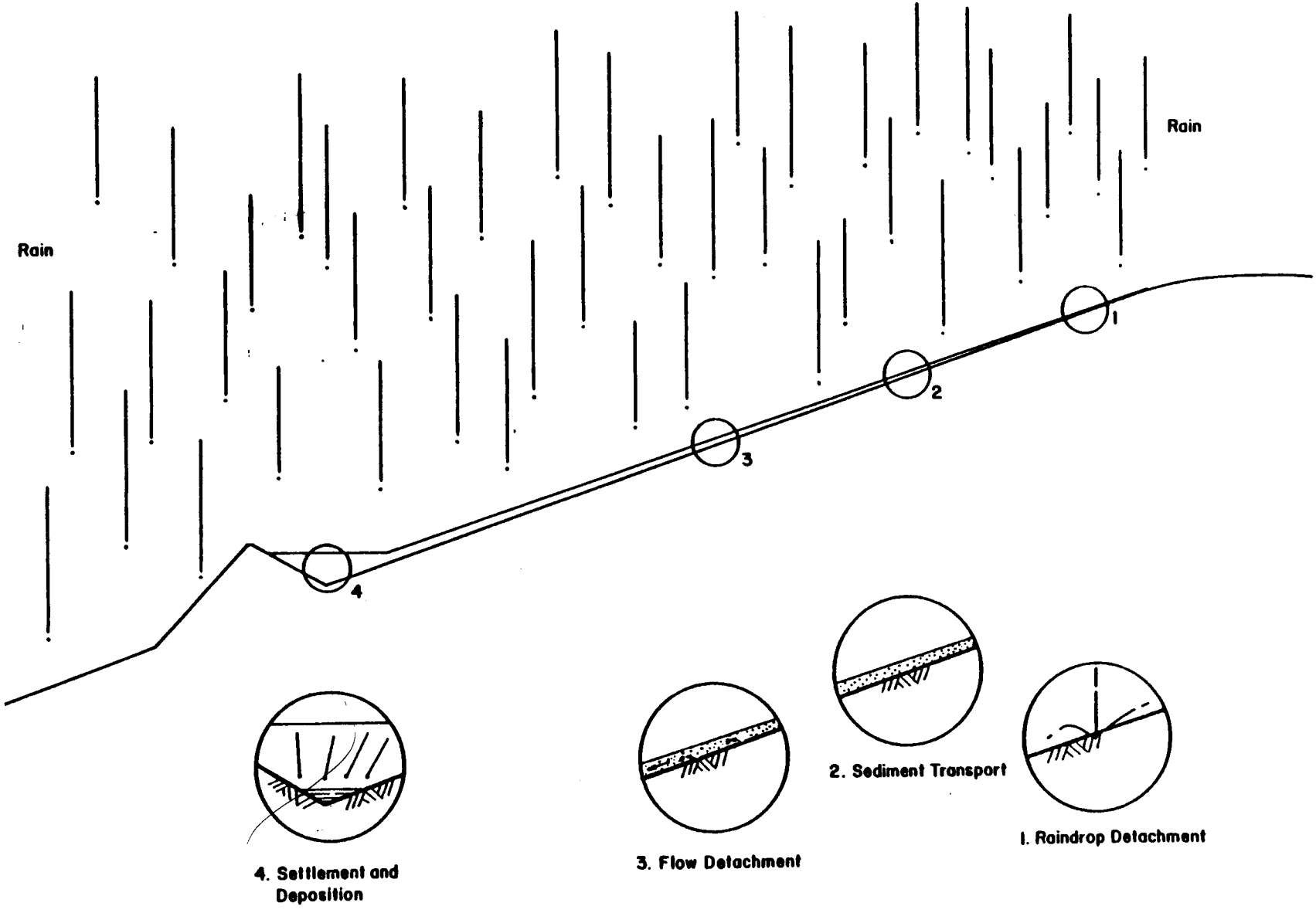

Figure 2.1. Physical processes governing sediment yield.

supply will control the sediment yield. This sediment yield condition is termed "supply controlled." Nonerosive soils such as those with a high clay content are often supply controlled. If the supply of sediment exceeds the transport capacity of the flow, the sediment yield will be controlled by the transport capacity of the flow and is termed "transport controlled." During high intensity rainfall periods or for very erosive soils, sediment yield is often transport controlled.

The fourth dominant physical process is settlement and deposition of sediment. Deposition of sediment occurs when the transport capacity of the flow is reduced. This can occur in properly designed detention ponds or diversion channels. Sediment particles will settle out dependent on their own weight and hydraulic conditions; larger sizes will settle rapidly and smaller sizes will require a much longer settling time. Sediment particles in the clay size range require very long settling times and for most practical considerations are essentially non-settleable. When sediment particles are settling in moving water, they must also overcome the effect of turbulence in the flow as well as the viscosity of the water. It is important to note that for detention structures designed to pass flow through them, the pond behind the structure must be long enough to allow most particles to settle before the flow leaves the structure.

Each of the four structure groups in this manual affects one or a number of the physical processes just discussed. The following discussion of each structure type shows how the physical processes are affected by these structures and how this modifies the sediment yield.

2.2 Surface Protection Measures

Surface protection measures include utilization of various types of mulches, vegetation, and erosion control products such as netting. These measures interact with the erosion process in a number of ways. First and most directly, they reduce the amount of bare soil area and therefore the amount of soil which can be detached by raindrop impact. The amount of raindrop detachment will decrease in direct proportion to the amount or cover provided by the surface protection measure. For example, if a straw mulch is applied to the soil surface which provides 50 percent cover, then the amount of soil detached by raindrop impact will also be reduced by 50 percent. In

this manual, cover ratios have been established for a variety of surface treatment measures.

Also, surface protection measures increase the surface roughness of a catchment area. This decreases the overland flow velocity, and therefore the sediment transport capacity of the flow. Surface protection measures increase roughness by both reducing the rilling potential of the surface and by adding small scale roughness elements to the surface.

Finally, surface protection measures increase the soil infiltration rate, provide additional retention storage for rainfall, and intercept rainfall before it reaches the soil surface. These effects work in combination to reduce the amount of rainfall excess (runoff) which in turn reduces the sediment transport capacity of the runoff.

Protection measures are among the most effective erosion control methods, since they can help halt soil erosion at the source. This group is also one of the least expensive treatments to implement, making it very cost effective.

2.3 Mechanical Treatment

Mechanical treatment measures are accomplished with the aid of heavy equipment and are used to add surface roughness and detain runoff. Individual treatment types included in this manual are contour furrowing, land imprinting, pitting and ripping. These treatment types are discussed in detail in Chapter V and a number of illustrations are given for each type.

Mechanical treatments control erosion by creating small detention volumes in the soil surface which reduce rainfall runoff. Additionally, a secondary effect is a reduction in overland flow velocities, thereby reducing the sediment transport capacity of the flow. Because of these two effects, infiltration is improved and rainfall runoff is further reduced. The depressions created by mechanically manipulating the surface provide a protected seedbed and improved soil moisture for plant germination and growth.

Equipment used for mechanical treatment of the soil usually has seeding devices attached. When vegetative cover is combined with mechanical treatment, the roughened surface lasts longer because it is protected from raindrop erosion.

2.4 Diversion and Conveyance Structures

Diversion and conveyance structures are widely used in surface mining to control runoff and erosion. The structures are small channels of various geometries used to collect overland flow before it concentrates to form unstable gullies. When the length and slope of these structures are correctly chosen, they will also trap sediment and therefore reduce sediment yield.

A diversion structure must have a low sediment transport capacity to effectively trap sediment. This means that the velocity of flow in the diversion should be low. The slope of the diversion should therefore be as flat as possible and have a wide cross section. The velocity of flow in a diversion can also be reduced if rough channel linings are selected. Stone and grass linings are often used. When a diversion channel is properly constructed, the transport capacity of the channel will be lower than the supply of sediment to the channel. Under this condition sediment will be deposited in the channel with the coarse sediment sizes settling out quickly and the finer sediment sizes settling out slowly. It should be noted that since settling times are quite long for small sediment sizes, diversion channels must be either very long or velocities very low for small particles to settle. Often these conditions cannot be attained in a diversion channel. Thus even though the transport capacity of small sediment sizes is less than the quantity of sediment supplied to the channel, deposition may not occur. Unless the settling time of a sediment particle is less than the travel time of the particle through the diversion channel, only partial settling will occur.

Conveyance channels which link diversion channels together (see Figures 6.1 and 6.2) are designed to remove water and sediment from an area without causing any further erosion. Therefore, deposition of sediments is usually only possible in the diversion channels. While conveyance channels are not designed to trap sediment, they do serve the important purpose of controlling any further erosion from the site.

Conveyance channels are often overlooked in erosion control designs, but they are crucial to the effective performance of all sediment control measures. Removal of sediment from water does little good if this water is discharged to an unstable erodible channel. An unstable channel can easily resupply sediment to the flow by erosion of the bank and bed of the channel.

2.5 Detention and Filtering Structures

Detention and filtering structures use two basic physical processes to remove sediment from runoff. First, these structures provide a local reduction in the sediment transport capacity by reducing the velocity of flow. Reductions in flow velocity can be achieved by ponding water (behind small check dams) or by roughening the overland flow surface (vegetative buffer strips). Second, if the structure is permeable, sediment can be trapped in the pore openings as water passes through the structure (hay bale or fabric structures). Since the permeability of the structure is low, water will also pool behind these structures and the trapped sediment will begin to settle out.

The performance of these structures (trapping efficiency) will vary with the size of sediment which is supplied. Large sediment which settles quickly or is easily caught in the pore openings of permeable structures is effectively controlled by these structures. In contrast to this, finer sediment can easily pass through the pore openings of most permeable structures. These sediments will settle only if long detention times are achieved in the pool behind the structure.

2.6 Guide to Selection of a Sediment Control Structure Type

The designer of sediment control measures and structures is faced with selecting a design which has a high rate of sediment removal and a reasonable cost. Obviously, evaluating the performance and cost of every possible treatment for a site is not practical. It can be seen from the previous discussion that some structures control certain physical processes while other measures control other processes. By understanding the importance of different physical processes, a guide to selecting sediment control treatments can be developed.

First, the largest source of sediment supply in small areas results from raindrop detachment. Only one erosion control group acts to control this supply, and that is the surface protection measures (i.e. mulches, revegetation). These measures control both the supply of large and fine sediments, whereas the other control measures have limited ability to control fine sediment. If a soil contains a large amount of fine material (specifically silt and very fine sand), surface protection measures will be the most effective means of controlling sediment.

Second, methods which reduce the amount of runoff (surface protection and mechanical treatment) will control the transport of sediment from the slope. These methods will reduce the volume of erosion. When combined with a method which protects the soil surface from raindrop detachment, a very effective sediment control system is developed.

Third, methods which rely primarily on settling of sediment (e.g. diversions, detention structures) will be most effective on larger sediment sizes (specifically fine through coarse sand). Usually adequate detention times can not be developed behind structures of this type to reduce the amount of finer sediment particles.

Fourth, any effective sediment control system for a small (or large) area will require a stable conveyance system. A concentrated flow of water can cause significant damage if it is not confined to a stable conveyance channel.

Once the erosion control groups are selected, the designer must then select the most appropriate and cost effective individual design type within each group. Many erosion control types can be eliminated simply on the basis of (1) availability of material or equipment, (2) specific climate conditions, or (3) nature of the mining operation. This type of review and selection of structures or measures should reduce the number of alternatives to a reasonable number. These can then be evaluated in a more detailed manner.

In summary, a physical process approach to sediment control allows a designer to quickly identify which structures or measures will be most effective. Trial and error selection of erosion control groups can be eliminated by utilizing the concepts of this approach. As a designer gains experience with the design procedures presented in the following chapters, he will gain a working knowledge of important physical processes for a mine site and the proper use of treatments to control sediment.

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III. DATA REQUIREMENTS

3.1 Hydrologic Data

Design Storms

In most mining locations, estimation of runoff hydrology must be used in place of measured data. This process begins by characterizing the design storm. Surface mining regulations specify that the design of many mine area features must safely pass the peak runoff of a storm of specified return period and duration. When calculating runoff, the storm volume associated with the specified return period (of a given duration) and the arrangement of intensities occurring within that storm must be determined. In general, the existence and length of record of on-site rain gages, as well as size and location of the mineland watershed will determine methods and considerations involved in determining the character and magnitude of the storm.

There are a number of methods available for determining rainfall volume and the distribution of rainfall intensities. In this manual we recommend the use of the National Oceanic and Atmospheric Administration's (NOAA) atlases for determination of rainfall volume and the Soil Conservation Service's (SCS) rainfall distributions for determining the distribution of rainfall intensity. Both rainfall volume and rainfall intensity distributions can be developed from local weather station information or from judicious application of other methods. The time and effort required for such analysis is not warranted for small areas, therefore methods presented in this manual are reasonably accurate for design of small area sediment control structures.

The use of the NOAA atlases is discussed in detail in the next section of this chapter (3.2). The SCS storm distributions are discussed in the remainder of this section.

Distribution of Storm Rainfall

The time distribution of storm rainfall used in this manual and commonly used with hydrologic methods for small areas is the Type I or Type II storms. The Type I distribution represents the Coastal side of the Sierra Nevada and Cascade Mountains in California, Oregon and Washington, Alaska and Hawaii. Type II distribution represents the remaining states, Puerto Rico and Virgin

Islands. These distributions, shown in Figure 3.1, are based on the generalized rainfall depth-duration relationships shown in National Weather Service (NWS) Technical Papers. The curves are established for 24-hour storms with a period of intense rainfall. The recommended procedure for shorter duration events is to center the event duration around the steepest portion of the curve. For use with this manual, the Type I and Type II storms are simplified.

Superimposed on the curvilinear distributions are a series of segmental lines which approximate the actual distributions closely. Five linear segments are needed to approximate the Type II distribution and six linear segments are needed for the Type I distribution. Rainfall intensity is constant over each segment. The linear distribution will slightly overestimate the rainfall intensity at the beginning of the 24-hour storm and underestimate the intensity toward the end of a 24-hour storm. Both distributions have a period of intense rainfall which lasts for approximately an hour. The linear distribution will give the mean rainfall intensity of the curvilinear distribution for this intense period. Use of linear segments to approximate the Type I and Type II storm distributions is necessary to reduce the computational effort required to predict the sediment yield. Tables 3.1 and 3.2 give the linearized values of the 24-hour rainfall distribution for the Type II and Type I storms, respectively.

3.2 Climatic Data

Data Requirements

Climatic data used to design and select erosion control structures and treatments include rainfall volumes, durations, and intensities. Climatic characteristics important for designing revegetation include local temperature, growing season, distribution of annual rainfall and local wind velocities.

Data Acquisition

The most common approach to obtaining point values of precipitation is through the use of the NOAA publications. Currently there are three publications by NOAA that are in regular use. In chronological order, the first is Technical Paper No. 40 (TP-40) by Herschfield (1961). This paper collected

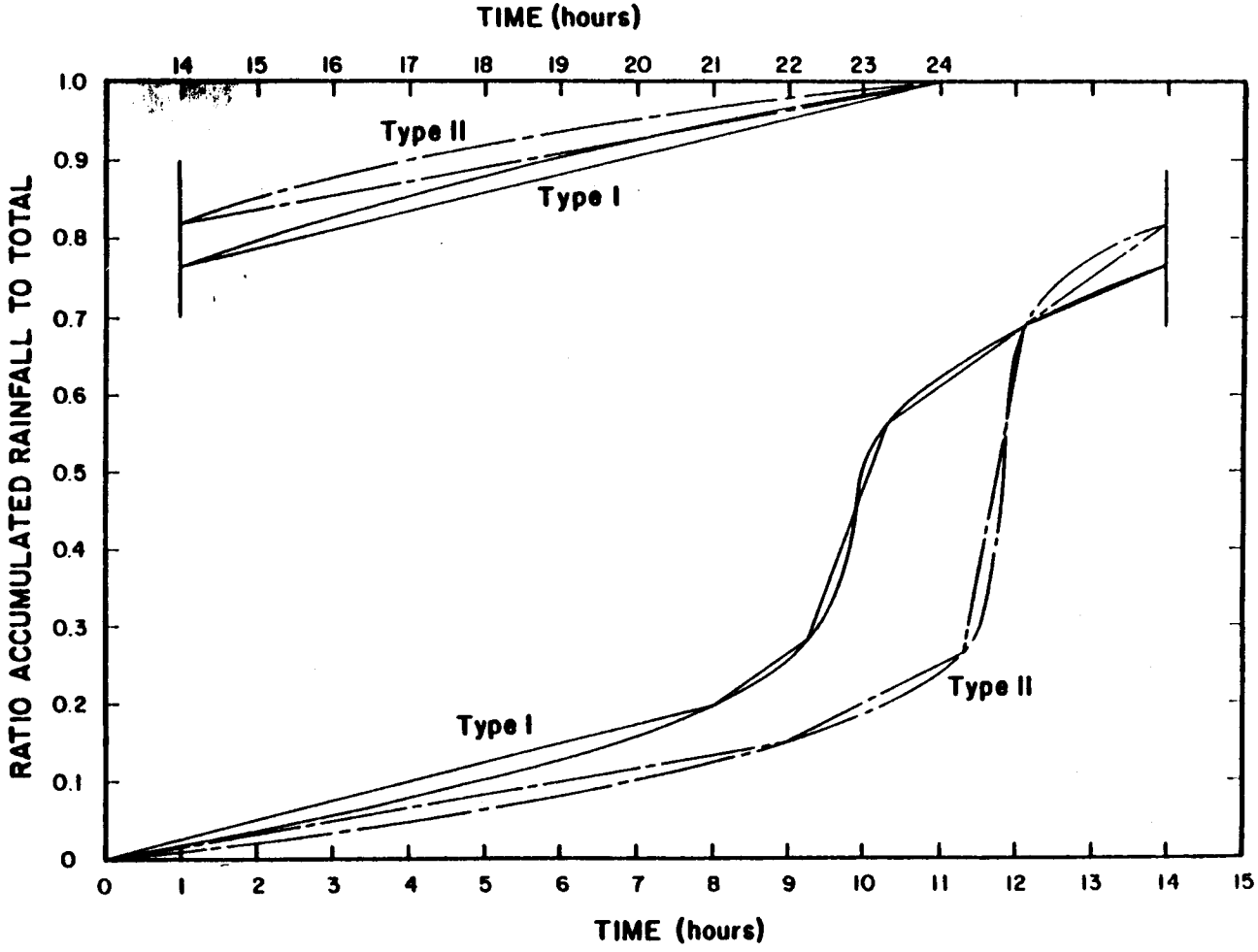


Figure 3.1. Twenty-four hour rainfall distribution (after Kent, 1968).

Table 3.1. Twenty-four Hour Type II Storm.

Time (hours)	P/P_t
0.00	0.000
9.00	0.150
11.25	0.250
12.17	0.695
14.00	0.820
24.00	1.000

Note: P = rainfall (at time in table)
P_t = total precipitation at 24 hours

Table 3.2. Twenty-four Hour Type I Storm.

Time (hours)	P/P_t
0.00	0.000
8.00	0.190
9.33	0.290
10.33	0.585
12.00	0.685
14.00	0.770
24.00	1.000

Note: P = rainfall (at the time in the table)
P_t = total precipitation at 24 hours

the results of depth-duration-frequency analysis investigations for the conterminous United States performed by the National Weather Service (NWS) and its precursor agency, the Weather Bureau. The maps presented in TP-40 are considered most reliable in relatively flat regions. However, in the western United States, the effects of mountainous terrain often cause large variations in precipitation. To correct this problem, the "Precipitation Frequency Atlas of the Western United States" (Miller, et al., 1973) in several volumes was introduced by NOAA. This publication contains much larger scale rainfall-duration-frequency maps than TP-40 and it corrects for such factors as slope, elevation, distance to moisture, location, normal annual precipitation, barriers to airflow, and surface roughness, not included in TP-40. For Alaska, the publication used is TP-47, "Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska." Storms in the eastern United States are still characterized by TP-40. A more recent document for storms of 5 to 60 minutes duration has been published by NWS (1977), under the title "Five to 60 Minute Precipitation Frequency for the Eastern and Central United States, (HYDRO-35)." For 24-hour duration events, the rainfall atlas for the Western United States, TP-40 and TP-47 are recommended for use with this manual.

The procedure for using the NOAA atlases to obtain point rainfall volumes is quite straightforward. Isopluvial maps are printed for storms of 2-, 10-, 25- and 100-year return periods for separate states in the West and for the eastern United States as a whole. Figure 3.2 shows the 10-year, 24-hour rainfall distribution for contiguous U.S. from TP-40; use of this figure is not recommended for the western U.S.

3.3 Determination of Runoff Volume Using the Curve Number Method

The SCS peak flow and hydrograph procedures estimate direct runoff based on a soil curve number (CN) (SCS, 1956). This method was developed for use with nonrecording rain gages to predict total volume of runoff from total volume of rainfall. In their publication, Design of Small Dams, (U.S. Bureau of Reclamation, 1977) summarized and modified the SCS method for use in predicting runoff volume during a storm. Their modification of the SCS method is used in this manual.

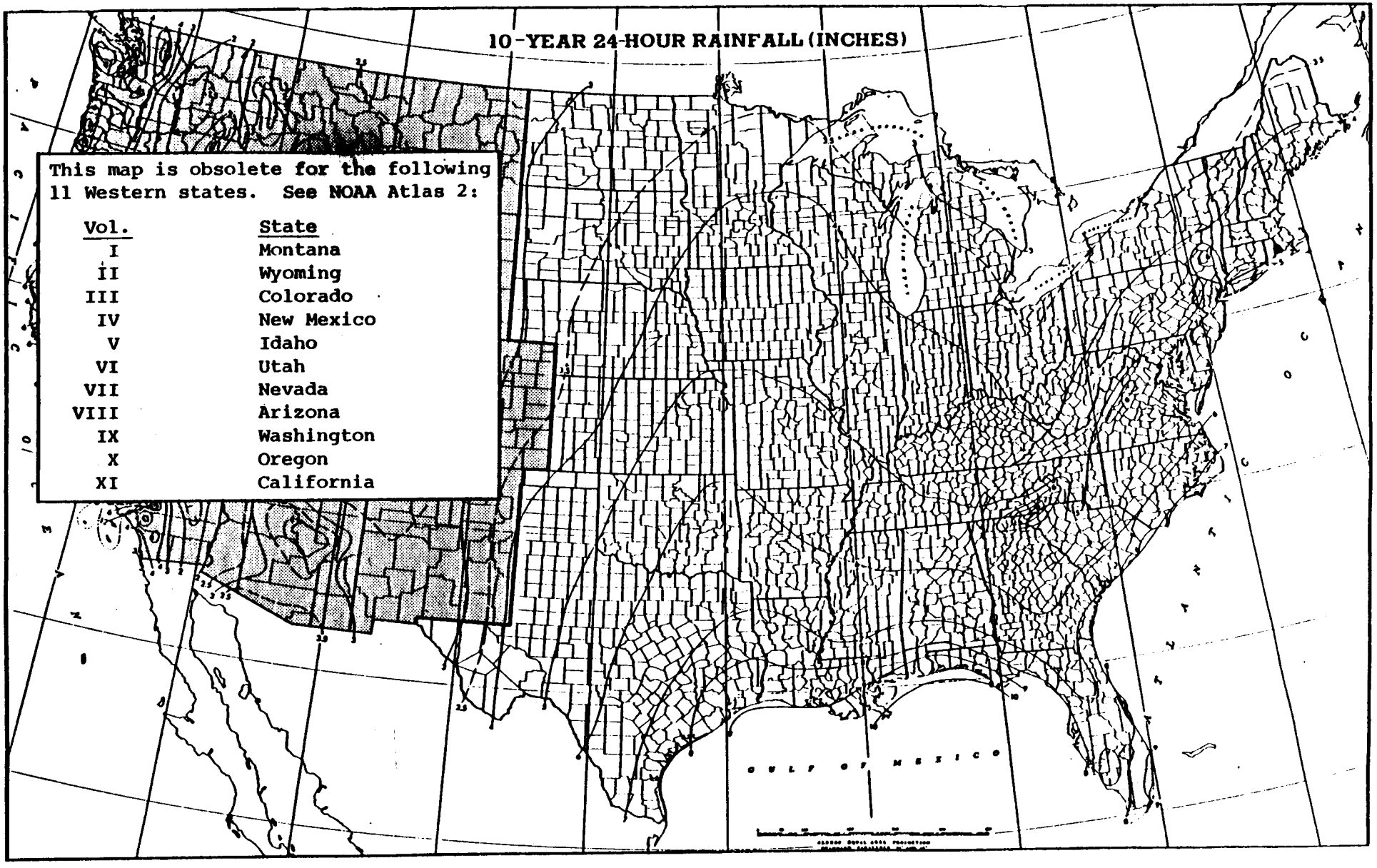


Figure 3.2. Isopluvial map showing the 10-year 24-hour rainfall (NOAA, TP40).

Values of CN range from 0 to 100, representing infinite and zero infiltration rates, respectively. Impervious surfaces will have a CN in the upper 90's. Pasture, range, or reclaimed soil can have CN's from about 40, for deep, well-drained sands and gravels, to 80, for clays or saturated soils. Data requirements for using the curve number method include soil type (see section 3.4), cover, land treatment, land use, antecedent moisture condition, and rainfall.

The amount of rainfall in a period of 5 to 30 days preceding a particular storm is referred to as antecedent rainfall, and the resulting condition of the watershed in regard to potential runoff is referred to as an antecedent condition. In general, the heavier the antecedent rainfall, the greater the direct runoff that occurs from a given storm. The effects of infiltration and evapotranspiration during the antecedent period are also important, as they may increase or lessen the effect of antecedent rainfall.

Because of the difficulties of determining antecedent storm conditions from data normally available, the andecedent moisture conditions (AMC) are reduced to the following three cases:

AMC-I. A condition of watershed soils where the soils are dry but not to the wilting point, and when satisfactory plowing or cultivation takes place.

AMC-II. The average case for annual floods, that is, an average of the conditions which have preceded the occurrence of the maximum annual flood on numerous watersheds.

AMC-III. When heavy rainfall or light rainfall and low temperatures have occurred during the five days previous to the given storm, and the soil is nearly saturated.

Curve numbers for one antecedent moisture condition may be converted to a different antecedent moisture condition by the use of Table 3.1. The corresponding curve number for AMC-I and AMN-III can be obtained from columns 2 and 3 of Table 3.3. For example, a CN of 73 for AMC-II gives curve numbers for AMC-I and AMC-III of 54 and 87, respectively.

Watershed soil determinations are used in the preparation of hydrologic soil-cover complexes, which in turn are used in estimating direct runoff. Four major soil groups are used. The soils are classified on the basis of intake of water at the end of long-duration storms occurring after prior

Table 3.3. Curve Numbers (CN) and Constants (from USBR, 1977).

(1) CN for Condition II	(2) CN for Conditions I	(3) CN for Conditions III	(1) CN for Condition II	(2) CN for Conditions I	(3) CN for Conditions III
100	100	100	60	40	78
99	97	100	59	39	77
98	94	99	58	38	76
97	91	99	57	37	75
96	89	99	56	36	75
95	87	98	55	35	74
94	85	98	54	34	73
93	83	98	53	33	72
92	81	97	52	32	71
91	80	97	51	31	70
90	78	96	50	31	70
89	76	96	49	30	69
88	75	95	48	29	68
87	73	95	47	28	67
86	72	94	46	27	66
85	70	94	45	26	65
84	68	93	44	25	64
83	67	93	43	25	63
82	66	92	42	24	62
81	64	92	41	23	61
80	63	91	40	22	60
79	62	91	39	21	59
78	60	90	38	21	58
77	59	89	37	20	57
76	58	89	36	19	56
75	57	88	35	18	55
74	55	88	34	18	54
73	54	87	33	17	53
72	53	86	32	16	52
71	52	86	31	16	51
70	51	85	30	15	50
69	50	84			
68	48	84	25	12	43
67	47	83	20	9	37
66	46	82	15	6	30
65	45	82	10	4	22
64	44	81	5	2	13
63	43	80	0	0	0
62	42	79			
61	41	78			

wetting and opportunity for swelling and without the protective effects of vegetation.

In the definitions that follow, the infiltration rate is the rate at which water enters the soil at the surface and which is controlled by surface conditions, and the percolation is the rate at which the water moves in the soil and which is controlled by the soil horizons. The hydrologic soil groups, as defined by SCS soil scientists, are as follows:

Group A (low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well- to excessively-drained sands or gravels. These soils have a high rate of percolation.

Group B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of percolation.

Group C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of percolation.

Group D (high runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water percolation.

The classification of soils into the hydrologic soil groups may be done on the basis of soils data, provided soil survey maps and reports are available. If such maps are not available, the soils will have to be classified on the basis of judgment utilizing any soils data which are discussed in the following section.

3.4 Soils Data

Data Requirements

Specific properties and characteristics of the soil are required to compute sediment transport capacities under a given set of climatic, vegetative, and slope conditions. The required soil parameters used in the design procedure are particle size distribution and erodibility expressed as a K_e factor. The K_e erodibility factor is a component in Wischmeier and Smith's (1965)

Universal Soil Loss Equation, and is used here to determine the roughness coefficient in the Simplified Sediment Yield Method. If a K_e factor has not been previously determined for the particular soil of interest, e.g. a mine soil, then the textural classification of the soil must be known to determine K_e.

Generally, soil physical properties occurring at a specific site can be identified using information given in standard SCS soil surveys. These investigations consist of classifying physical, chemical and biological characteristics of soils extending to depths of up to 6 feet. The U.S. Department of Agriculture (USDA) publishes reports and maps of their soil surveys, usually on a county basis. In addition, many smaller areas, individual farms and land surrounding urban areas are mapped and published as separate reports.

These soil surveys, if in print, can be obtained from the Superintendent of Documents, Washington, DC. Out-of-print maps and unpublished reports may be available from the USDA, county extension offices, colleges, universities and libraries. Local and regional offices of the Bureau of Reclamation have special area maps for most river basins in the western states. These maps and accompanying reports usually include physical and chemical properties of soils to a depth of approximately four feet.

Often, information on particle size distribution for disturbed soils and mine soils in a mining area is not available. However, testing may have been done during the premining stages of a mining operation and these data may be sufficient to determine the particle size classes.

Soil information should be evaluated to determine which soil condition will represent the worst case over the duration of mining operation. For example, final grading and topsoil application often leads to the greatest potential erosion condition until vegetation is established. Soil information and the mine operation schedule should be reviewed together and the worst case condition clearly identified.

Data from field observations and sediment sampling may be required to supplement survey data and assess site-specific conditions. These data are necessary if soil surveys have not been done or if conditions and characteristics of mine soil are not included in a soil survey.

Field data collection and laboratory analysis by a soil scientist may be necessary to evaluate soil characteristics at a particular mine site. Sediment size classes can be determined using the standard mechanical sieve method (Black, 1965; Dept. of the Army, 1970). The soil textural class can be determined by a series of field and laboratory tests. Likewise, structure and permeability can be measured in the field, while organic matter content requires laboratory analysis.

Simplified Soils Data Procedure

A simplified procedure for determining particle size distribution is presented for use with this manual, although a detailed procedure, Appendix A, for defining a distribution on a site-specific basis is recommended. For the simplified procedure, only the textural classifications of the mine soils at a site are needed. A textural class is simply a name given to each soil which designates the ranges of sand, silt, and clay sizes it contains. This class can be obtained from SCS soil series descriptions, other soil survey data in the vicinity, soil data from the mine plan, field estimation by a soil scientist or laboratory analysis. After determining the textural classification, the corresponding particle size groups are then determined from Table 3.4.

These values are not recommended for use if more detailed soils data are available at a mine site. A design particle size distribution from more detailed soils data can be determined from the guidelines given in Appendix A.

3.5 Topographic Data

Data Requirements

Topographic data which needs to be collected or measured include average slope, changes in slope (both parallel and perpendicular to the slope), slope length, width and geometric shape. If the geometric shape of the area of disturbance is irregular, some geometric simplification is required for use with the sediment yield computation procedure.

Data Acquisition

Sources of topographic information may be obtained from U.S. Geological Survey topographic maps and topographic maps specially produced for the area at a large scale by the SCS or county agencies. Often, the mining company will have a large scale map which can be used to determine topographic data.

Table 3.4. Suggested Particle Size Distributions of Soil Textural Classes (For use only if requirements and data acquisition in Appendix A cannot be met).

Textural Class	Clay (<0.002 mm) %	P_1 Silt (0.002-0.05 mm) %	P_2 Very Fine Sand (0.05-0.1 mm) %	P_3 Fine, Medium Coarse Sand (0.1-1.0 mm) %	P_4 Very Coarse Sand (1.0-2.0 mm) %
Sand	2	10	15	35	38
Loamy Sand	5	15	20	40	20
Sandy Loam	5	25	20	20	30
Loam	10	30	10	25	25
Silty Loam	20	60	5	15	--
Silt	5	90	5	--	--
Sandy Clay Loam	25	25	10	30	10
Clay Loam	30	40	10	10	10
Silty Clay Loam	35	55	5	--	5
Sandy Clay	55	5	5	10	25
Silty Clay	45	45	5	5	--
Clay	65	20	10	5	--

Field measurements or estimates may be the most expedient and satisfactory approach on many small areas.

If the geometric shape of the area is irregular, it is not suitable for analysis, and geometric simplification is required. The approach to this problem consists of selecting a number of planes to represent the area, sometimes referred to as an "open book" approximation. An example of a simplified geometric approximation of a small area is illustrated in Figure 3.3. The drainage pattern, in this case, is the intersection of the two planes (i.e., an open book). The irregular geometric shape in Figure 3.3a could be approximated by more than 2 planes if the size of the area and heterogeneity of the slopes and soils justify the extra effort required to meet reclamation standards.

After transforming an irregularly shaped area into a planar representation, the appropriate widths, lengths and slopes can be determined and used in the sediment yield calculations. Sediment yield calculation must be carried out for each plane.

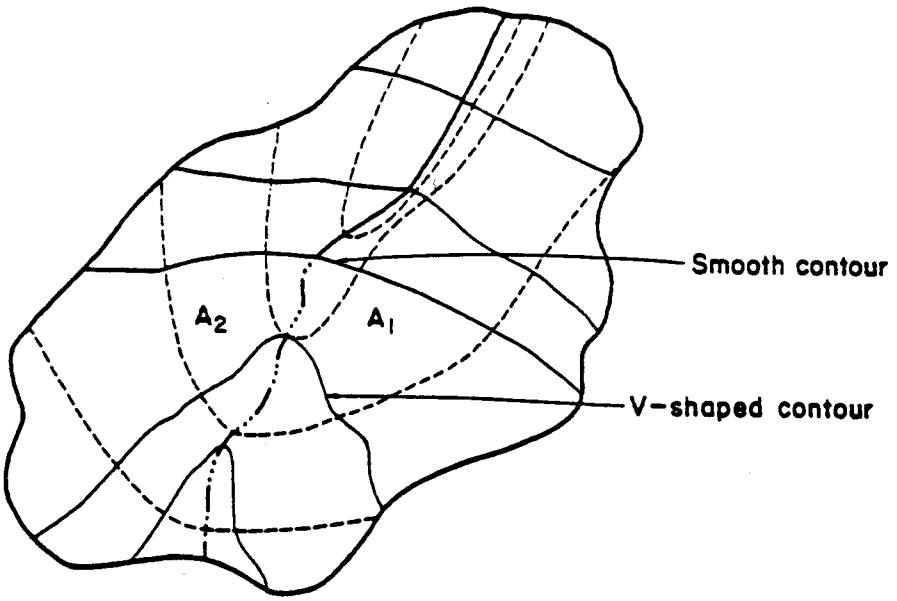
3.6 Revegetation Data

Data Requirements

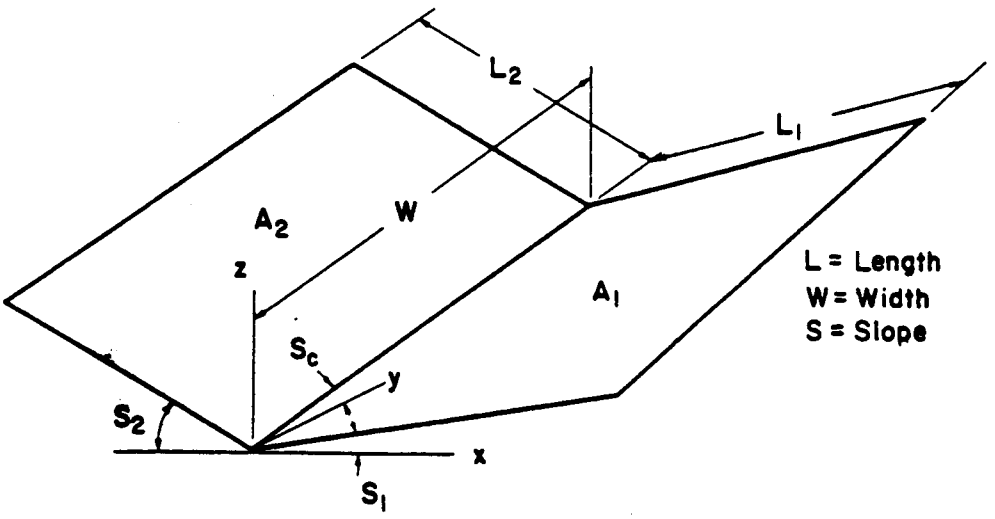
Vegetative data required at a site generally include identification of existing vegetation by species composition, native versus introduced species, productivity and cover density. The yearly and seasonal variability on both undisturbed and disturbed areas, pest problems, and animals supported by the vegetation should also be noted. Knowledge of the productivity of subsoil and overburden may be necessary if these materials are to be used as a postmining plant media.

Physical characteristics of a site which need to be identified are elevation, length and grade of slopes, aspect, geometry (see section 3.5), and projected mine soil type (see section 3.4). Climatic characteristics include local temperature, growing season, distribution of precipitation and local wind velocities (see section 3.2).

In addition, information on legal and regulatory requirements, land management goals, preliminary land use and planned postmining land use is necessary.



(a) Original topographic map of disturbed mine area subdivided into two areas (A_1 and A_2).



(b) Open book plane representation.

Figure 3.3. Transformation of a topographic map into a planar geometric representation of the watershed (after Wooding).

The types of data required to select introduced or native species to revegetate a site include plant growth, drought resistance or tolerance to stress, mineral nutrition requirements, reproduction characteristics, and germination rates. Seed and seedling availability, species compatibility, maintenance, cost, plant succession and adaptability to available planting methods are also important factors.

Data Acquisition

Baseline vegetative data may be available from the U.S. Forest Service, SCS (soil series publications) and related state agencies. For example, technical standards and specifications for critical area planting are available on a state by state basis for some states, eg. SCS (1981). These standards describe optimum conditions relating to topsoil, fertilizer, seed bed preparation, seeding method, timing, mulch, irrigation, and seed selection, rates and application. Data from State and Federal wildlife agencies and published lists of endangered species can also be utilized to meet the vegetative data requirements. Information on hybrid plant breeding is available from Crops Research Laboratory, Utah State University, Logan Utah. Two sources of data for retrieving computerized information on plant species in the semi-arid west are the Reclamation Research office at Montana State University, Bozeman, Montana and the Plant Informaiton Network (P.I.N.), Department of Botany and Plant Pathology at Colorado State University, Fort Collins, Colorado. Another source that should not be overlooked is the local SCS field offices. These offices offer excellent assistance with revegetation and critical area planting methods.

Direct field observations, measurements, and mine plan reports are useful for acquiring data on physical characteristics of a particular site. A vegetation specialist may be required to gather site-specific data using exclosures, plots, and transects on site.

Sources of climatic and local weather data will vary depending on the state in which the mining site is located. Data may be obtained from NWS publications, SCS publications, U.S. Geological Survey-Water Resources Division records, and state or local agencies which may monitor and record local climatic data.

Additional sources of revegetation data are listed below.

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IV. SURFACE PROTECTION MEASURES

4.1 General

The application of plant residues or other suitable materials to the soil surface is one of the best and most economical means of controlling erosion. Surface protection measures control erosion by protecting the soil surface from raindrop impact and by reducing the velocity of overland flow (see section 2.1 and 2.2). These measures also enhance the growth of vegetation by increasing the moisture capacity of the soil and insulating the seed bed against extremes in temperature. Surface protection measures presented in this manual include:

1. Mulches (straw, woodchips and stone)
2. Hydrologic Mulching
3. Revegetation
4. Mulch Binders

Surface protection measures can be applied to a wide range of soil surface conditions. Temporary protection can be provided for exposed soil surfaces which have not been regraded. These areas include soil stockpiles, denuded areas, temporary road banks, and dikes. These can be mulched and a temporary vegetative cover established by seeding with appropriate rapid growing annual plants. Permanent erosion control for disturbed areas can be accomplished by establishing perennial vegetative cover. Mulches, hydraulic-mulches, or mulch binders should be used in conjunction with revegetation. These measures provide protection from erosion during seed germination and seedling establishment. Mulches can be used alone in areas where seeding cannot be undertaken, with seeding beginning as soon as possible.

4.2 Procedural Guide - Surface Protection Measures

The procedure described in this section is used to determine the sediment control performance of surface protection measures. This is the same procedure used for the design of mechanical treatment (Chapter V) and also provides the basis for the design of diversion and conveyance structures (Chapter VI), and the design of detentions and filtering structures (Chapter VII). When no

surface protection is specified, this procedure gives an estimate of total uncontrolled sediment yield for an area.

The procedure consists of eight major steps which are shown in the flow chart in Figure 4.1. These can be grouped into three major areas involving: 1) determination of the physical characteristics of the catchment including soil characteristics, ground cover, area, slope, roughness, and soil detachment coefficient; 2) determination of hydrologic characteristics of the catchment including the rainfall excess (runoff) and rainfall intensity distributions; and 3) determination of the sediment yield including raindrop detachment, sediment transport capacity, overland flow soil detachment, controlling physical processes, and concentration of sediment yield. The procedure is designed for determining sediment yield for a single event but can also be used to estimate a mean annual sediment yield (Chapter IX). The standard application of the design procedure will be based on the 10-year, 24-hour storm using either a Type I or Type II rainfall distribution (see section 3.1, Figure 3.1 and Tables 3.1 and 3.2). Because of the long duration of these storms, they are broken down into several time intervals (five for the Type I storm and six for the Type II storm). This requires that most steps in the design procedure must be carried out for each time step. The design procedure is very flexible, however, and any type of storm could be used if other climatic data were available.

In the procedural guide, the sequence of solving for the sediment yield for a design storm is as follows:

1. Determine the design particle size distribution.

2. Determine the catchment area, ground cover, surface roughness, and flow detachment coefficients.

3. Determine the rainfall amount, the distribution of runoff and rainfall intensity distribution.

4. Determine the raindrop soil detachment.

5. Determine the sediment transport capacity of the runoff.

6. Determine the overland flow soil detachment and the total sediment supply.

7. Determine the controlling process and actual sediment yield.

8. Determine the concentration of sediment yield.

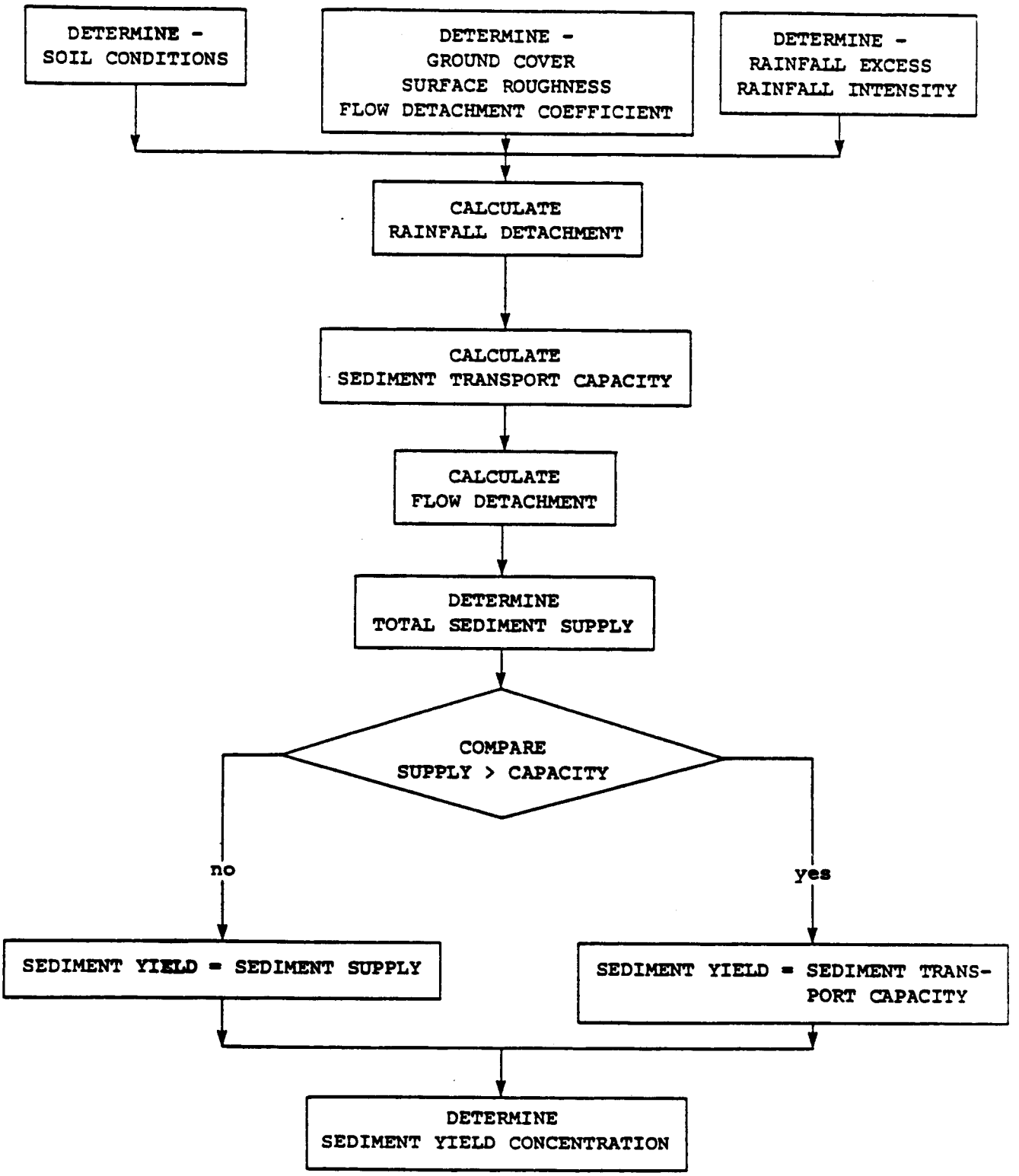


Figure 4.1. Flow chart of design procedure for surface protection measures.

A detailed explanation of each of the above steps is given in the following sections, along with worksheets and nomographs. Sections 4.3 to 4.6 given design information, planning considerations, specifications, and in-service performance for each type of treatment. Two detailed design examples given in section 4.7 illustrate an untreated and treated condition. These design examples will aid in understanding and applying the steps of the design procedure outlined below.

Step One: Determination of the Design Particle Size Distribution

Particle size distribution refers to the relative proportions of various size groups of individual grains in a soil or sediment sample. The particle size groups which need to be identified are:

clay: less than 0.002 mm

p_1 = silt (si): 0.002 mm - 0.05 mm (x_g=0.01)

p_2 = very fine sand (vfs): 0.05 mm - 0.1 mm (x_g=0.0707)

p_3 = fine, medium & coarse sand: 0.1 mm - 1.0 mm (x_g=0.316)

p_4 = very coarse sand: 1.0 mm - 2.0 mm ([x_g=geometric mean] x_g=1.41)

The percent of the particle size distribution in each of these groups can be determined from available data (Appendix A) or by correlation with the appropriate textural class given in Table 3.4 of Chapter III.

Step Two: Determination of Physical Characteristics of the Catchment Area

Five physical characteristics of a catchment area must be determined for this design procedure: 1) catchment area, 2) slope, 3) ground cover, 4) overland flow roughness, and 5) soil detachment coefficient. Catchment area (in acres) is determined either from direct field measurement or from maps of the site. The general shape of the catchment and the location and length of drainageways should be determined. The shape of the catchment can be simplified as either a single plane or as several planes (see "open book plane" described in section 3.5). These planes are then used to determine the cross slope and longitudinal slope of the catchment. Ground cover for various surface treatments is given in the design information sections of this chapter (4.3 and 4.4). In the case of vegetation, ground cover should be estimated from suitable reference plots (section 4.5).

Surface roughness is a function of soil erodibility and the amount of ground cover on the soil surface. The roughness coefficinet, K_g, is determined as a function of these two parameters. The soil erodibilty factor, K_e, (a factor in the Universal Soil Loss Equation) is related to particle size, soil permeability, soil structure, and the organic matter content. If these parameters can be determined for a site, then values of soil erodibility can be estimated by using a nomograph (see Appendix B). This approach is recommended if data is available. Very general values of K_e have been developed for use with this manual based on the soil texture classes. Estimated K_e values for these general soil classifications are given in Table 4.1 and are suitable for the specified mine soil/spoil conditions defined in the table.

Values of erodibility, K_e, and percent cover are used to estimate slope roughness, K_g, in Figure 4.2. Values of K_g corresponding to general soil textural classifications under various cover conditions are given in Table 4.2.

The overland flow detachment coefficient is a function of the percentage of clay in the soil (see Step One). A graph of the overland flow detachment coefficient, D_f, versus the percent clay is given in Figure 4.3. Values of D_f are also given in Table 4.2 for the general soil textural classifications.

Step Three: Determination of Rainfall and Rainfall Excess Distribution

Five tasks are accomplished in this procedural step.

1. A curve number is selected based on soil and treatment condition.
2. Maximum allowable catchment area is determined.
3. The time to the beginning of rainfall runoff is computed.
4. The rainfall and rainfall runoff distributions are calculated based on either the Type I or Type II storm.
5. The rainfall intensity and the overland flow rate are computed.

The first task of Step Three is to select a curve number (CN) which is representative of the mined land condition. The CN value is a function of the hydrologic grouping of the soil and the land use present in the catchment area. The hydrologic grouping of the soil is based on the runoff potential of the soil and is discussed in more detail in section 3.3. Three land use types are identified in this manual: 1) surface facilities (road and work areas),

Table 4.1. Suggested K_e Values of Soil Textural Classes (For use only if requirements in Appendix B cannot be met).

Textural Class	Suggested K_e
Sand	.20
Loamy Sand	.30
Sandy Loam	.43
Loam	.36
Silty Loam	.48
Silt	.83
Sandy Clay Loam	.26
Clay Loam	.28
Silty Clay Loam	.31
Sandy Clay	.13
Silty Clay	.25
Clay	.20

Note: Mine soil/spoil condition: roughly 12 inches of topsoil overlying scarified spoil of moderate to low permeability. The overall permeability of the mine soil/spoil profile is impeded due to differences in saturated and unsaturated hydraulic conductivities.

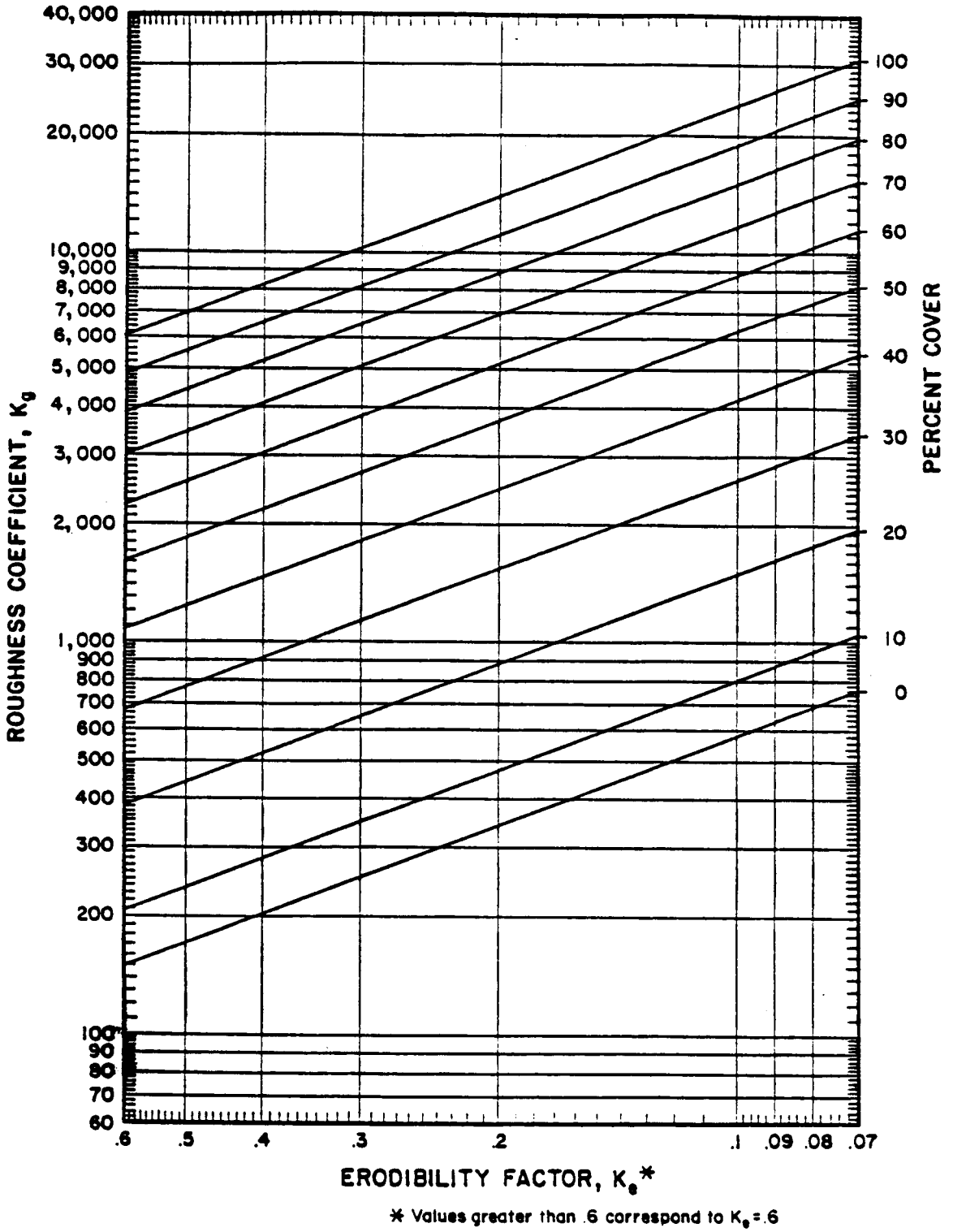


Figure 4.2. Relationship between erodibility factor, percent cover, and roughness coefficient (from Simons, Li & Associates, Inc., 1982).

Table 4.2. Values of Roughness Coefficient, K_g, and Overland Flow Detachment Coefficient, D_f, for General Soil Textural Classifications.

Textural Class	Detachment Coefficient D_f	K_g % Cover 0	10	20	30	40	50	60	70	80	90	100
Sand	1.000	340	480	890	1570	2530	3760	5260	7030	9000	11400	14000
Loamy Sand	1.000	260	360	660	1160	1870	2770	3870	5180	6690	8390	10300
Sandy Loam	1.000	190	270	500	880	1420	2120	2970	3970	5120	6440	7900
Loam	.550	220	310	570	1010	1620	2420	3380	4520	5840	7330	9000
Silty Loam	.160	180	250	460	820	1320	1960	2740	3670	4740	5950	7300
Silt	1.000	150	210	380	680	1090	1610	2260	3020	3890	4900	6000
Sandy Clay Loam	.088	280	390	710	1240	2000	2960	4140	5530	7140	8960	11000
Clay Loam	.046	270	370	680	1190	1900	2830	3950	5280	6820	8560	10500
Silty Clay Loam	.025	250	350	640	1130	1810	2690	3760	5030	6490	8150	10000
Sandy Clay	.0023	470	670	1250	2230	3600	5350	7500	10000	13000	16300	20000
Silty Clay	.0074	290	410	760	1340	2160	3220	4510	6030	7780	9780	12000
Clay	0.0	340	480	890	1570	2530	3760	5260	7030	9000	11400	14000

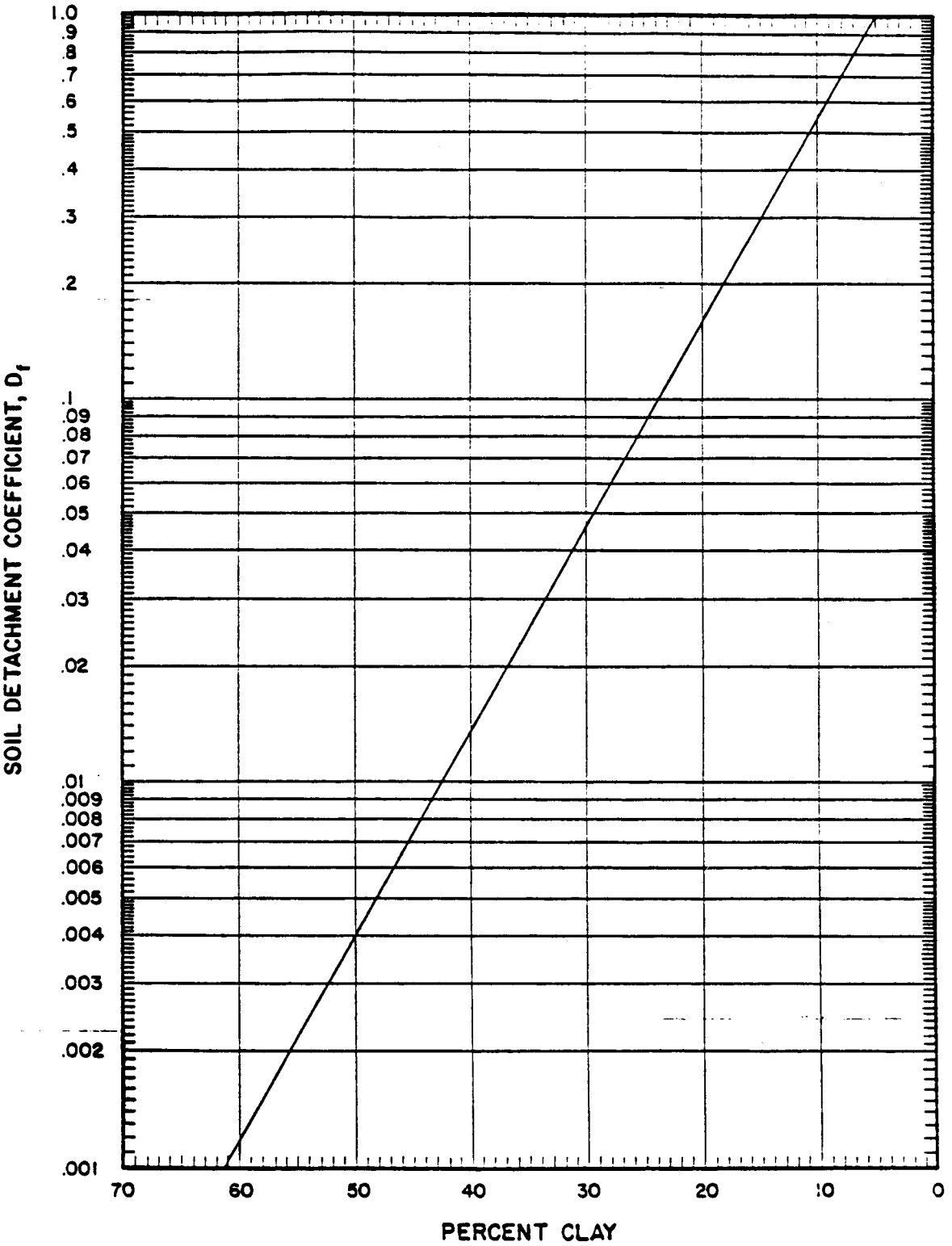


Figure 4.3. Soil detachment coefficient versus percent clay (from Simons, Li & Associates, Inc., 1982).

2) disturbed areas (unreclaimed land or an active mining area), and 3) reclaimed areas. For surface facilities and disturbed areas, a fixed CN value is used. For reclaimed areas, a range of CN values is given and the actual value of CN will depend on the amount of ground cover. Table 4.3 gives CN values for the hydrologic soil groups and the land use conditions. For reclaimed land, the high and low ends of the range are given and the actual value of CN to be used is given by the following equation.

$$CN = CN_H - (CN_H - CN_L)C_g \tag{4.1}$$

where CN_H and CN_L are the high and low values in the range, respectively, and C_g is the decimal percent cover as determined in Step Two.

The second task is to determine the maximum area allowable for the design procedure. The maximum area is governed by two factors. First, the peak discharge from the area should not exceed 20 cfs; and second, the time of concentration should not exceed 20 minutes. The first constraint is a function of the curve number and the basin area; the second constraint is a function of the roughness coefficient, the overland flow length, and slope of the basin (decimal percent). The maximum allowable area for which the method is applicable is obtained by using the nomograph in Figure 4.4. The smaller of the two areas given by the nomograph is the maximum allowable area. If the design area exceeds the maximum allowable area then the methodology developed in the remainder of this manual should not be used. The design area could be physically divided into several smaller areas if necessary, but in general large areas will require larger scale erosion control efforts, i.e., sediment ponds.

The third task is to compute the time when rainfall runoff begins. Rainfall runoff will not occur until after the initial abstraction capacity of the soil has been exceeded. The initial abstraction includes the amount of rainfall which infiltrates into the soil, intercepted by vegetation, or detained in depressions. The initial abstraction for the curve number method is given by

$$P_o = 0.2\ S \tag{4.2}$$

Table 4.3. Curve Number Values for Surface Mining.

Land use or cover	Hydrologic soil group[1] A	B	C	D
Surface facilities				
Paved	92	98	98	98
Gravel	76	85	89	91
Dirt	72	82	87	89
Disturbed area (active mining)	72	81	88	91
Reclaimed spoil[2] (low)	39	61	74	80
(high)	72	81	88	91

[1]See section 3.3

[2]High and Low end of range for reclaimed mine spoil with ground cover. See Equation 4.1.

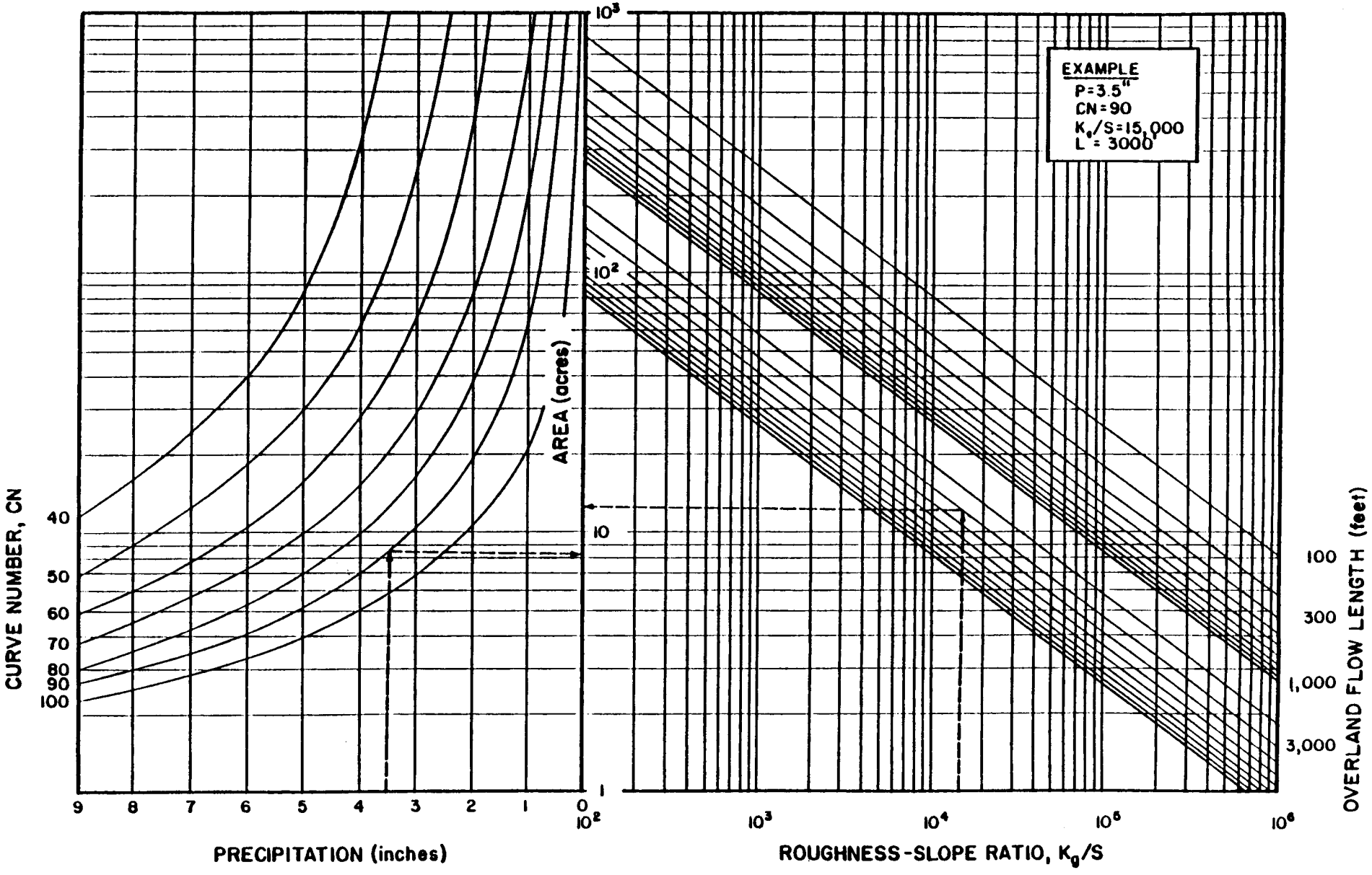


Figure 4.4. Maximum allowable area (from Simons, Li & Associates, Inc. 1982).

where: P_o = the initial abstraction, inches

S = the maximum potential abstraction, inches.

S is a function of curve number (CN) where

$$S = \frac{1000}{CN} - 10 \tag{4.3}$$

Once the initial abstraction is determined the ratio of initial abstraction to total rainfall is calculated. The time of initial rainfall runoff is determined by extrapolating a value from the tables of rainfall distribution for either a Type I or Type II storm (see Tables 3.1 and 3.2). All further calculations begin at the time of initial rainfall runoff.

Tasks 4 and 5 for step three make use of Worksheet 4.1 to carry out the calculations of several important hydrologic variables. Column one of the work sheet begins with the time of initial rainfall excess, and subsequent times are taken from Table 3.1 or 3.2 depending on the type of storm used. Rainfall excess is that amount of rain which does not infiltrate and is not intercepted or detained in depressions. Column two is the incremental difference between time steps. Column three begins with the ratio of initial abstraction to total rainfall, with subsequent values taken from Table 3.1 or 3.2 for the corresponding time in column one. Column four is calculated by multiplying column three by the total rainfall, which gives the actual accumulated rainfall for the design storm. Column five is calculated from the following equation

$$P_e = \frac{(P - 0.2\ S)^2}{P + 0.8\ S} \tag{4.4}$$

where: P_e = rainfall excess, inches

P = rainfall, inches

S = maximum potential abstraction, inches

Values of P are given in column four, S is given by equation 4.3, and the initial abstraction is given by Equation 4.2 which is the first value in column four. A graphical solution of equation four is given in Figure 4.5. Columns 6 and 7 are the incremental difference in columns 4 and 5, respectively. Column 8 is obtained by dividing the values in column 6 by the corresponding values in column 2. Column 9 values are given by the following equation

(1) Time (hr)	(2) Δt (hr)	(3) P/P_t	(4) P (inches)	(5) Pe (inches)	(6) ΔP (inches)	(7) ΔPe (inches)	(8) I (in/hr)	(9) Q (cfs)	(10) q (cfs/ft)

Small area characteristics:

Area = _____

Length = _____

Width = _____

Worksheet 4.1. Step Three worksheet.

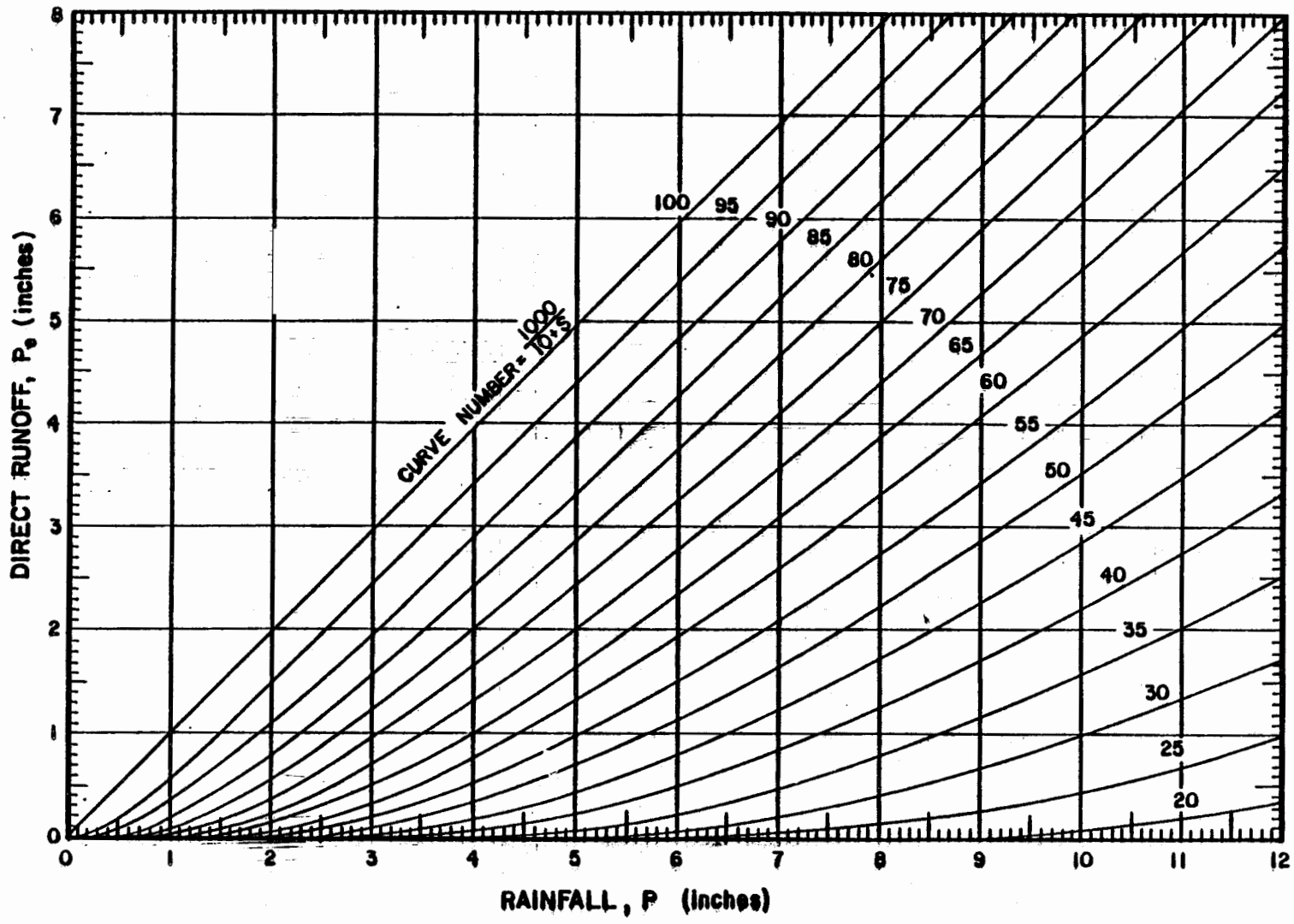


Figure 4.5. Solution of runoff equation (after Mockus & Victor, 1955).

$$Q = \frac{(\Delta Pe)A}{\Delta t} \tag{4.5}$$

where: Q = runoff rate in cubic feet per second (cfs)

ΔP_e = incremental rainfall excess in inches as given in Column 7

A = area, acres

Δt = incremental time in hours as given in Column 2

Column 10 values are obtained by dividing the values in column 9 by the mean width of the contributing area. The mean width is given the following equation

$$W = \frac{A}{L} \times 43560 \tag{4.6}$$

where: W = width, feet

A = area, acres

L = length in feet of a rectangular plane of the same area as that of the original area

(See 3.5 for a discussion of how to determine an equivalent rectangular plane representation.)

<u>Step Four:</u> Raindrop Detachment Calculation.

Total raindrop detachment of the soil is given by the following equation

$$G_r = 6.48\, \Delta t\, I^2\, A_b \tag{4.7}$$

where: G_r = total raindrop detachment, tons,

Δt = incremental time, hours

I = rainfall intensity, inches/hour

A_b = bare soil area, acres

A_b is given by the following equation

$$A_b = (1 - C_g)\, A \tag{4.8}$$

where: C_g = decimal percent cover

A = area, acres

Worksheet 4.2 is provided to carry out the calculation of Equation 4.7 for each time interval. Columns 1 and 2 are taken directly from columns 2 and 8 of the step three work sheet. Column 3 is calculated from Equation 4.7.

Worksheet 4.2 is provided to carry out the calculation of Equation 4.7 for each time interval. Columns 1 and 2 are taken directly from columns 2 and 8 of the step three work sheet. Column 3 is calculated from Equation 4.7.

Step Five: Sediment Transport Capacity

The sediment transport capacity of overland flow from a catchment depends on the slope of the catchment, the overland flow rate of water, and the roughness of the catchment. Four nomographs are given in this section which solve for the sediment transport rate of each of the four sediment particle sizes. The nomograph gives the sediment transport rate per unit width of the catchment area. The sediment transport capacity for a particular sediment size and time interval is given by the following equation

$$G_t = g_t W p \quad t \tag{4.9}$$

where: G_t = sediment transport capacity for a given time step in tons

g_t = sediment transport rate, tons/foot/hour

W = width of the catchment area, feet

p = decimal percentage of a particular sediment size

t = incremental time in hours

Worksheet 4.3 is given to aid in calculating the sediment transport capacity. Column 1 is taken directly from column 2 of the Step Three worksheet and column 2 from column 10 of the same worksheet. Column 3 is determined from the nomograph given in Figure 4.7 for the 0.01 mm particle size. Column 4 is determined from the nomograph given in Figure 4.8 for the 0.0707 mm particle size. Column 5 is determined from the nomograph given in Figure 4.9 for the 0.316 mm particle size. Column 6 is determined from the nomograph given in Figure 4.10 for the 1.414 mm particle size. To use the nomographs the roughness coefficient (K_g), the catchment slope (S), and the unit overland flow discharge (q) are input into the nomographs and the sediment transport rate (g_t) determined. Prior to using the sediment transport rate nomographs, the motion or nonmotion of the particle size is first checked using Figure 4.6. This check is necessary since certain particle sizes may not be able to move unless certain overland flow velocities are attained. Steps in solving for the sediment transport rate using the nomographs are as follows:

(1) Δt (hr)	(2) I (in/hr)	(3) G_r (tons)

Area = _____

$G_r = 6.48\ \Delta t\ I^2\ A_b$ (Eq. 4.7)

Ground Cover Ratio = _____

$A_b = (1 - C_g)A$ (Eq. 4.8)

Width = _____

Worksheet 4.2. Step Four worksheet.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Δt	q	g_{t1}	g_{t2}	g_{t3}	g_{t4}	G_{t1}	G_{t2}	G_{t3}	G_{t4}	G_t
(hours)	(cfs/ft)	(tons/ ft/hr)	(tons/ ft/hr)	(tons/ ft/hr)	(tons/ ft/hr)	(tons)	(tons)	(tons)	(tons)	(tons)

Roughness Coefficient, K_g = _____

Slope, S = _____

Width = _____

Worksheet 4.3. Step Five worksheet.

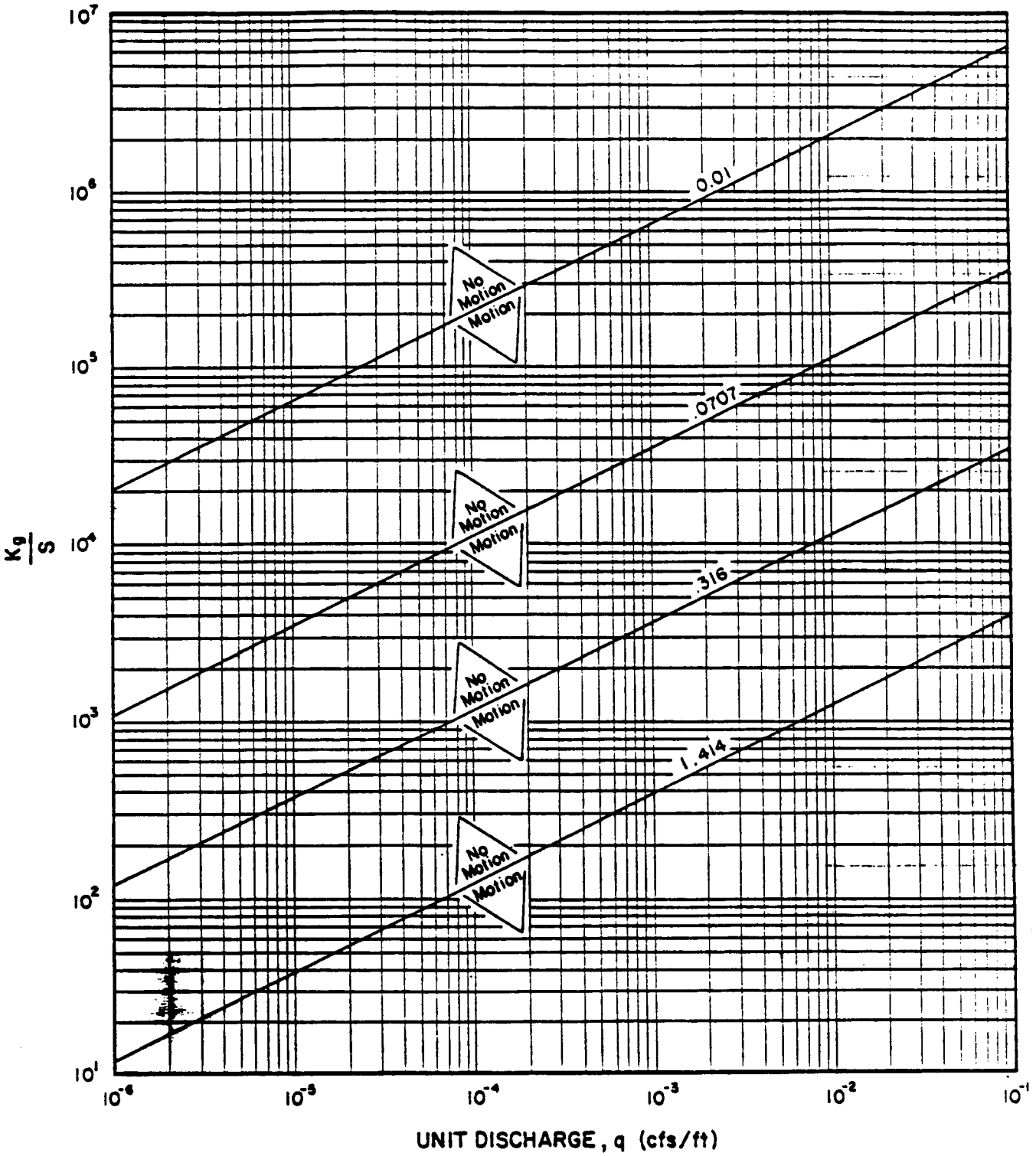
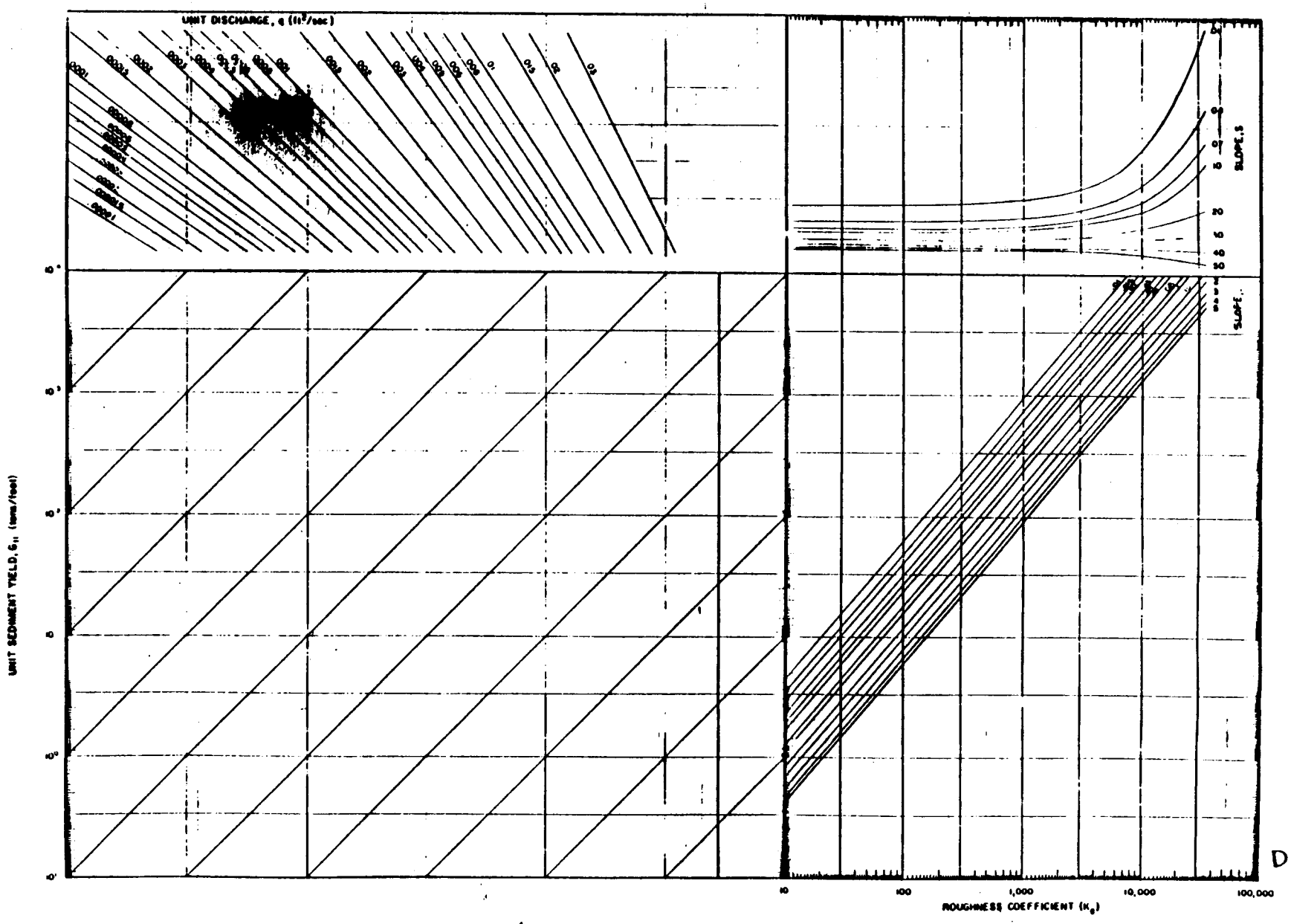
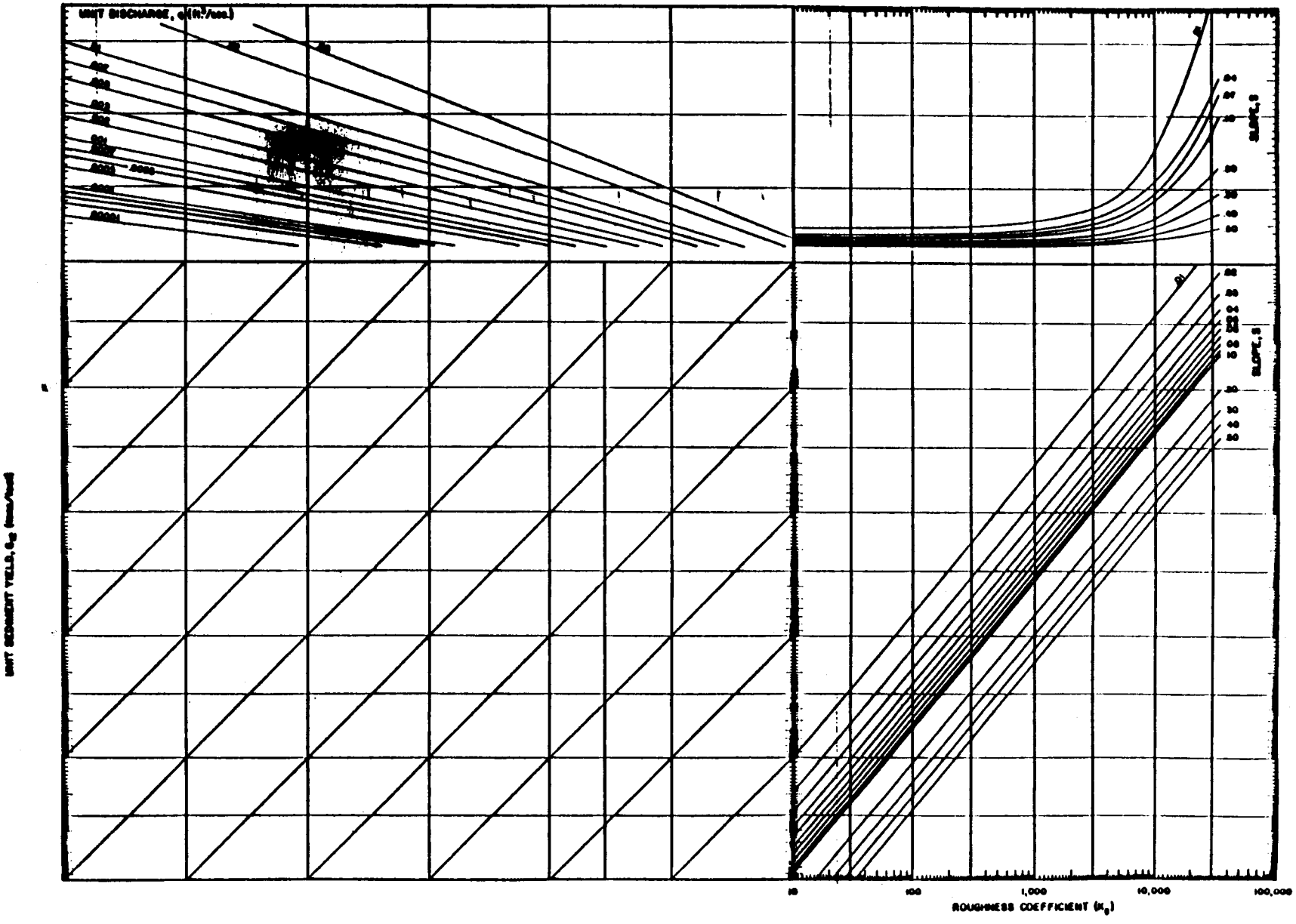


Figure 4.6. Critical discharge (from Simons, Li & Associates, Inc., 1982).



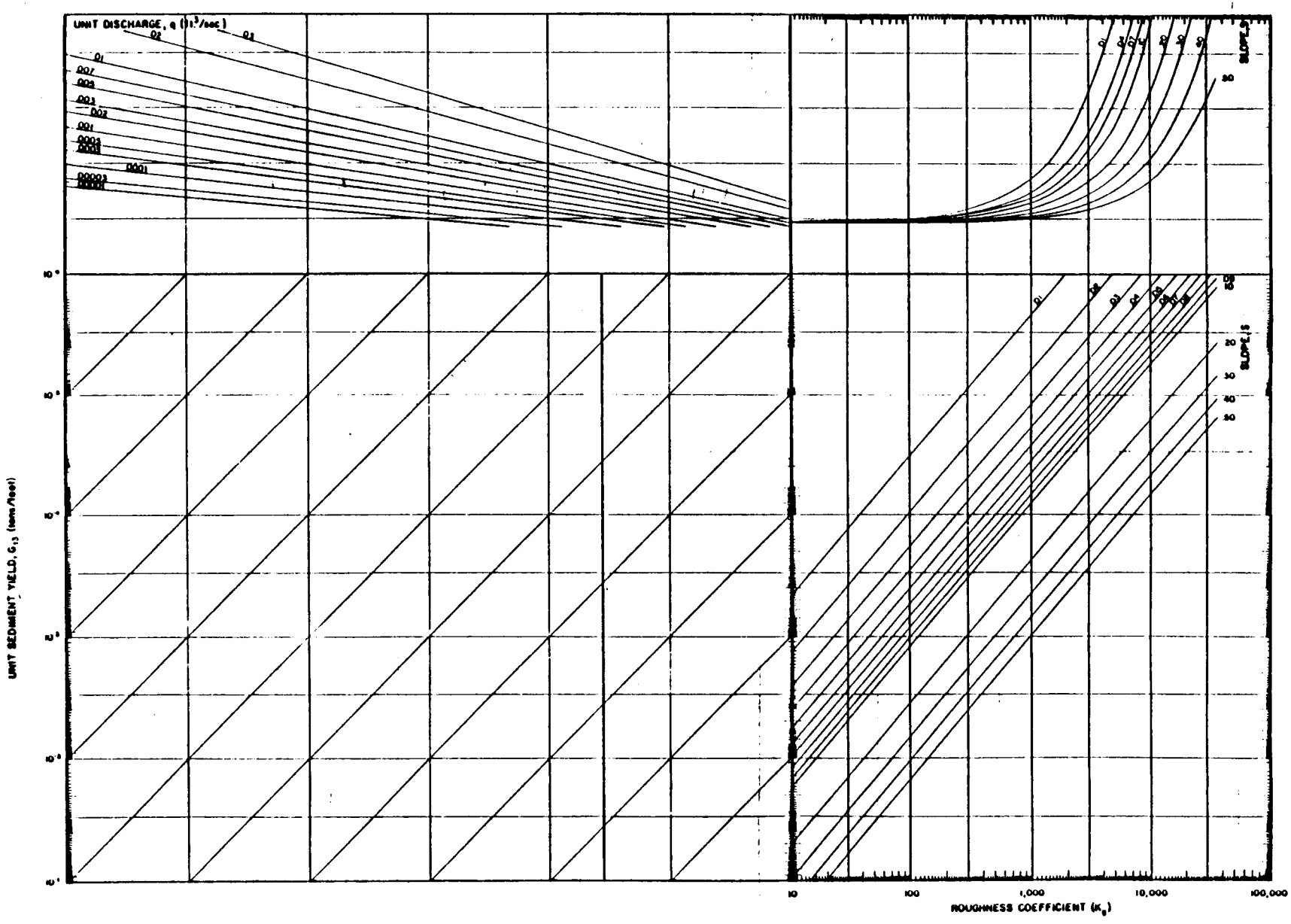
D = [redacted].01

Figure 4.7. Sediment transport rate, D = [redacted].01.



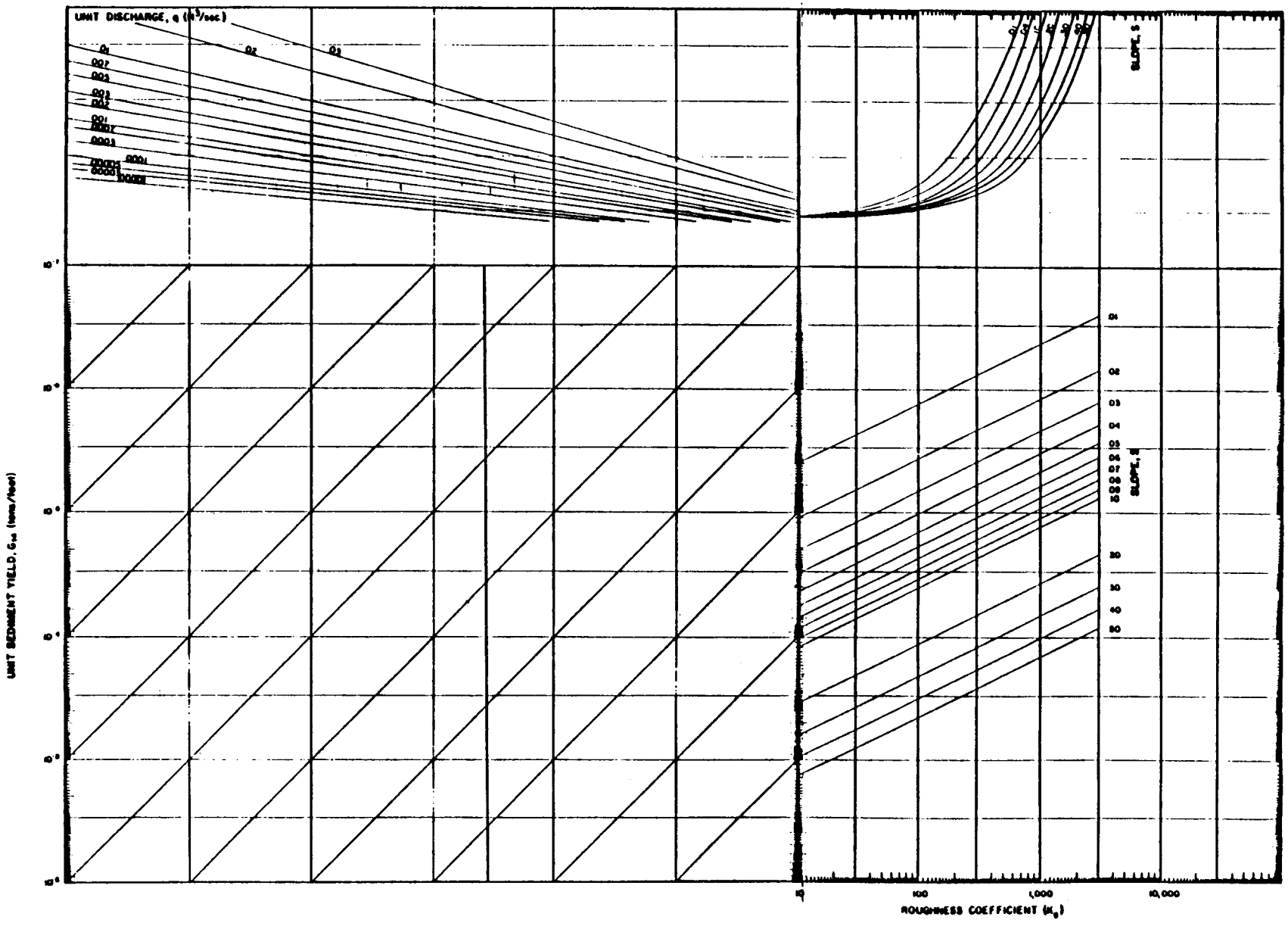
D=.0707

Figure 4.8. Sediment transport rate, D=.0707



D = .316

Figure 4.9. Sediment transport rate, D=.316.



D = 1.414

Figure 4.10. Sediment transport rate, D = 1.414.

1. Enter a value of roughness-slope ratio, K_g/S, and the unit discharges for each time step on the critical discharge graph (see Figure 4.6). If the point on the graph is above the line for a particular sediment size, then no sediment transport will occur for that size at that time step. This step should be completed for each particle size and each time step before computing the sediment yield from the nomographs. Sediment yield need only be computed for sediment sizes and time steps where motion is indicated.

2. Enter a roughness value on the roughness coefficient axis.

3. Extend a vertical line up to the correct slope curve in the first quadrant.

4. Extend a vertical line up to the correct slope curve in the fourth quadrant.

5. Extend a horizontal from the intersection point in the first quadrant to the correct unit overland flow discharge in the second quadrant.

6. Extend a horizontal line from the intersection point in the fourth quadrant to an area in the third quadrant beneath the intersection point in the second quadrant.

7. Extend a vertical line down from the intersection point in the second quadrant until it intersects the horizontal line from the fourth quadrant.

8. From this intersection point in the third quadrant extend a line parallel to the 45° lines in this quadrant until it intersects the vertical pivot line.

9. Extend a horizontal line to the left until it intersects the edge of the graph. Read the unit sediment transport rate in tons/ft/hour.

Columns 7 through 10 are computed using Equation 4.9. Column 11 is the given by the sum of columns 7 through 10 for a time interval and gives the sediment transport capacity for that time interval.

Step Six: Flow Detachment and Total Supply Calculation.

Raindrop impact and overland flow detachment are the two sources of sediment supply from a small area. Supply from overland flow detachment is given by the following equation

$$G_f = D_f(G_t - G_r) \tag{4.10}$$

when $G_t > G_r$

where: G_f = flow detachment for a time interval in tons

D_f = flow detachment coefficient (from step two)

G_t = sediment transport capacity, tons

G_r = total rainfall detachment, tons

If the sediment supply from raindrop detachment, G_r, exceeds the sediment transport capacity, G_t, then no flow detachment would be possible and the flow detachment for the time interval would be zero. In this case, the supply from raindrop detachment would equal the total supply. Worksheet 4.4 is given to aid in computing flow detachment supply and total supply. Total supply is simply the sum of raindrop detachment plus flow detachment. Column 1 is from column 1 of Step Five worksheet. Column 2 comes directly from column 11 of the Step Five worksheet, and column 3 comes directly from column 3 of the Step Four worksheet. Column 4 is given by equation 4.10 and column 5 is the sum of columns 3 and 4 is given by the following equation

$$G_s = G_r + G_f \tag{4.11}$$

where: G_s = sediment supply capacity, tons

G_r = supply from rainfall capacity, tons

G_f = flow detachment for a time interval in tons

Columns 6 through 9 are the total supply multiplied by the fraction of the sediment distribution of each respective particle size.

<u>Step Seven</u>: Determination of Controlling Process and Calculation of Actual Sediment Yield.

Actual sediment yield will be controlled by either the supply of sediment available or by the transport capacity of the overland flow. If the available supply of sediment exceeds the transport capacity of the flow for a particular particle size, then the transport capacity will control the sediment yield. If transport capacity exceeds available supply, then the supply of sediment will control the sediment yield. Stated mathematically the sediment yield is

(1) Δt (hours)	(2) G_t (tons)	(3) G_r (tons)	(4) G_f (tons)	(5) G_s (tons)	(6) G_{s1} (tons)	(7) G_{s2} (tons)	(8) G_{s3} (tons)	(9) G_{s4} (tons)

Flow Detachment Coefficient = _____

$G_f = D_f(G_t - G_r)$ (Eq. 4.10)

where $G_t < G_r$

Worksheet 4.4. Step Six worksheet.

$$G_y = G_s \quad \text{if} \quad G_t > G_s \tag{4.12}$$

and

$$G_y = G_t \quad \text{if} \quad G_t < G_s \tag{4.13}$$

where: G_y = actual sediment yield, tons

G_s = sediment supply capacity, tons

G_t = sediment transport capacity for a given time step in tons

Worksheet 4.5 is given for step seven to aid in accounting for the controlling processes.

The information on the Step Seven worksheet is developed by repeated comparisons between the values on the worksheet for Step Five and the worksheet for Step Six. For example, column one is given by comparing column 3 on the Step Five worksheet with column 7 on the Step Six worksheet. Other columns of this worksheet are developed in a similar manner. Column 5 is the sum of columns 1 through 4. Columns 1 through 4 must also be summed vertically for use in the last step of the procedure.

Step Eight: Calculation of Settleable Solids Concentration.

The mean concentration of settleable solids is determined by the weight of settleable sizes divided by the weight of water for the entire storm. The weight of settleable sizes is given by the sum of columns 1 through 4 of the step seven work sheet. The weight of water is given by the accumulated rainfall volume over the area multiplied by the unit weight of water. The mean concentration of settleable solids is therefore

$$\bar{C}_s = \frac{(G_{y1} + G_{y2} + G_{y3} + G_{y4})}{P_e A} (8830) \tag{4.14}$$

where: C_s = mean concentration of settleable solids, ppm

G_y = sums of actual sediment yields (sums of columns 1 through 4 for the Step Seven worksheet)

P_e = rainfall excess at the end of the storm in inches (the last value from column 5 of the Step Three worksheet)

A = area, acres

8830 = conversion factor from tons/acre-inch to parts per million (ppm)

	(1)	(2)	(3)	(4)	(5)
	G_{y1}	G_{y2}	G_{y3}	G_{y4}	G_y
TOTAL YIELD					

Worksheet 4.5. Step Seven worksheet.

4.3 Design of Mulch Protection

Three types of materials are widely used throughout the U.S. for mulching purposes. These materials are straw, woodchips, and stone. The effectiveness of mulches is related to the amount of groundcover which is provided. The size and shape of the mulch particle also influences the ability of the mulch to resist raindrop detachment and increase the resistance to overland flow. Long narrow particles (such as straw) offer the best erosion protection, more massive particles (woodchips and stone) protect the soil from raindrop impact but still allow for significant overland flow velocities. Finely ground mulch products are the least effective since they are capable of being detached by raindrop impact and can be easily transported by overland flow.

Design Information

Mulch controls erosion by providing ground cover which protects the soil surface from raindrop impact and adds roughness to the surface. Mulches are applied by weight usually in tons/acre, while the amount of ground cover is expressed as the ratio of area covered by mulch to the total area. There is a direct relationship between the application rate of mulches and the ground cover ratio. Figure 4.11 gives the cover ratios for straw, woodchip and stone mulches as a function of application rate. The cover ratio is then used in the procedural guide to determine the roughness coefficient (step two), the curve number (step three), and the raindrop detachment (step four). Values of the cover ratio for straw mulch are used directly to determine the roughness coefficient, curve number, and raindrop detachment. For woodchip and stone mulches, the value of the cover ratio is reduced by 30 percent to determine the roughness coefficient. The cover ratio is reduced by 50 percent to determine the curve number.

Planning Considerations

Mulching can significantly reduce the amount of sediment yield from an area. Approximately a 20 percent reduction in sediment yield will occur for a mulch cover of 10 percent; for a mulch cover of 50 percent sediment yield will decrease by over 85 percent; and for a mulch cover of 90 percent sediment yield will decrease by over 95 percent (Meyer, et al., 1970). As illustrated in Figure 4.11, 90 percent cover can be obtained with 2.2 tons/acre of straw, 9.6 tons/acre of woodchips, or 135 tons/acre of stone. Sediment yield will vary

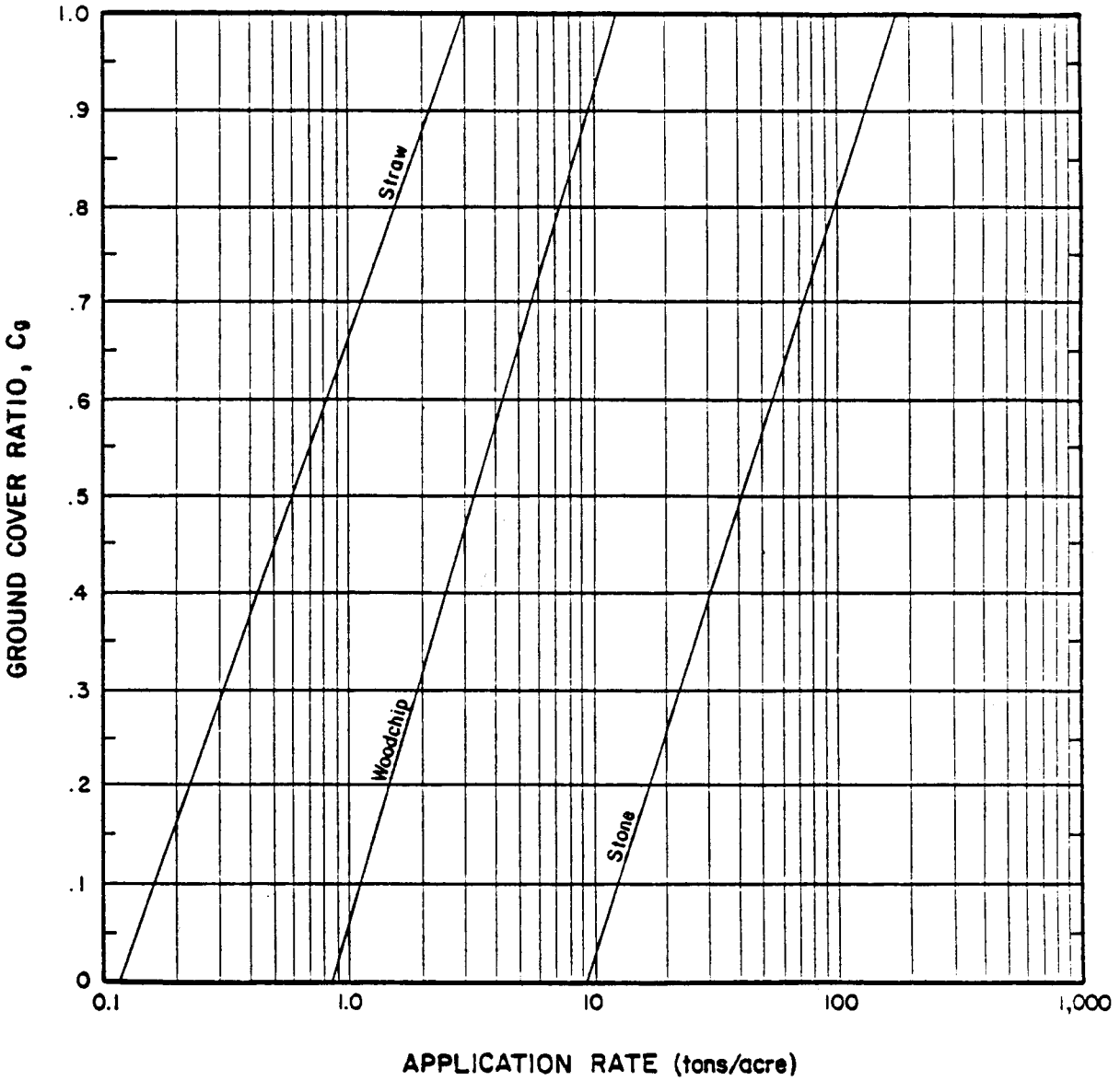


Figure 4.11. Mulch application rate versus cover ratio (from Simons, Li & Associates, Inc., 1982).

depending on the type of soil and the type of mulch used, but it can be seen from the approximate estimates given above that mulches are a very effective means of reducing sediment yield.

The amount of mulch to be used will depend on the type of mulch, the erodibility of the soil, and what type of plant growth is required. Increasing the rate of mulching gives increased erosion protection until full cover is reached. Mulch can substitute for seed coverage when moisture is adequate, but on arid and semi-arid sites, mulches may encourage premature germination with the first rainfall and the seedling may soon die from lack of sufficient moisture for continued growth (Kay, 1978). The best assurance against premature seed germination in dry regions is a soil seed coverage and a reduced mulching rate. Planting and mulching as near as practical to a date when adequate moisture is expected is helpful. Over mulching will smother seedling by limiting light and moisture reaching the soil surface. Some soil should be visible to assure good plant growth. Over mulching with straw may also present a fire hazard. Special considerations for each type of mulch recommended in this manual are as follows.

Straw Mulch. The straw should come from wheat or oats, and may be spread by hand or machine. Some grass straw may contain growth inhibitors that have a toxic effect if used in excess. Commerical mulch spreaders or straw blowers (Figure 4.12) are capable of delivering up to 6 tons/acre at distances up to 85 feet. The length of the applied straw should be relatively long to produce an effective mulch. The length of baled straw will vary depending on the agricultural practice used to harvest the straw. Straw blowers will also reduce the size of the straw element. This can be controlled in most blowers by adjusting or removing the flail chains. Blown straw lies in closer contact with the soil than hand-spread straw and is more easily anchored with mulch binders (see section 4.6). Wind can seriously reduce the original straw mulch application rate, therefore straw mulches must be tacked down with binders.

Woodchip Mulch. Woodchips are usually available as a by-product of land clearing operations or as waste from the forest product industry. Small wood particles, such as shavings or sawdust, are subject to wind erosion and are not recommended. Woodchips can be applied with a conventional straw blower at distances up to 60 feet. The application rate to achieve similar soil coverage as straw is about four to six times that of straw mulch. Poor distribution of woodchip mulch is a problem and may result in poor plant cover. Heavy application (100+ percent cover) will prevent any plant establishment.

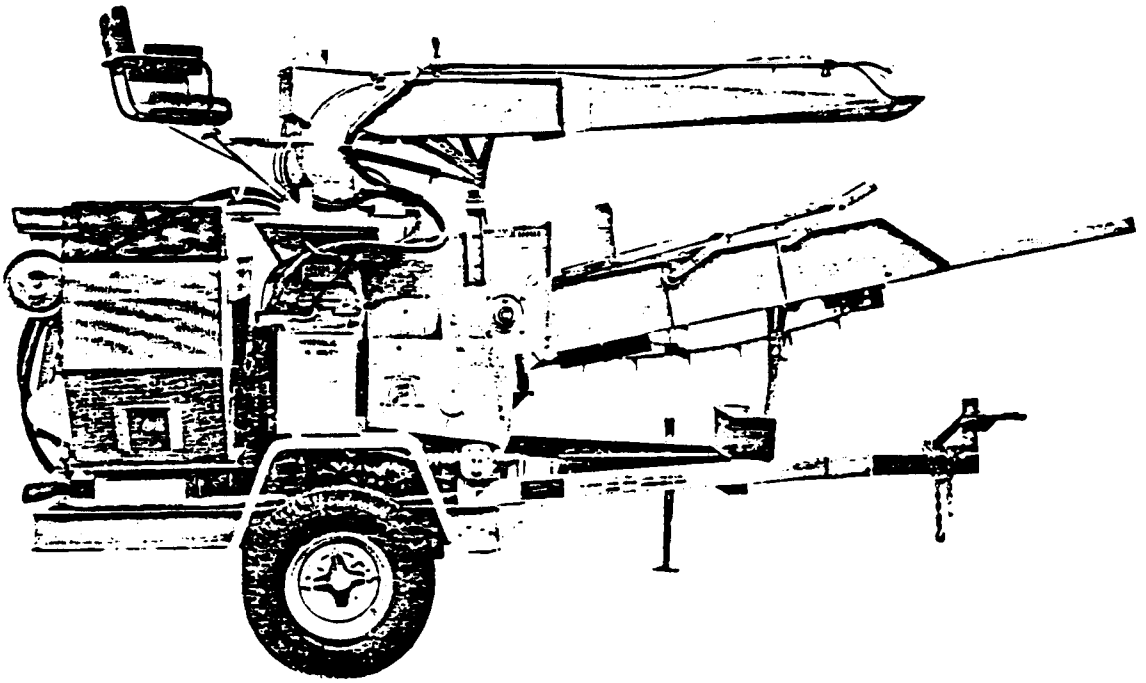


Figure 4.12. Power mulch spreader (from USDA Forest Service, 1979).

Stone Mulch. Mulches of crushed stone or gravel provide effective erosion control and are not susceptible to wind erosion. Stone mulch corresponds to standard road paving mixes with most of the material in a range from 1/4 to 1-1/2 inches in diameter. Application of stone mulch is made with grading equipment and use of stone mulches will be limited by equipment performance, steep slopes and other access problems. Stone mulches provide good microsites for the establishment of plants. In dry areas, stone mulches can be combined with soil seed cover to reduce the problem of premature germination.

The rates involved in stone mulching suggest that such mulches are very expensive to haul and apply onto the ground surface. Costs vary considerably depending on local availability of stone.

Stone mulches should last indefinitely except when their effectiveness is decreased by soil washed or blown onto the stones.

In-Service Performance

All mulches should be inspected periodically, especially after rainstorms, to check for excessive rill erosion. If small washouts occur, additional mulch should be applied. If gullies form, additional erosion measures should be considered to stabilize these areas (see section 4.6 and Chapter VI). Inspections should take place until vegetation is well established.

Specifications - Straw Mulch

Description. This item shall consist of the application of straw mulch to areas indicated on the plans or as designated by the engineer. Straw mulching will be accompanied by a mulch anchoring tool or a type of binder such as asphalt or a chemical binder to protect against wind-blow. The specific type of straw mulching method when required will be shown on the plans.

Materials. Materials for straw mulching shall consist of oats, barley, wheat or rye and shall not contain noxious weeds. Straw or hay in such an advanced state of decomposition as to impede the application and effectivness of the mulch will not be accepted. Old dry straw which breaks excessively in a crimping or blowing application will not be accepted. Straw mulch must be relatively moisture free; water logged straw will not be accepted.

Construction Requirements. After seeding has been completed, straw shall be uniformly applied at the rate shown on the plans or as directed by the engineer. It shall be anchored immediately after spreading to prevent windblow.

Method of Measurement. The quantity of straw mulch to be measured under this item will be the actual number of tons based on the air dry weight of the straw mulch in accordance with the preceding requirements.

Basis of Payment. The accepted quantities for straw mulching measured as provided above will be paid for at the contract unit price per ton.

Payment will be made under:

PAY ITEM	PAY UNIT
Straw Mulching (amount)	Ton

Binding materials required will be measured and paid for in accordance with that specification. Water required will not be paid for as a separate item unless specified for separately in the plans.

Specifications - Woodchip Mulch

Description. This item shall consist of the application of woodchip mulch to areas indicated on the plans or as designated by the engineer. The specific type of woodchip mulching method when required will be shown on the plans.

Materials. Materials for woodchip mulching shall consist of coarse, chipped wood and shall not contain sand or gravel. Small wood residue particles, such as shavings or sawdust, will not be accepted.

Construction Requirements. After seeding has been completed, woodchips shall be uniformly applied at the rate shown on the plans or as directed by the engineer.

Method of Measurement. The quantity of woodchip mulch to be measured under this item will be the actual number of tons based on the air dry weight of the woodchip mulch in accordance with the preceding requirements.

Basis of Payment. The accepted quantities for woodchip mulching measured as provided above will be paid for at the contract unit price per ton.

Payment will be made under:

PAY ITEM	PAY UNIT
Woodchip Mulching (amount)	Ton

Specifications - Stone Mulch

Description. This item shall consist of the application of stone mulch to areas indicated on the plan or as designated by the engineer. Stone mulch may be incorporated with the topsoil application during the final grading of the site. Enough fine-grained material will be provided either in the soil layer beneath the mulch or in the mulch-soil mix to maintain adequate moisture and nutrient supply. The specific gradation, type, application method, and quality of stone mulch when required will be shown on the plans.

Materials. The grading and composition requirements for coarse and fine aggregates for stone mulch are set forth in Table 4.4. The stone mulch material shall provide a suitable medium for plant growth. Stone mulch material must be such that it is not toxic, usually between pH 6.0 to 7.0. Acid material will not be accepted. Stone mulch shall be free of excessive quantities of roots, branches, clods of earth, or trash of any kind.

Construction Requirements. Stone mulch shall be uniformly applied at the rate shown on the plans or as directed by the engineer. It is necessary to compact the stone mulch to ensure good contact with the underlying soil and to obtain a level seedbed. Dense compaction by heavy equipment should be avoided.

Method of Measurement. Stone mulch will be measured by the ton.

Basis of Payment. The accepted quantities of stone mulch of the type specified will be paid for at the contract price per ton.

Payment will be made under:

PAY ITEM	PAY UNIT
Stone Mulch (type and amount)	Ton

Haul for stone mulch will be measured and paid for as a separate item. When topsoil is combined with stone mulch, it will be measured and paid for as a separate item.

Table 4.4. Stone Mulch Aggregate Gradation Table
Percentages Passing Designated Sieves
and Nominal Size Designation.

	Coarse Aggregates (From AASHTO M 43)						
Sieve Size	*No.3 2" to 1"	*No. 4 1-1/2" to 3/4"	No. 6 3/4" to 3/8"	*No. 57 1" to #4	*No. 67 3/4" to #4	*No. 357 2" to #4	*No. 467 1-1/2" to #4
2"	95-100	100				95-100	100
1-1/2"	35-70	90-100		100			95-100
1"	0-15	20-55	100	95-100	100	35-70	
3/4"		0-15	90-100		90-100		35-70
1/2"	0-5		20-55	25-60		10-30	
3/8"		0-5	0-15		20-55		10-30
#4			0-5	0-10	0-10	0-5	0-5
#8					0-5		

4.4 Design of Hydraulic Mulches

Hydraulic mulching (or hydromulching) is a mulch applied in a water slurry by commercially available equipment (Figure 4.13). The slurry mixture is composed of small size wood fibers or recycled paper. After the mulch has dried on the slope, it forms a stable matted layer. Commonly used wood fibers are alder, aspen, and western hemlock. Recycled paper products include office waste, corrugated boxes, and chopped newspaper. Agricultural products sucn as ground rice hulls, ground cereal straw, washed dairy waste, and alfalfa pellets have been tested and found unsatisfactory. Only wood fiber and recycled paper products are recommended as hydraulic mulch in this manual. The mulch particles must not be too buoyant and should remain in suspension with moderate agitation. The slurry may also contain seed, fertilizer, and other soil amendments. Hydraulic mulching has a low labor requirement since a number of revegetation requirements can be combined into a single step.

Since the individual particles of an hydraulic mulch are small, they must bind to the slope and other particles in the slurry to form an effective mulch. If the slurry is too dilute the binding effect will not be achieved and the mulch will not be able to withstand rainfall and wind. In general, hydraulic mulches will not be effective in areas where intense rainfall is common because the mulch mat breaks apart and is washed away.

Design Information

As with other mulches, the performance of a hydraulic mulch in controlling erosion depends on the amount of groundcover provided by a certain application rate of the mulch. For hydraulic mulches the dry unit weight should be used in determining the amount of cover. The coverage of hydraulic mulches is the same as that of straw and can be determined from Figure 4.1 section 4.3 for an application rate in tons/acre. The maximum rainfall intensity which a hydraulic mulch can withstand must also be determined. This is done by using the nomograph in Figure 4.14. The nomograph illustrates an example where a 1.7 ton/acre application rate provides the intended cover up to a rainfall intensity of 1.8 in/hr. Wood fiber alone will maintain its binding strength for several weeks to resist the rainfall intensity determined in the nomograph. If longer-term protection is required, a mulch binder should be added to the slurry (see Design Information, section 4.6).

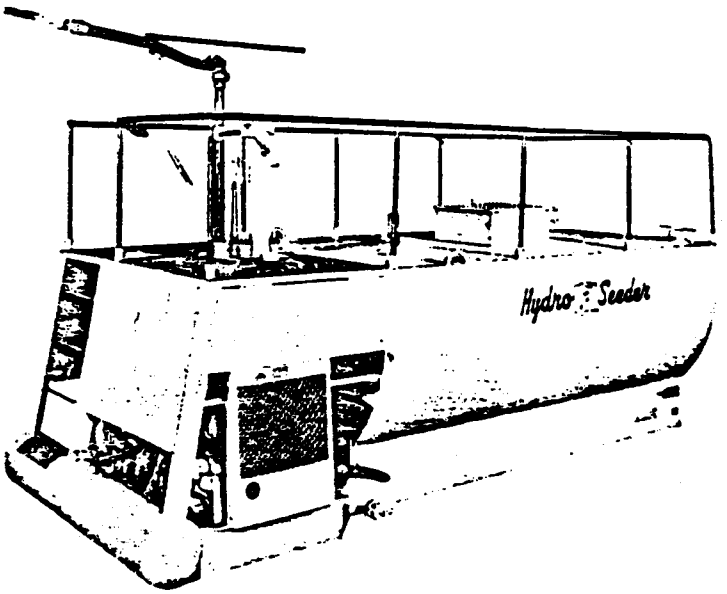


Figure 4.13. Hydraulic mulching spreader to be mounted on a trailer or truck frame (from USDA Forest Service, 1979).

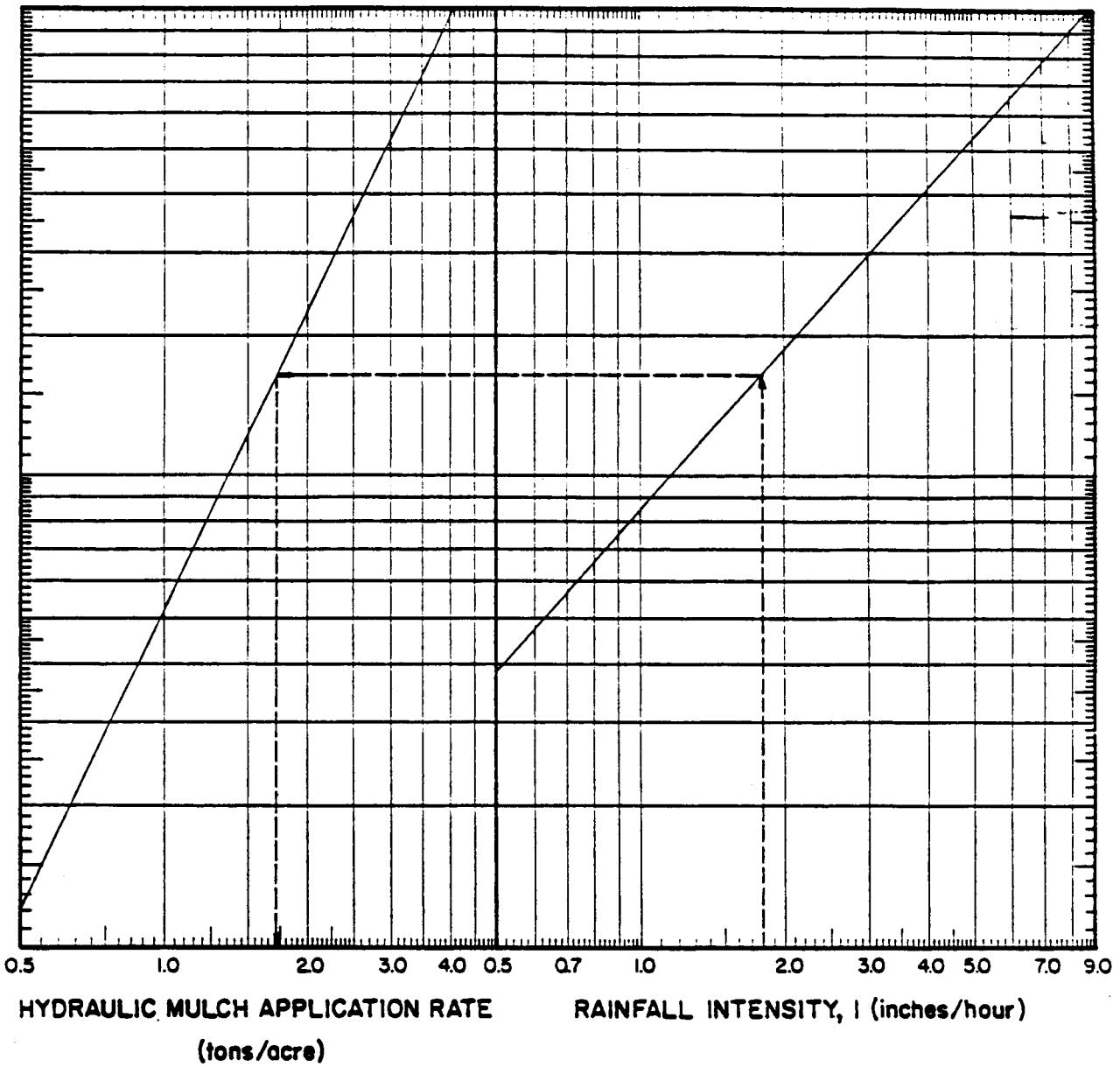


Figure 4.14. Maximum allowable rainfall intensity for hydraulic mulches (from Simons, Li & Associates, Inc., 1982).

Planning Considerations

Hydraulic mulches are vulnerable to intense rainfall. This factor should be considered carefully when designing a hydraulic mulch. If the application rate of a hydraulic mulch becomes large in order to meet the rainfall intensity requirement, it will probably be more economical to specify a straw, stone or woodchip mulch. With heavy applications of hydraulic mulch, seeds applied with the mulch will "hang up" in the mulch and not germinate properly. This can be particularly damaging on arid and semi-arid sites since premature germination will occur and the seedlings will soon die from lack of adequate moisture. As with other mulches, hydraulic mulching should be timed as near as possible to a date when adequate moisture will be available to sustain plant growth. An important property of mulch is its moisture-holding capacity. Hydraulic mulches should wet easily when mixed in the slurry. In general, products with long fibers and good binding characteristics will also have a high moisture-holding capacity.

When recycled paper is used in hydraulic mulching, "slick" grades of paper (magazines) should be removed from the mulch. These grades contain clays which reduce the stability of the mulch significantly. The inorganic matter content (ash) of the hydraulic mulch should be less than 7 percent by weight to overcome this problem.

Hydraulic mulch should not contain boric acid or borate as a fire retardant, since it is a very effective soil sterilant. Hydraulic mulches often contain dyes which aid in obtaining an even distribution of the mulch and these do not retard plant growth.

In-Service Performance

All mulches should be inspected periodically, especially after rainstorms, to check for excessive rill erosion. If small washouts occur, additional mulch should be applied. If large gullies form, additional erosion measures should be considered to stabilize these areas (see Chapter VI). Inspections should take place up until grass is well established.

Specifications - Hydraulic Mulch

Description. This item shall consist of the application of hydraulic mulch to areas indicated on the plans or as designated by the engineer.

Materials. Materials for hydraulic mulching shall consist of wood fiber or recycled paper. Recycled paper shall contain less than seven percent inorganic matter by weight. The mulch shall not contain any substance which might inhibit germination or growth of grass seed. Hydraulic mulch shall be dyed an appropriate color to allow visual metering of its application. The fibers shall have the property of becoming evenly dispersed when agitated in water.

Construction Requirements. Wood fiber or recycled paper shall be added after the proportionate quantities of water and other approved materials have been placed in the slurry tank. All ingredients shall be mixed to form a homogeneous slurry. Using the color of the mulch as a guide, the operator shall apply the slurry mixture in a uniform spray over the designated area. Unless otherwise ordered for specific areas, hydraulic mulch shall be applied at the rate shown on the plans.

Hydraulic mulching shall not be done in the presence of free surface water resulting from rain, melting snow or irrigation.

Method of Measurement. The quantity of hydraulic mulching to be measured under this item will be the actual number of tons of mulch material applied in accordance with the preceding requirements.

Basis of Payment. The accepted quantities for hydraulic mulching will be paid for at the contract unit price per ton.

Payment will be made under:

PAY ITEM	PAY UNIT
Mulching (amount)	Ton

Water required for hydraulic mulching will not be paid for separately but shall be included in the work. Seed, fertilizer and other soil amendments shall be paid for separately.

4.5 Revegetation

Permanent plant growth is the best method of controlling erosion from slopes. A wide range of plant species are available to suit many different soil and climatic conditions. Immediate erosion control needs can be satisfied by establishing a temporary cover of small grains, grasses, or legumes. Permanent vegetation which can be established after final grading of an area will provide long-term erosion control.

Design Information

The most important characteristics of a revegetated area for erosion protection is the amount of cover provided by the vegetation. Unlike mulches, the amount of cover provided by vegetation cannot be related to the gross weight of plant material. Vegetative cover will vary depending on the species of plant, and the density and height of the plants. Plant height and density will also vary depending on spoil and topsoil conditions at the site.

Measurements can be obtained using a vegetative sampling plot frame (30 x 30 inches, covering 6.25 sq. ft.) and a grid frame (15 x 15 inches) consisting of 100 cells (1.5 x 1.5 inches each) (Figure 4.15). The grid frame is used to sample quandrants within the plot frame. Two methods are commonly used in obtaining data from the plot and grid frame. The first, a point hit method, utilizes a metal rod, or "pin", beginning in the upper left cell. The pin is lowered in the corner of every second cell along a row and every other row within the frame, producing a total of 25 points (or 25 percent of the plot). All first hits from the grid to the plant canopy are recorded for each of the 25 points in the quadrant. The frame is then moved to each remaining quadrant until 100 points (100 percent) have been lowered and recorded.

The second method, the cell count, requires counting components (i.e., cover, bare ground, etc.) in each of the 100 cells in the grid frame for each quadrant. Thus, every cell is equivalent to 25 percent of the total plot. This method of observation requires that each component occupy the entire area of a cell to be recorded as "1". The cell is recorded as "0.5" when only half of the cell is occupied. Individual components are then averaged over the four quadrants to yield a percentage value for the plot. Crown cover is identified as normal foliage cover for each plant.

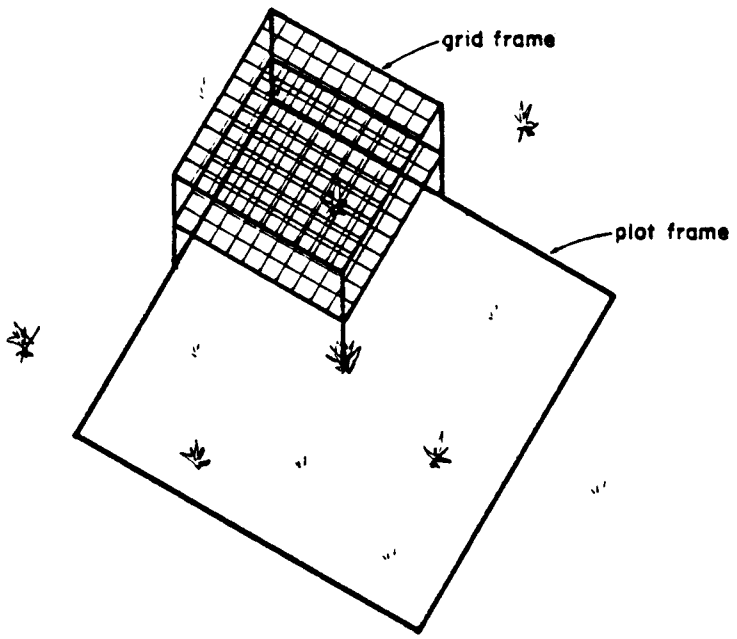


Figure 4.15. Sampling plot frame and grid frame covering one quadrant of the sample plot.

The plot and grid frame methods are suitable for smaller vegetation which is fairly dense. For larger vegetation or very sparse conditions a transect method is often recommended (see Figure 4.16). First, four 100-foot lines are extended in random directions through the sample area. Several methods of generating random directions are possible but bias is avoided if a standard table of random numbers is used. Four random numbers are selected from the table (see Spiegel, 1975, Chapter 5, Random Numbers) with a value between zero and one. These are then multiplied by 360 to give the bearings for each transect. Then, by walking along each line, the canopy of any vegetation which crosses the line is visually projected onto the line. The canopy lengths are tallied for each line and then averaged over the four lines to yield a percent cover value for the area.

Once experience is gained in sampling cover density, the need for the above methods will decrease. Experienced personnel will be able to make accurate visual assessments of cover density. An example of changes in cover from the first to 4th year for grass stands is illustrated in Figure 4.17. If unusual conditions are encountered, such as evaluation of new species or soil conditions, more detailed methods should be used. Cover estimates for design should always reflect the possible reduction in cover due to conditions such as drought, grazing or other factors which might damage the cover. Cover estimates based on carefully maintained reference plots are not acceptable for estimating erosion. Rather, random measurements over time and space give a better indication of potential erosion. For a complete description of techniques to measure and analyze revegetation and stabilization of a mined area, see Cook and Bonham (1977), Packer et al (1978), Milner & Hughes (1968), U.S. Forest Service (1958), Vogel (1981), and Cook et al (1974).

Planning Information

Areas which must be stabilized after the land has been disturbed require vegetative cover. The most common and economical means of establishing this cover is by seeding grasses and legumes. Advantages of seeding over other means of establishing plants include the small initial establishment cost, the wide variety of grasses and legumes available, low labor requirement, and ease of establishment in difficult areas. Disadvantages which must be dealt with are the potential for erosion during the establishment stage, a need to reseed areas that fail to establish, and a need for water and appropriate climatic conditions during germination.

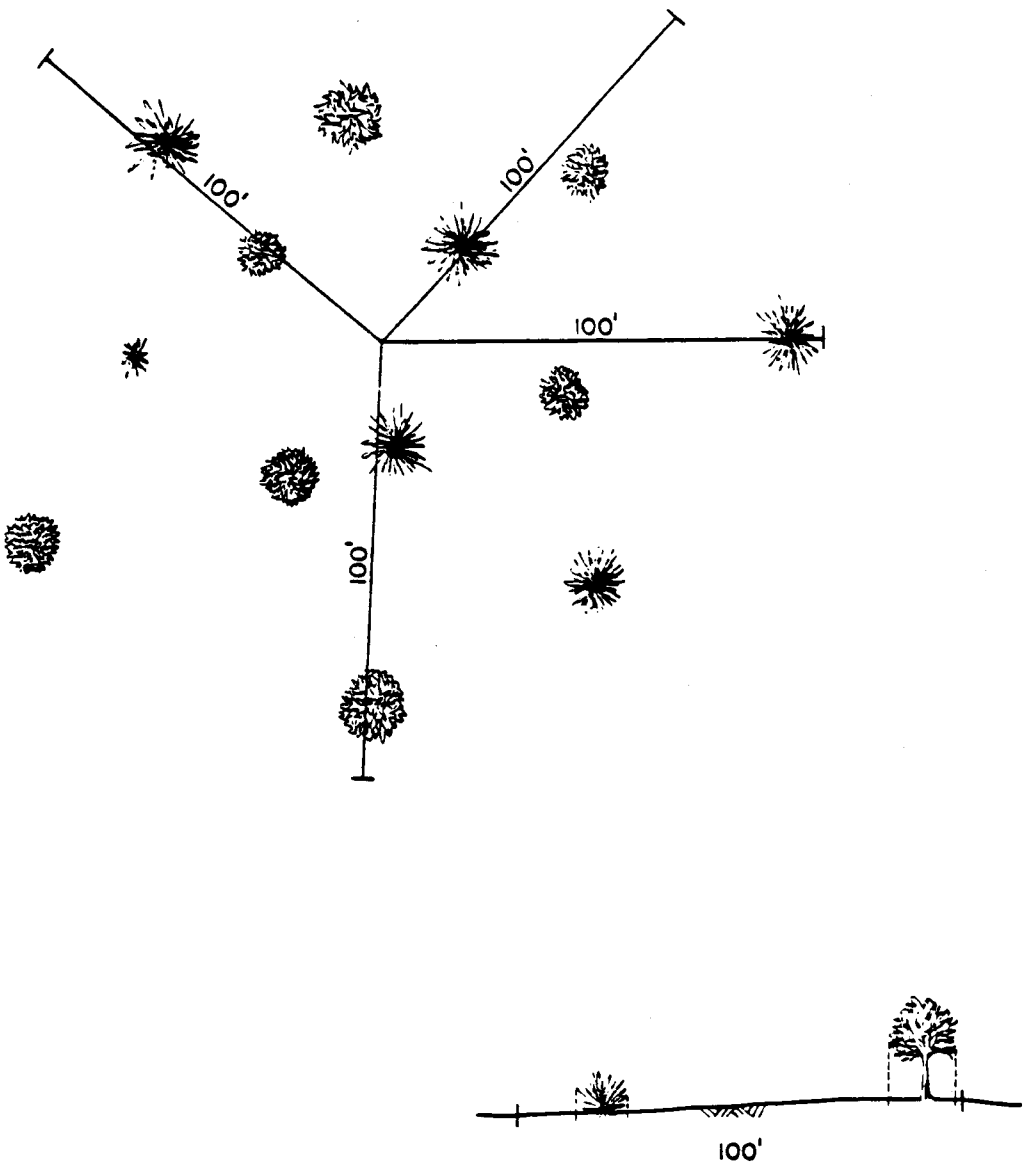


Figure 4.16. Transect method of determining ground cover.

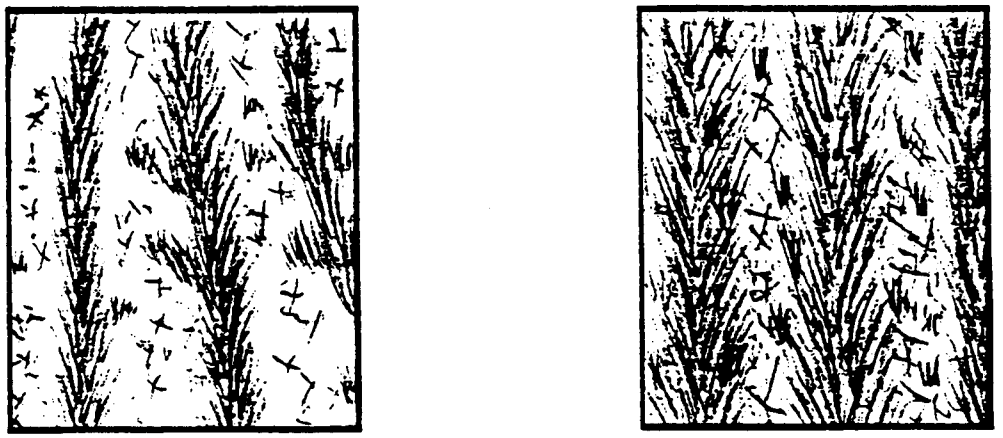


Figure 4.17. Grass stands, such as creeping red fescue, 1st (left) and 4th (right) growing seasons.

There are so many variables in plant growth that an end product cannot be guaranteed. However, much can be done in the planning stages to increase the chances for successful seeding. Selection of the right plant materials and species for the site, good seedbed preparation, and conscientious maintenance are important. An important set of guidelines to assist in critical area planting decisions is available from some state SCS offices. These technical guidelines define species, seeding times, topsoil conditions, and other criteria pertinent to particular regions within a state.

The adapted species (whether native or introduced) should be chosen by a vegetation specialist who is familiar with post mining land use affecting revegetation. Species selection is complex and involves a trade-off of many interacting factors: legal requirements, rehabilitation objectives, timing, species compatibility, seed availability, maintenance, and cost. For example, a vegetative specialist must understand the laws for a particular area which may affect importation of seeds and use of native and introduced species, even though both types can successfully adapt to a disturbed site. A vegetation specialist must be knowledgeable about the type of minesoil at a particular site because characteristics such as texture, depth, slope, aspect and pH will affect species selection. Field observation and revegetation experience of others are valuable in developing criteria for selection of adaptable species. Proper seedbed preparation of the minesoil provides an optimum environment for seed germination and seedling growth. The rooting medium must be loose enough for water infiltration and root penetration. For example, salt affected soils will require a gypsum or $CaCl_2 \cdot H_2O$ treatment to increase soil permeability and structure conducive to plant growth. The pH (acidity and alkalinity) of the soil must be such that it is not toxic and nutrients are available, usually between pH 6.0-7.0.

Sufficient nutrients must be present and if necessary are added during the establishment period as nitrogen, phosphorus and potassium fertilizer. The addition of lime is equally as important as applying fertilizer. Lime is best known as a pH, or acidity modifier, but it also supplies calcium and magnesium which are plant nutrients. Its effect on pH makes other nutrients more available to the plant. It can also prevent aluminum toxicity by making aluminum less soluble in the soil.

The use of mulch is of value during the germination and seeding establishment stages of revegetation. Mulch will hold moisture, modify temperature extremes, and reduce erosion while seedlings are growing.

Irrigation may be used as a temporary measure to enhance germination, establish cover and build up soil moisture. In some cases, irrigation can be used judiciously to leach salts from the minesoil and spoil. However, it is important to plan the total revegetation program so that the plant community will eventually maintain itself under natural conditions.

Irrigation should be considered for establishment when: less than 10 inches of precipitation are received annually, acquired water rights allow use of irrigation water, and water requirements of the selected species dictate that irrigation be used. Alternatively, irrigation may be practical in areas receiving greater than 10 inches of annual precipitation if water is relatively inexpensive and available for use and if irrigation will improve the scheduling of revegetation. The amount and schedule of irrigating depend on site-specific conditions and should be assessed by the vegetation specialist. State guidelines for optimum irrigation are often available from state or local agencies.

Even with well planned seeding programs, failure can occur due to a combination of many factors, including climatic conditions. When plants fail to germinate, the site should be reseeded immediately to prevent erosion.

Additional data requirements and appropriate sources of information to increase the likelihood of successful revegetation are listed in section 3.5.

In-Service Performance

New seedlings should be supplied with adequate moisture, especially during abnormally hot or dry weather, or on adverse sites. Revegetated sites should be inspected for failure and the necessary repairs and reseeding made within the same season, if possible. If poor plant cover results, the choice of plant material as well as the quantities of lime and fertilizer should be re-evaluated. A site specific soil test for soil nutrients is recommended to test for acidity and nutrient imbalances. Seedlings should be fertilized as required after planting to insure proper stand density.

If severe rill or gully erosion occurs on the site, the use of other erosion control measures should be evaluated (see Chapter VI). All sites should be inspected periodically, especially after rainstorms, for excessive rill erosion. If small washouts occur, mulch and seed should be applied.

Specifications - Revegetation

Description. This work shall consist of furnishing and spreading fertilizers, soil preparation, furnishing and drilling or sowing seed in accordance with these specifications and accepted horticultural practice, and in reasonably close conformity with the locations and details on plans or as designated.

Materials. Containers or bags of seeds shall be labeled to show the supplier, seed name, lot number, weight, origin, pounds of Pure Live Seed (PLS) and other information required by the vegetation specialist to insure that the seeds have been tested at a recognized seed testing laboratory six months prior to the delivery date. Wet, moldy or damaged seeds are not acceptable. Seed and seed labels should conform to current Federal and state regulations. If available seeds do not meet PLS requirements, additional quantities of seed must be furnished to equal the specified product. Application rates of seeds shall be based on PLS.

When the use of fertilizer for seeding is called for on plans, it shall consist of a standard form or mixture of standard forms. Other forms may be used only if written request is submitted by a contractor and permission is granted.

Construction Requirements. The time of seeding shall be restricted to the times specified by a vegetation specialist. Seeding at any time other than the times cited above shall be allowed only when the contractor submits a written request and permission is granted. Soil preparation, fertilizer, and seeding shall follow the specifications and requirements set forth by the vegetation specialist unless an alternative means as described and requested by the contractor is approved. Seeded areas damaged due to circumstances beyond the control of the contractor shall be repaired and reseeded. Payment for this work shall be at the contract prices.

Method of Measurement. The quantity of seeding to be measured will be in actual pounds of PLS according to the above requirements, completed and accepted. The quantity of fertilizer to be measured will be the actual pounds of the available nutrients placed in accordance with the foregoing requirements, completed and accepted.

Basis of Payment. The accepted quantities for seeding, soil preparation and fertilizer, measured as provided above, will be paid for at the contract unit price. Payment will be made under:

PAY ITEM	PAY UNIT
Seeding	Pound
Fertilizer	Pound
Soil preparation	Acre

Payment for water requirements shall be according to written agreement between contractor and contractee.

4.6 Design of Mulch Binders

Straw mulch is an extremely effective surface protection measure but can be damaged by wind unless secured to the soil surface. Several methods of securing straw mulch to the surface are available including crimping, rolling, chemical binders, and fabric netting. Crimping is accomplished with commerical machine implements which utilize blunt, notched disks. Disks are forced into the soil by a weighted tractor-drawn carriage. Crimping can be accomplished on slopes of up to 20 percent and is done parallel to the contour of the slope. Hard, over compacted soils will not be penetrated by a crimper, and should be tilled or scarified before seeding and mulching begin. Rolling or "punching" is also accomplished with a specially designed commercial machine implement. Rollers contain staggered rows of one inch steel plate studs which are six inches apart spaced every eight inches. Studs are rounded so that straw will not be withdrawn from the soil during the punching process.

Chemical binders are a common means of holding straw on steeper slopes which cannot be reached by crimping or rolling equipment. Chemical binder products can be grouped based on the type of substances used to make up the binder. Three groups of substances are presently on the market: 1) asphalt emulsions, 2) natural organic substances, and 3) synthetic emulsions. Chemical binders are either applied over the top of straw or simultaneously with the straw-blowing operation.

A variety of nets are available to hold straw in place, including jute mat, plastic netting, woven craft paper, and plastic mat. Use of these products is usually reserved for very steep slopes or special erosion conditions such as repair of gully eroded slopes. The products can also be used as a channel lining in diversion and conveyance channels (see Chapter VI). These products must be anchored at enough points to prevent the net from whipping in the wind and the straw mulch from being blown away.

Design Information

Mulch binders alone do not control erosion but they do play an important role in erosion control by protecting straw mulch from wind-blow. The design criterium used in this manual for mulch binding products is that at a wind speed of 80 miles per hour, 50 percent of the straw should remain on the slope.

Crimping and Rolling. When straw is mechanically secured to the soil surface by crimping or rolling implements it will be effectively protected from wind-blow. Straw should penetrate the soil at least three inches to be effective. Equipment used in mechanically securing mulch can perform on slopes of 20 percent and on short slopes of up to 30 percent.

Chemical Binders. Three groups of chemical binders have been identified for use with this manual. These are asphalt emulsions, natural organic substances, and synthetic emulsions. Asphalt emulsions used for mulch binders are the same type and grade as that used for tack coats on roadway paving. Asphalt emulsion is nearly inert in this application and does not interfere with germination or plant growth. Natural organic substances are derived from the gum extracted from various plants (guar and plantain are plants commonly used) or semi-refined seaweed extracts. Wood fiber alone (used in hdyraulic mulching) is an effective short-term binder, but the binding properties persist for only a few weeks. Synthetic emulsions are commerically available products commonly used in making adhesives and paints. Amoung the synthetic emulsions used are polyvinyl acetate homopolymers or vinyl acrylic copolymers, generally called PVA. Another chemical group of synthetic emulsions which is similar in effectiveness to PVA is a copolymer of methacrylates and acrylates. Another chemical group which is an effective binder is styrene butadiene (SBR).

The effectiveness of all chemical binders will increase as the application rate increases. Most chemical binders can be applied during a blowing operation without any effect on their binding performance. Natural organic substances, however, are not compatible with commercial fertilizers and require a separate application. Synthetic emulsions are sold dispersed in a continuous aqueous phase, while organic substances are sold dry. Both are diluted with water to achieve the desired application rate. Asphalt emulsions are not diluted. Table 4.5 gives recommended application rates for chemical binders.

Mulch Netting. Mulch nettings include products such as jute mat, excelsior (curled wood), plastic netting, and woven paper (all are provided in rolls which are fastened to the soil with wire staples). Fiberglass roving (which is blown on with compressed air and tacked with asphalt emulsion) is also available as a nonbiodegradable substitute. Use of these products requires high labor inputs for installation which can substantially increase

Table 4.5. Application Rates of Chemical Binders for Wind Stability Per Ton of Straw Mulch.

Chemical	Rate/Acre
Asphalt Emulsion	500 gal.
Natural Organic Substances	
Guar gum	45 lbs.
Plantain gum	90 lbs.
Seaweed extract	45 lbs.
Synthetic Emulsions	
Polyvinyl acetate (PVA)	110 gal.
Copolymer of methacrylates and acrylates	100 gal.
Styrene butadiene copolymer emulsion	60 gal.

the cost over other mulch binding methods. Mulch netting provides some additional ground cover and hence increased protection against raindrop detachment. Erosion from beneath these products is common, however, because they do not have close contact with the soil surface. Usually the more cover a product provides, the more rigid and difficult it becomes to secure the net close to the soil.

The cover factor, C_g, and roughness, K_g, can be modified in the following manner to account for an increase in cover due to a mulch netting. First, a new cover factor is computed using the following equation

$$C_g = C_S + C_N - C_S C_N \tag{4.15}$$

where: C_g = the cover factor for straw with netting

C_S = the cover factor for straw alone

C_N = the cover factor for netting alone

Second, the cover factor used to determine the roughness coefficient, K_g, (Figure 4.2, section 4.2) is computed using the following equation

$$C'_g = C_S + F(C_g - C_S) \tag{4.16}$$

where: C'_g = the cover factor used to determine the roughness coefficient

C_s and C_g are given above

F = a factor to account for contact with the soil surface where

F = 0.0 for poor contact

F = 0.5 for moderate contact

F = 1.0 for good contact

Netting cover factors, C_N, and contact factors for several types of nettings are given in Table 4.6.

Planning Considerations

Crimping or Rolling of straw mulch is suitable to establish good contact with the soil surface and prevent wind-blow for large areas with moderate slopes. Hard soils should be tilled or scarified prior to crimping and rolling operations. On slopes greater than 30 percent, other mulch binding methods should be considered. Dry straw which breaks during crimping will not be acceptable. Straw should penetrate the soil surface by approximately three inches. Crimping and rolling should be carried out on the contour of the slope.

Table 4.6. Netting Cover and Contact Factors.

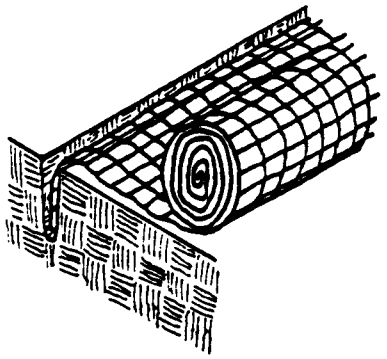
Product	Cover Factor, C_N	Contact Factor, F
Jute Mat	0.40	1.0
Excelsior	0.80	0.5
Woven Paper	(check with manufacturer)	0.0
Plastic Netting	0.01	0.0

Chemical Binders require proper drying conditions to be effective. Fog or rain before the binder has cured may damage the binder and make it ineffective. Another restriction on curing is temperature. The minimum curing temperature for PVA is 56°F; the temperature is 40°F for SBR and natural organic substances. Chemical binders are not toxic to plants, even if sprayed directly on them. Chemical binders must be applied either during or after mulching. Seed and mulch will wash off if the binder is applied before these operations. Another precaution when dealing with chemical binders is that they cannot be stored for extended periods and will be damaged if stored at freezing temperatures (see manufacture information).

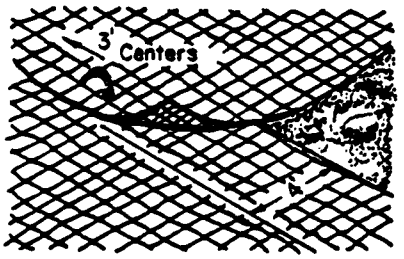
Mulch Netting should be used for small areas or to repair erosion damaged areas. Netting is useful on steep slopes which are not accessible to equipment. Figure 4.18 illustrates important application requirements which must be followed when installing mulch netting on slopes.

In-Service Performance

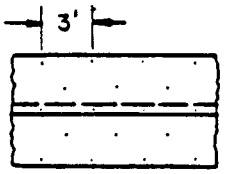
All mulches should be inspected periodically, especially after rainstorms, to check for excessive rill erosion. Where erosion is observed, additional mulch should be applied. Netting should be inspected after rainstorms for failure. If washouts occur, netting should be reinstalled after repairing the damage to the slope. If gullies form, additional erosion measures should be considered to stabilize these areas (see Chapter VI). Inspections should take place up until grass is well established.

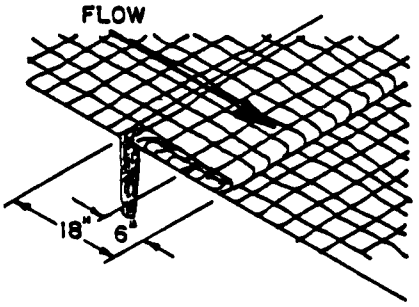


Anchor Slot: Bury the up-channel end of the net in a 6" deep trench. Tamp the soil firmly. Staple at 12" intervals across the net.

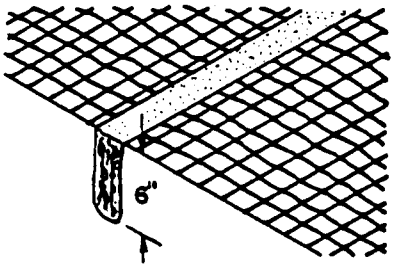


Overlap: Overlap edges of the strips at least 4". Staple Every 3 feet down the center of the strip.

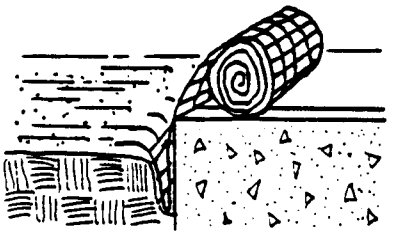




Joining Strips: Insert the new roll of net in a trench, as with the Anchor Slot. Overlap the up-channel end of the previous roll 18" and turn the end under 6". Staple the end of the previous roll just below the anchor slot and at the end at 12" intervals.



Check Slots: On erodible soils or steep slopes, check slots should be made every 15 feet. Insert a fold of the net into a 6" trench and tamp firmly. Staple at 12" intervals across the net. Lay the net smoothly on the surface of the soil - do not stretch the net, and do not allow wrinkles.



Anchoring Ends At Structures: Place the end of the net in a 6" slot on the up-channel side of the structure. Fill the trench and tamp firmly. Roll the net up the channel. Place staples at 12" intervals along the anchor end of the net.

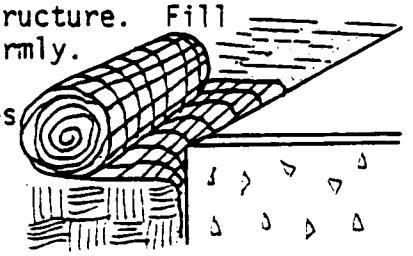


Figure 4.18. Installation of netting and matting (Conwed Products Brochure. In: VSWCC, 1980).

Specification - Jute Mat

Description. This time shall consist of furnishing, preparing, applying, placing and securing jute mat for surface protection on slopes or ditches as shown on the plans or as directed.

Materials. Jute mat shall consist of heavy mesh of a uniform open plain weave of unbleached, smolder resistant, single jute yarn. The yarn shall be of a loosely twisted construction having an average twist of not less than 1.6 turns per inch and shall not vary in thickness by more than one-half its normal diameter. The jute mesh shall be furnished in approximately 90-pound rolled strips and shall meet the following requirements:

Length - approximately 75 yards. Width - 48 inches plus or minus 1 inch. 78 warp ends per width of cloth. 41 weft ends per yard. Weight of cloth to average 1.22 pounds per linear yard with a tolerance of plus or minus 5 percent.

Construction Requirements. The blankets shall be placed in designated locations immediately after seeding and mulching operations have been completed.

The material shall be applied smoothly but loosely on the soil surface without stretching. The upslope end of each piece of jute mesh shall be buried in a narrow trench six inches deep. After the jute is buried, the trench shall be tamped firmly closed.

In cases where one roll of jute mesh ends and a second roll starts, the upslope piece should be brought over the buried end of the second roll so that there is a 12 inch overlap to form a junction slot.

Where two or more widths of jute mesh are applied side by side, an overlap of at least four inches must be made.

Check slots should be made before the jute mesh is rolled out. A narrow trench should be dug across the slope perpendicular to the direction of flow. A piece of jute, cut the same length as the trench, is folded lengthwise. The fold is placed in the trench and the trench is tamped closed. The portion of the jute remaining above ground is unfolded and laid flat on the soil surface.

Check slots will be spaced so that one check slot or junction slot occurs within each 50 feet of slope.

Overlaps which run down the slope, outside edges and centers shall be stapled on 2-foot intervals. Each width of jute mesh will have a row of

staples down the center as well as along each edge. Check slots and junction slots will be stapled across at 6 inch intervals.

For extra hard soil, use sharp pointed hardened steel 3 inch fence type staple.

The blanket must be spread evenly and smoothly and be in contact with the seeded area at all points.

Method of Measurement. Jute mat, including staples, complete in place and accepted, will be measured by the square yard of finished surface. No allowance will be made for overlap.

Basis of Payment. The accepted quantities of jute mat will be paid for at the contract unit price per square yard.

Payment will be made under:

PAY ITEM	PAY UNIT
Jute Mat	Square yard

Specification - Excelsior Blanket

Description. This item shall consist of furnishing, preparing, applying, placing and securing excelsior blanket for surface protection on slopes or ditches as shown on the plans or as directed.

Materials. Excelsior blanket shall consist of a machine-produced mat of 80 percent curled wood excelsior, 8 inch or longer fiber length with consistent thickness and the fiber evenly distributed over the entire area of the blanket. The top side of the blanket shall be covered with a biodegradable extruded plastic mesh. The blanket shall be made smolder resistant.

Width	48 inches ± 1 inch
Length	180 feet avg.
Weight per roll	78 lbs. ± 8 lbs.
Weigth per sq. yd.	0.875 lbs. ± 10 percent
Square yds. per roll	80, average

Construction Requirements. The area to be covered shall be properly prepared, fertilized and seeded before the blanket is placed. When the blanket is unrolled, the netting shall be on top and the fibers shall be in contact with the soil. In ditches, blankets shall be unrolled in the direction of the flow of water. The end of the upstream blanket shall overlap the buried end of the downstream blanket by a maximum of eight inches and a minimum of four inches, forming a junction slot. This junction slot shall be stapled across the blanket at eight inch intervals. Adjoining blankets (side by side) shall be offset eight inches from center of the ditch and overlapped a minimum of four inches. Use six staples across the start of each roll, at four foot intervals, alternating the center row so that the staples form an "x" pattern. A common row of staples shall be used on adjoining blankets.

Method of Measurement. Excelsior blanket, including staples, complete in place and accepted, will be measured by the square yard of finished surface. No allowance will be made for overlap.

Basis of Payment. The accepted quantities of excelsior blanket will be paid for at the contract unit price per square yard.

Payment will be made under:

PAY ITEM	PAY UNIT
Excelsior Blanket	Square Yard

Specification - Woven Paper Mulch Blanket

Description. This item shall consist of furnishing, preparing, applying, placing, and securing paper mulch netting for surface protection on slopes as shown on the plans or as directed.

Materials. Woven paper mulch blanket shall be smolder resistant and shall consist of knitted, natural polypropylene yarn fabricated in a uniform open weave having 1/4-inch square openings through which strips of paper are woven. Paper shall be green or brown contrast or as approved by the Engineer. Fabric shall be furnished with suitable protection for outdoor storage at construction sites and shall meet the following characteristics:

Widths:	5 ft. min., 10 ft. max.
Length:	360 ft. average
Roll Sizes:	5 ft. width-200 sq. yd.; 10 ft. width-400 sq. yd.
Weight:	Approximately 0.2 lbs. per sq. yd.
Packaging:	4-6 mil. opaque polythylene bag

Construction Requirements. Woven paper mulch blanket shall be placed immediately after seeding operations have been completed in each location designated for erosion control.

The fabric shall be draped smoothly but loosely on the soil surface without stretching. The upslope end of each piece of fabric shall be buried in a narrow trench 6 inches deep. After the fabric end is buried the trench shall be firmly tamped closed.

In cases where one roll of fabric ends and a second roll starts, the upslope piece shall be brought over the buried end of the second roll so that there is a 12 inch overlap to form a junction slot. Where two or more widths of fabric are applied side by side, an overlap of at least 4 inches shall be made.

The fabric shall be anchored to the ground by staples at 9 inch intervals along the ends of each strip of fabric.

For extra hard soil, use sharp, pointed, 3-inch, fence-type staples of hardened steel.

Fabric shall be in contact with the seeded area at all points.

Method of Measurement. Woven paper mulch blanket, including staples, complete in place and accepted, will be measured by the square yard of finished surface. No allowance will be made for overlap.

Basis of Payment. The accepted quantities of woven paper mulch blanket will be paid for at the contract unit price per square yard.

Payment will be made under:

PAY ITEM	PAY UNIT
Woven Paper Mulch Blanket	Square Yard

Specification - Plastic Mulch Netting

Description. This item shall consist of furnishing, preparing, applying, placing and securing plastic mulch netting for surface protection on slopes as shown on the plans or as directed.

Materials. Plastic mulch netting shall be an extruded polypropylene or other approved plastic material, extruded in such a manner as to form a net with 3/4 inch minimum square openings. The netting shall be furnished in rolls to meet the following characteristics:

Width:	48 inch minimum
Length:	Convenience lengths, 50 yds. minimum
Weight:	2.6 lbs. per 1,000 sq. ft. minimum

Construction Requirements. Plastic mulch netting shall be placed as soon as possible after mulching operations have been completed in locations designated in the plans. Netting shall be used only to secure hay or straw mulch to the finished slope.

The netting shall be applied smoothly but loosely on the mulched surface without stretching. The netting shall be unrolled from the top to bottom of the slope. The top edge of the netting shall be buried and stapled at the top end of the slope in a narrow trench six inches deep. After the edge is buried and stapled, the trench shall be backfilled and tamped.

In cases where one roll of netting ends and a second roll starts, the upslope piece shall be brought over the start of the second roll so that there is a 12 inch overlap.

Where two or more widths of netting are applied side by side, an overlap of at least four inches must be made.

Insert one staple every foot along top and bottom of edges of netting. Also, insert staples every four feet on each edge and down center of net so that the staples alternate between edges and center to form an X shape pattern.

Method of Measurement. Plastic mulch netting, including staples, complete in place and accepted, will be measured by the square yard of finished surface. No allowance will be made for overlap.

Basis of Payment. The accepted quantities of plastic mulch netting will be paid for at the contract unit price per square yard.

Payment will be made under:

PAY ITEM	PAY UNIT
Plastic Mulch Netting	Square Yard

4.7 Example Problems

Example 4.1 - Baseline Conditions

The following are characteristics of a disturbed area at a mining site which will be considered as the baseline conditions from which the effects of erosion control treatments and structures given in subsequent design problems throughout this manual can be evaluated.

Site Characteristics: Disturbed site, 10 acres in area and 660 feet in length, at a coal mining site in Montana. Area is regraded to a 9 percent slope and topsoiled with 12-14 inches of sandy loam. The mine soil overlies a moderately consolidated shaley, clayey spoil material. This compacted spoil forms a moderately impermeable subsurface layer.

Design Rainfall Amount: 4 inches

Problem: Compute the sediment yield from the disturbed site without vegetation or application of erosion control measures or structures.

Input Data:	Hydrologic soil group:	C
	Curve number, CN:	88 (from Table 4.3)
	Textural class:	Sandy loam
	Storm rainfall amount:	4 inches
	Percent ground cover:	0%
	Catchment area:	10 acres
	slope:	9%
	length:	660 feet

Step One: Particle Size Distribution

For a sandy loam textural class, the particle size distribution is given in Table 3.4 as the following:

Clay:	= 5%
Silt,	p_1 = 25%
Very Fine Sand,	p_2 = 20%

Cover Ratio, $C_g = 0$

Erodibility Factor, $K_e = 0.43$ (from Table 4.1)

Roughness Coefficient, $K_g = 190$ (from Table 4.2 for sandy loam soil, when $C_g = 0$)

Detachment Coefficient, $D_f = 1.00$ (from Table 4.2 for sandy loam soil)

Step Three through Step Seven: see the attached worksheets.

Step Eight: Concentration of Settleable Solids (C_s)

$$C_s = \frac{393.21 + 93.82 + 8.02 + 0.43}{2.73 \times 10} (8830)$$

$$= 160{,}300 \text{ ppm}$$

Example 4.2 - Straw Mulch

This example illustrates the use of straw mulch as a surface protection measure. A 1.5 ton/acre application rate is used in this example. The same soil, site characteristics and design storm conditions are used in this example as in Example 4.1.

Problem: Compute the sediment yield from the disturbe site which has been mulched with straw at the rate of 1.5 tons/acre.

Input Data:	Hydrologic soil group:	C
	Curve number, CN:	77 (from Table 4.3 and Equation 4.1)
	Textural class:	Sandy loam
	Storm rainfall amount:	4 inches
	Catchment area:	10 acres
	slope:	9%
	length:	660 feet

The ground cover is determined using Figure 4.11 in section 4.3 of this chapter.

Step One: Particle Size Distribution

For a sandy loam textural class, the particle size distribution is given in Table 3.4 as the following:

(1) Time (hr)	(2) Δt (hr)	(3) P/P_t	(4) P (inches)	(5) Pe (inches)	(6) ΔP (inches)	(7) ΔPe (inches)	(8) I (in/hr)	(9) Q (cfs)	(10) q (cfs/ft)
4.09		0.068	0.27	0.00					
	4.91				0.33	0.063	0.067	0.129	.000196
9.00		0.15	0.60	0.063					
	2.25				0.40	0.190	0.178	0.843	.00128
11.25		0.25	1.00	0.253					
	0.92				1.78	1.37	1.93	14.9	.0226
12.17		0.70	2.78	1.62					
	1.83				0.50	0.45	0.273	2.43	.00368
14.00		0.82	3.28	2.07					
	10.00				0.72	0.66	0.072	0.660	.00100
24.00		1.00	4.00	2.73					

Small area characteristics:

Area = 10 acres

Length = 660 feet

Width = 660 feet

Example Problem 4.1. Step Three worksheet.

(1) Δt (hr)	(2) I (in/hr)	(3) G_r (tons)
4.91	0.0667	1.41
2.25	0.1778	4.61
0.92	1.9348	223.17
1.83	0.2732	8.85
10.00	0.0720	3.36

Area = 10 acres

$G_r = 6.48\ \Delta t\ I^2\ A_b$ (Eq. 4.7)

Ground Cover Ratio = 0.00

Width = 660 feet

$A_b = (1 - C_g)A$ (Eq. 4.8)

Example Problem 4.1. Step Four worksheet.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Δt	q	g_{t1}	g_{t2}	g_{t3}	g_{t4}	G_{t1}	G_{t2}	G_{t3}	G_{t4}	G_t
(hours)	(cfs/ft)	(tons/ ft/hr)	(tons/ ft/hr)	(tons/ ft/hr)	(tons/ ft/hr)	(tons)	(tons)	(tons)	(tons)	(tons)
4.91	.000196	0.0129	0.00954	.000270	0.00	10.4	0.62	0.18	0.00	11.2
2.25	.00128	0.153	0.0118	.00184	0.00	56.9	3.50	0.55	0.00	61.0
0.92	.0226	6.79	0.549	.0340	.00238	1030.	66.7	4.12	4.43	1100.
1.83	.00368	0.621	0.0487	.00540	0.00	187.	11.8	1.30	0.00	201.
10.00	.00100	0.111	0.00850	.00144	0.00	183.	11.2	1.89	0.00	196.

Roughness Coefficient, K_g = 190

Slope, S = 0.09

Width = 660 feet

Example Problem 4.1. Step Five worksheet.

(1) Δt (hours)	(2) G_t (tons)	(3) G_r (tons)	(4) G_f (tons)	(5) G_s (tons)	(6) G_{s1} (tons)	(7) G_{s2} (tons)	(8) G_{s3} (tons)	(9) G_{s4} (tons)
4.91	11.2	1.41	9.82	11.2	2.81	2.25	2.25	3.37
2.25	61.0	4.61	56.36	61.0	15.2	12.2	12.2	18.3
0.92	1100.	223.	879.	1100.	276.	220.	220.	331.
1.83	201.	8.85	192.	201.	50.1	40.1	40.1	60.2
10.00	196.	3.36	193.	196.	49.1	39.3	39.3	58.9

Flow Detachment Coefficient = 1.0

$G_f = D_f(G_t - G_r)$ (Eq. 4.10)

where $G_t < G_r$

Example Problem 4.1. Step Six Worksheet.

	(1)	(2)	(3)	(4)	(5)
	G_{y1}	G_{y2}	G_{y3}	G_{y4}	G_y
	2.81	0.62	0.18	0.00	3.61
	15.2	3.50	0.55	0.00	19.25
	276.	66.7	4.12	0.43	347.25
	50.1	11.8	1.30	0.00	63.20
	49.1	11.2	1.89	0.00	62.19
TOTAL YIELD	393.21	93.82	8.04	0.43	495.50

Example Problem 4.1. Step Seven worksheet.

Clay	= 5%
Silt,	p_1 = 25%
Very Fine Sand,	p_2 = 20%
Fine-Medium-Coarse Sand,	p_3 = 20%
Very Coarse Sand,	p_4 = 30%

Step Two: Cover Ratio, Roughness and Detachment Coefficients

Cover Ratio, C_g = 0.78 (from Figure 4.11 for 1.5 tons/acre of straw mulch)

Erodibility Factor, K_e = 0.43 (from Table 4.1 for sandy loam soil)

Roughness Coefficient, K_g = 4880 (from Figure 4.2 for sandy loam soil)

Detachment Coefficient, D_f = 1.00 (from Table 4.2 for sandy loam soil)

Step Three through Step Seven: see the attached worksheets.

Step Eight: Concentration of Settleable Solids (C_s)

$$C_s = \frac{(13.00 + 0.83)\ 8830}{1.81(10)} = 6{,}500 \text{ ppm}$$

Discussion of Example Problem Results

The baseline condition given in Example Problem 4.1 represents very poor conditions resulting in an extremely high erosion potential. Realistically, there may be some surface roughness (due to grading operations) or vegetation (weeds) which could reduce erosion, although these will be difficult to evaluate.

Comparison of the results of the two previous problems indicates that a large reduction in sediment yield can be achieved by the use of a straw mulch as a surface protection measure. Comparison of sediment yield concentrations from Step Eight of examples 4.1 and 4.2 shows a 97 percent reduction in sediment yield concentration. This large reduction occurred because of a reduction in rainfall excess from 2.73 inches to 1.81 inches and an increase in the surface roughness coefficient, K_g, from 190 to 4880. The sediment yield with a straw mulch cover is moderate (1.33 tons/acre). It should be noted, that the remaining sediment yield is silt which is a difficult size to control. Increasing the mulch application rate to 2.5 tons/acre gives a cover ratio of 0.94, a curve number of 75, and a roughness coefficient of 7000. Under these

(1) Time (hr)	(2) Δt (hr)	(3) P/P_t	(4) P (inches)	(5) Pe (inches)	(6) ΔP (inches)	(7) ΔPe (inches)	(8) I (in/hr)	(9) Q (cfs)	(10) q (cfs/ft)
8.96		0.15	0.60	0.000					
	0.04				0.00	0.00	0.067	0.00	0.00
9.00		0.15	0.60	0.000					
	2.25				0.40	0.048	0.178	0.213	0.000322
11.25		0.25	1.00	0.048					
	0.92				1.78	0.874	1.93	9.50	0.0144
12.17		0.70	2.78	0.921					
	1.83				0.50	0.348	0.273	1.90	0.00288
14.00		0.82	3.28	1.27					
	10.00				0.72	0.543	0.072	0.543	0.000822
24.00		1.00	4.00	1.81					

Small area characteristics:

Area = 10 acres

Length = 660 feet

Width = 660 feet

Example Problem 4.2. Step Three worksheet.

(1) Δt (hr)	(2) I (in/hr)	(3) G_r (tons)
0.04	0.0667	0.00
2.25	0.178	1.01
0.92	1.93	49.1
1.83	0.273	1.95
10.00	0.0720	0.74

Area = 10 acres

$G_r = 6.48\ \Delta t\ I^2\ A_b$ (Eq. 4.7)

Ground Cover Ratio = 0.78

Width = 660 feet

$A_b = (1 - C_g)A$ (Eq. 4.8)

Example Problem 4.2. Step Four worksheet.

(1) Δt (hours)	(2) q (cfs/ft)	(3) g_{t1} (tons/ft/hr)	(4) g_{t2} (tons/ft/hr)	(5) g_{t3} (tons/ft/hr)	(6) g_{t4} (tons/ft/hr)	(7) G_{t1} (tons)	(8) G_{t2} (tons)	(9) G_{t3} (tons)	(10) G_{t4} (tons)	(11) G_t (tons)
0.04	0.00	0.0	0.0	0.0	0.0	0.00	0.00	0.00	0.00	0.00
2.25	0.000322	0.000450	0.0	0.0	0.0	0.17	0.00	0.00	0.00	0.17
0.92	0.0144	0.0755	0.00218	0.0	0.0	11.5	0.26	0.00	0.00	11.7
1.83	0.00288	0.00864	0.000180	0.0	0.0	2.61	0.04	0.00	0.00	2.65
10.00	0.000822	0.00160	0.000018	0.0	0.0	2.63	0.03	0.00	0.00	2.66

Roughness Coefficient, K_g = 4,880

Slope, S = 0.09

Width = 660 feet

Example Problem 4.2. Step Five worksheet.

(1) Δt (hours)	(2) G_t (tons)	(3) G_r (tons)	(4) G_f (tons)	(5) G_s (tons)	(6) G_{s1} (tons)	(7) G_{s2} (tons)	(8) G_{s3} (tons)	(9) G_{s4} (tons)
0.04	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00
2.25	0.17	1.01	0.00	1.01	0.25	0.20	0.20	0.30
0.92	11.7	49.1	0.00	49.1	12.27	9.82	9.82	14.7
1.83	2.65	1.95	0.70	2.65	0.66	0.53	0.53	0.79
10.00	2.66	0.74	1.92	2.66	0.67	0.53	0.53	0.80

Flow Detachment Coefficient = 1.00

$G_f = D_f(G_t - G_r)$ (Eq. 4.10)

where $G_t < G_r$

Example Problem 4.2. Step Six worksheet.

	(1)	(2)	(3)	(4)	(5)
	G_{y1}	G_{y2}	G_{y3}	G_{y4}	G_y
	0.00	0.00	0.00	0.00	0.00
	0.17	0.00	0.00	0.00	0.17
	11.5	0.26	0.00	0.00	11.76
	0.66	0.04	0.00	0.00	0.70
	0.67	0.03	0.00	0.00	0.70
TOTAL YIELD	**13.00**	**0.33**	**0.00**	**0.00**	**13.33**

Example Problem 4.2. Step Seven worksheet.

a straw mulch cover is moderate (1.33 tons/acre). It should be noted, that the remaining sediment yield is silt which is a difficult size to control. Increasing the mulch application rate to 2.5 tons/acre gives a cover ratio of 0.94, a curve number of 75, and a roughness coefficient of 7000. Under these conditions, rainfall excess would decrease to 1.667 inches and the sediment yield (without going through the details of the calculations) would decrease to 4.26 tons (0.43 tons/acre) with a concentration of 2,250 ppm.

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V. MECHANICAL TREATMENT MEASURES

5.1 General

A viable means of reestablishing and maintaining a stable post mining landscape is to mechanically manipulate the land surface. The ultimate purpose is to decrease the time required to reconstruct a relatively stable land surface. This is done by (1) reducing runoff, (2) increasing rainfall depression storage and (3) converting concentrated flow to diverse flow, with the ultimate goal being to establish or improve vegetative cover.

Science and technology of land surface treatments (including conservation tillage) of cropland and rangeland have reached an advanced stage in the United States and similar practices have been adapted to mine lands. Surface roughening treatments which have been modified from rangeland practices include furrowing, terracing, trenching, ripping, chiseling, tracking, pitting and water spreading and harvesting. Equipment commonly used are modified versions of rangeland, agricultural and industrial implements including backhoes, bulldozers, disks, harrows, rakes, tillers, drills, chiselers and scrapers.

These practices have been developed largely for semi-arid and arid lands where water and soil conservation is critical. On mined lands in these regions, several complementary treatments may be necessary to offset scanty moisture supplies resulting from (1) erratic and low rainfalls (4 to 14 inches of average annual precipitation), (2) high evapo-transpiration, (3) low spoil water-holding capacity and (4) low infiltration rates. Land manipulation in humid areas is generally considered inefficient because standard seedbed preparation, seeding and vegetative management are more successful and well-accepted reclamation practices.

Four land surface treatments are presented in this manual: furrowing, imprinting, pitting and ripping. The following design methodology quantifies and assesses the effects of these land surface treatments.

5.2 Design Procedures

The procedural guidelines for predicting the effects of erosion control structures and land treatments are given in Chapter IV. Two additional sets of design information are required before applying this design procedure to land surface treatments.

First, the relationship between the treatments and the roughness coefficient, K_g, is graphically illustrated in Figure 5.1. Values of K_g can also be determined for different ages of the treatment, depending on when the treatments were implemented. If vegetation is established during this time, the largest K_g value corresponding to the appropriate cover in Figure 4.2 (Chapter IV) or selected treatment in Figure 5.1 should be chosen for use in the design procedure.

Values of K_g and the detachment coefficient, D_f, for each of the treatments corresponding to general soil textural classes are tabulated in Table 5.1. As previously stated, if vegetation is established, the largest K_g value corresponding to the appropriate cover (Table 4.2) or treatment (Table 5.1) should be selected. If sufficient data are available to determine particle size distribution (Appendix A) and site specific values of erodibility, K_e, (Appendix B), then more specific values of K_g and D_f can be determined from Figures 5.1 and 4.3, respectively.

Values of the curve number, CN, are also required for each of the treatments. Table 5.2 gives the CN values for the 4 mechanical treatments corresponding to zero vegetative cover and 100 percent cover. The actual value of CN to be used will be based on the percent ground cover as given by the equation (4.1), $CN = CN_H - (CN_H - CN_L)C_g$, where CN_H and CN_L are the 100 and zero percent CN values, respectively, and C_g is the decimal percent cover.

5.3 Contour Furrowing - Design Information, Planning Considerations Specifications, and Maintenance

Design Information

Furrowing is a mechanical treatment done on the contour which creates small trenches or grooves by throwing the soil on each side of the trench. Contour furrows are generally spaced five feet apart, are 20 to 30 inches wide and 8 inches deep, and should be dammed at intervals of 4 to 9 feet (see Figure 5.2). This treatment is considered to be a highly successful mechanical treatment for establishing vegetation. Although the land surface pattern illustrated in Figure 5.2 is the result of a disk furrower, a similar roughening pattern can be effectively produced by modifying equipment listed in Table 5.3, e.g., a moldboard plow bottom creates dikes by throwing the soil on the downslope side of the ditch, forming a ridge or dike (one to two feet high).

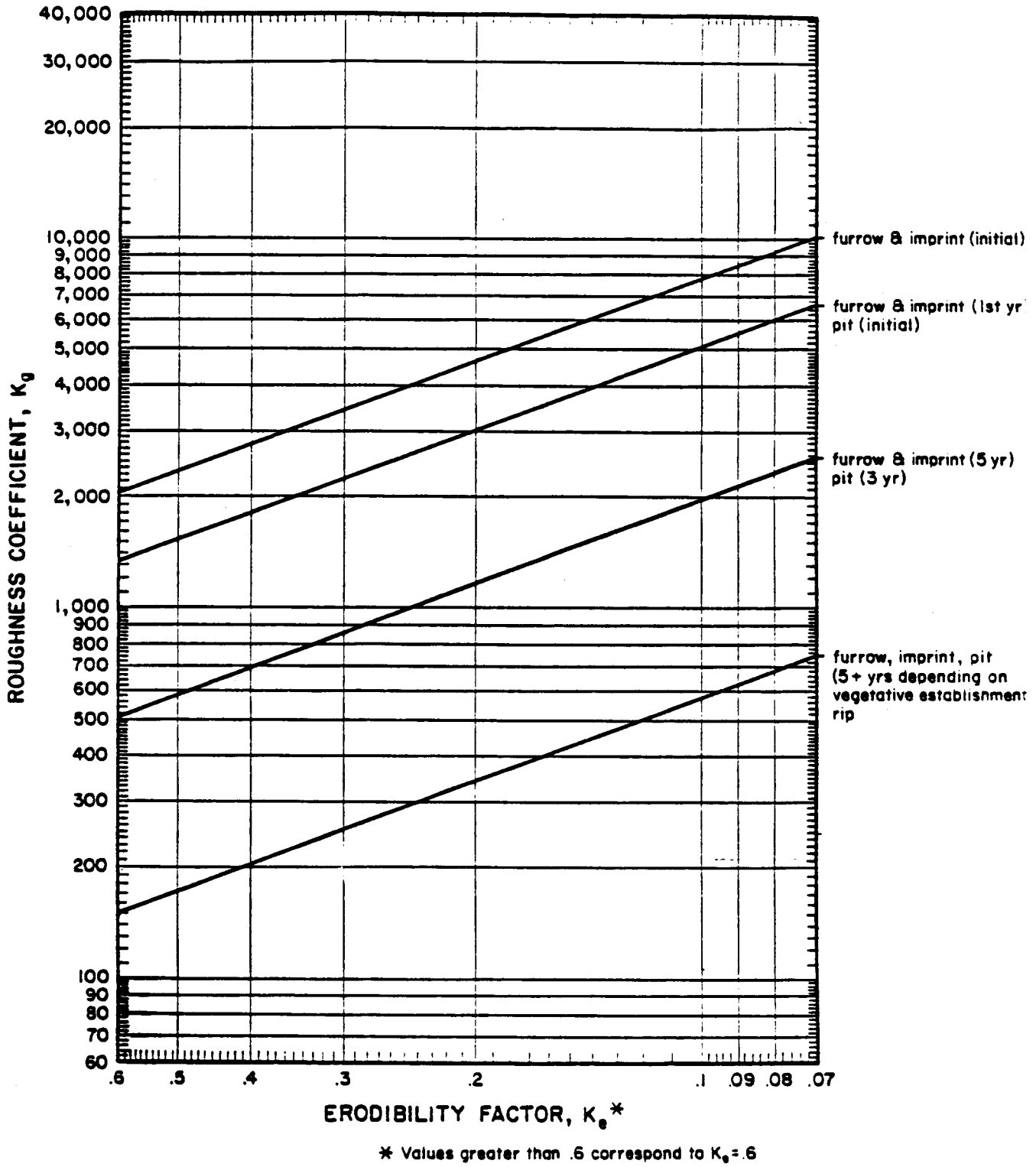


Figure 5.1. Relationship between mechanical treatments, roughness coefficient and erodibility factor (from Simons, Li & Associates, Inc., 1982).

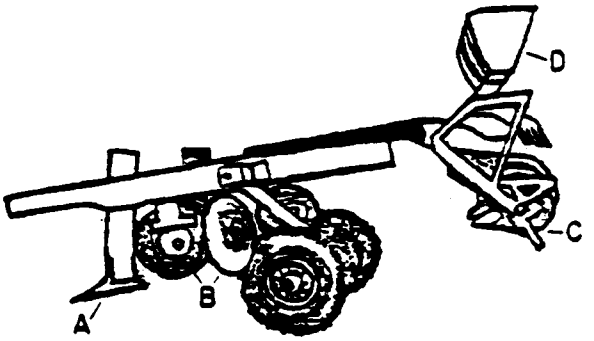
Table 5.1. Simplified Listing of Roughness Coefficient, K_g, and Overland Flow Detachment Coefficient, D_F, for General Soil Textural Groups and Associated Erodibility Values, K_e (Table 4.1)

Textural Class	Suggested K_e	K_g				D_f
		Furrow, Imprint (Initial)	Furrow, Imprint (1st Year) Pit (Initial)	Furrow, Imprint (5 Years) Pit (3 Years)	Furrow, Imprint Pit (5+ Years) Rip	
Sand	.20	4,900	3,000	1,150	340	1.000
Loamy Sand	.30	3,600	2,200	860	255	1.000
Sandy Loam	.43	2,700	1,720	680	190	1.000
Loam	.36	3,150	1,950	750	220	.550
Silty Loam	.48	2,550	1,600	610	180	.160
Silt	.83	2,100	1,350	500	150	1.000
Sandy Clay Loam	.26	4,000	2,500	960	280	.088
Clay Loam	.28	3,800	2,400	920	270	.046
Silty Clay Loam	.31	3,500	2,150	840	250	.025
Sandy Clay	.13	6,800	4,200	1,600	470	.0023
Silty Clay	.25	4,200	2,600	1,000	290	.0074
Clay	.20	4,900	3,000	1,150	340	(~0.0)

Table 5.2. CN Values of Surface Treatments Under No Vegetative Cover Conditions and 100 Percent Cover Conditions.

		Hydrologic[1] Soil Group			
		A	B	C	D
Contour Furrowing	(low)[2]	26	57	70	78
	(high)	47	67	81	88
Imprinting	(low)	30	58	71	78
	(high)	47	67	81	88
Pitting	(low)	34	59	72	79
	(high)	57	73	83	88
Ripping	(low)	39	61	74	80
	(high)	68	79	86	89

[1] See section 3.3
[2] Low and high end of range for reclaimed mine spoil with vegetative ground cover (see Equation 4.1)



Keith O. Eggleston

E

Figure 5.2. Contour furrowing implement and land pattern. A. ripper tooth to rip soil about 2 inches below furrow depth; B. standard disks that open furrow; C. damming device; D. broadcast seeder; E. surface pattern of dammed furrow system.

Table 5.3. Specifications for Contour Furrowing.

Item	Common Specifications
Equipment	Disk-type, modified moldboard plow, modified listers, blade-tips of graders (broad base furrower)
General Components	Furrow opener creating ditch and throwing soil on opposite sides or on the downslope side; an adjustable ripper tooth may precede the furrow opener (optional); damming device
Number of Furrows	1 - 3 depending on equipment
Maximum Penetration of Ripper	12" (or approximately 2" below depth of furrow)
Damming Interval	4' to 20'
Furrow Spacing	3' to 5'
Width of Furrow	18" to 30"
Maximum Furrow Depth	8"
Power Requirements	Minimum of 15 to 20 HP per furrow former (equivalent of caterpillar D6)
Pay Item	Per acre

Planning Considerations

Contour furrowing is a versatile treatment on slopes less than 10 percent which are not rocky. Furrowing is best accomplished on moderately deep and deep soils (approximately 10 to 12+ inches) in arid and semi-arid regions which receive greater than 8 inches of annual precipitation. Limited data do not show significant beneficial results from humid regions or regions receiving less than 8 inches of precipitation.

Specifications - Contour Furrowing

This work shall consist of mechanically contour furrowing in accordance with the specifications given in Table 5.3. The accepted basis of payment for standard furrowing will be paid at the contract unit price according to the pay unit given in the Table.

In-Service Performance

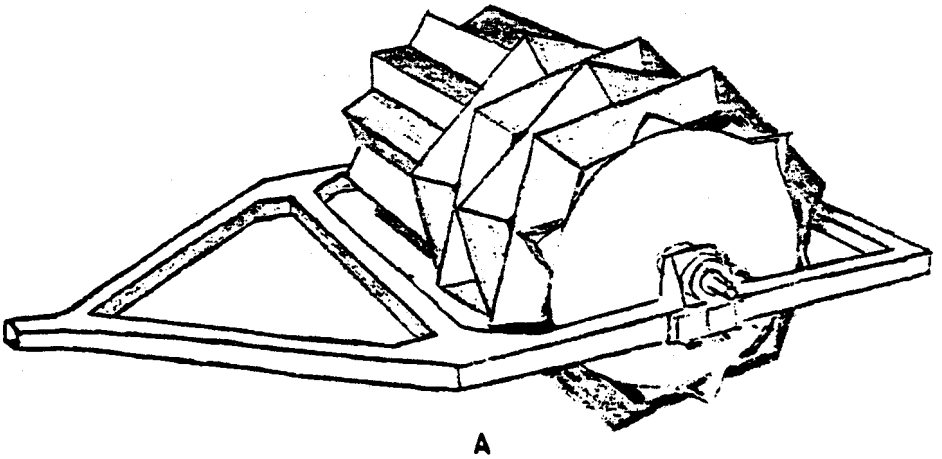
Of the mechanical treatments used on rangeland and mined land, the conservation effects of furrowing are relatively well documented. Under the recommended field conditions and standard specifications, the water holding capacity is approximately two inches of rain the first year and one inch by the 5th year. Infiltration rates can increase by 10 fold and runoff can decrease by 84 percent. The effects of furrowing generally persist (in a degrading mode) from five to twelve years. The in-service performance is dependent upon a complex interaction between pit size and soil type, microclimate, and vegetative establishment. A general rule of thumb for furrowing and most mechanical treatments is that the hydrologic conditions of a site can be expected to improve as vegetative cover is established and approaches that of the surrounding landscape or approaches 70 percent cover if annual precipitation is adequate.

Although little data are available on broad-base furrows, their performance appears to be comparable with standard contour furrows.

5.4 Land Imprinting

Design Information

Land imprinting is a relatively new minimum tillage practice which forms microfurrows to reduce and diffuse runoff and microbasins to pond water (see Figure 5.3). It concentrates above-ground plant material at the surface



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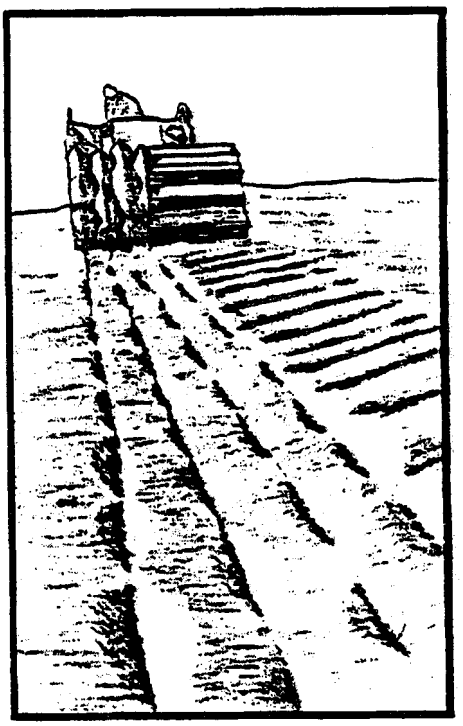

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Figure 5.3. Land imprinting implement and land surface pattern. A. Standard imprinter consists of a single moving part, which is a compound roller having angle irons on external surface. B. Mechanically formed geometric pattern. V furrows (RH) collect and shed runoff to microbasins (LH) where runoff is collected and absorbed.

thereby increasing the effective mulch. Imprinting roughens the surface with wedges creating geometric patterns approximately four inches deep, depending on soil compaction, soil moisture, and weight on the implement. The V-furrows combined with the closed geometric ponding pattern create a relatively stable seed bed and runoff is diffuse. The microbasins have been found to perform successfully in concentrating meager amounts of rainfall runoff in arid lands.

Design and specification instructions for home fabrication can be obtained from Robert Dixon, USDA-SEA, 2000 E. Allen Road, Tucson, Arizona 85719.

Planning Considerations

Land imprinting can be used to treat all soil textures including rocky, soil and shallow or deep soils. Imprints can be constructed under wet or dry conditions although the optimum condition of soil in humid-subhumid regions is the lower end of the plasticity range for a particular soil; optimum conditions in arid and semi-arid regions are the plasticity range on less. In regions receiving less than 8 inches of annual rainfall, imprinting should be done in conjunction with ripping, topsoiling and mulching.

Imprinting can be done parallel to the slope to enhance harvesting of runoff from the V-furrows to the microbasins. However, imprinting perpendicular to the slope is recommended for steep slopes (greater than 8 percent) to create firm microterraces or horizontal stairsteps on the hillside (see Figure 5.4). The maximum slope for imprinting depends on operator safety. Cabling can be utilized for steeper slopes.

Soils with less than 150 lb/in^2 load bearing capacity require a 3 ton imprint implement. For soils with higher bearing capacities, 3 to 5 ton implements perform well, or, alternatively, the soil can be ripped prior to imprinting. To increase the weight of standard imprints, the imprinter can be filled with water or sand (Figure 5.3).

Specifications - Land Imprinting

This work shall consist of mechanically imprinting in accordance with the specifications given in Table 5.4. These specifications are defined for the standard imprinter illustrated in Figure 5.3. Specifications for other imprinting patterns, such as a simple V-furrow pattern or the crimped V-furrow (see Figure 5.5) are not included, although many of the specifications are

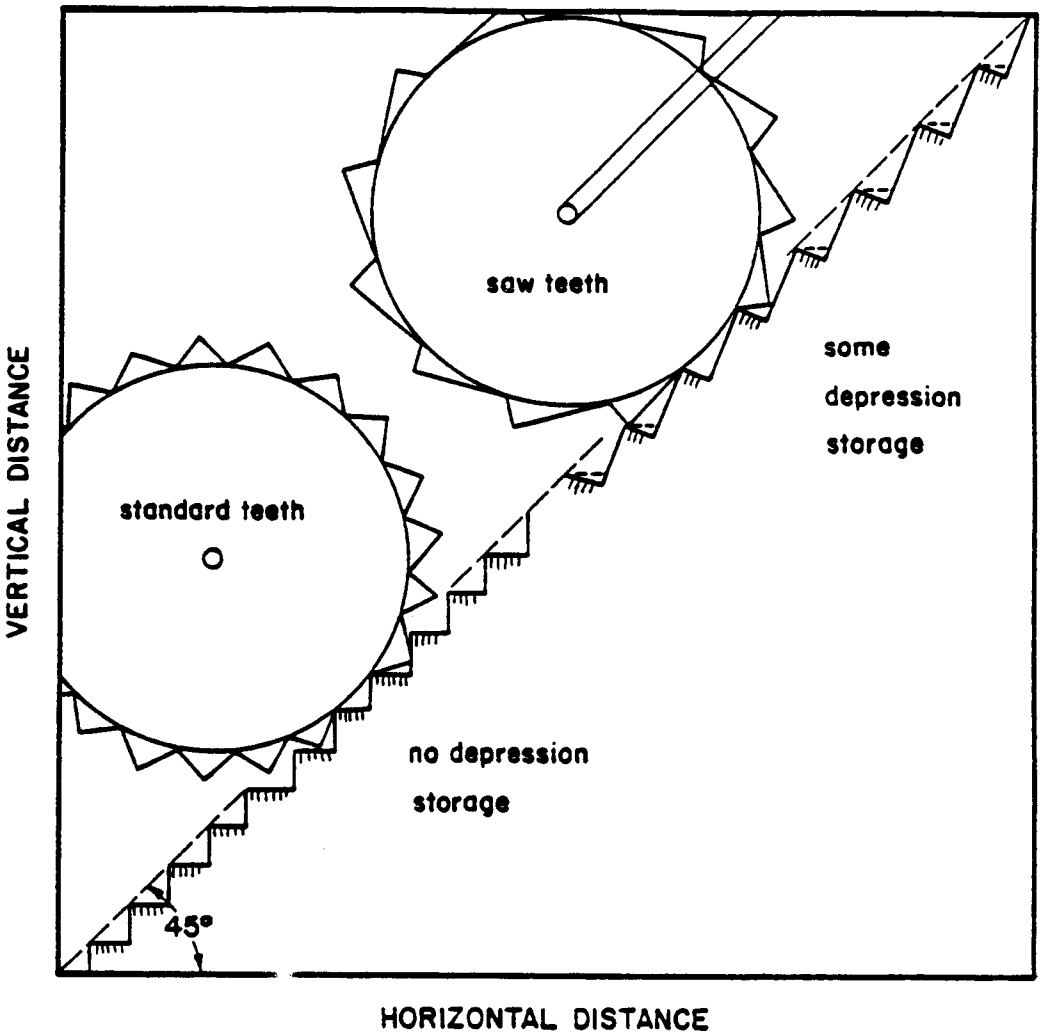


Figure 5.4. Comparison of imprints made on a 45° (100%) slope by imprinting angles having equal legs (standard teeth) and unequal legs (saw teeth). Saw teeth on $\geq$ 45° slopes provide some depression storage. For slopes > 45°, capsules can be cabled onto the slope (after Dixon, R.M., unpub.).

Table 5.4. Specifications for Land Imprinting.

Item	Common Specifications
Equipment	Commercial or home-fabricated imprinter modified crawler or tillage implements
General Components	V-furrow former; microbasin former
Imprint Implement Weight	3 to 5 t
Furrow Width	10" to 12"
Furrow Depth	4" to 6"
Furrow Length	40" to 45"
Furrow Spacing	10" to 12"
Microbasin Width	2" to 10" (variable)
Microbasin Depth	2" to 5" (variable)
Microbasin Length	Continuous with direction of travel
Microbasin Spacing	10" to 12"
Number of Microbasin/Trip	4
Power Requirement	30 HP
Pay Item	Per acre

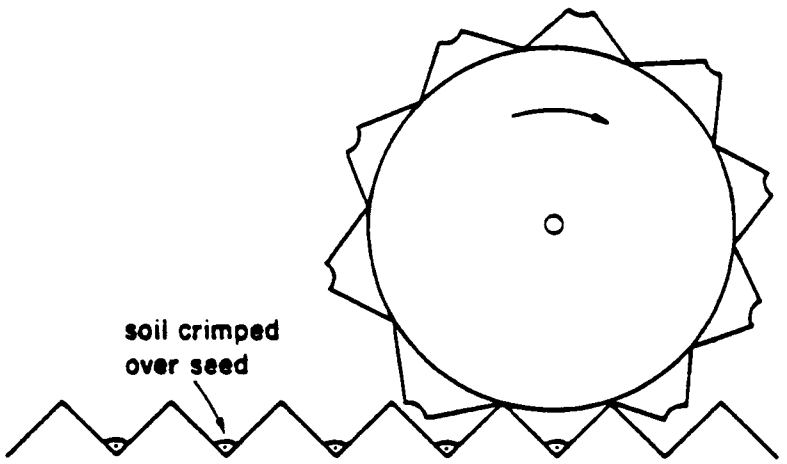


Figure 5.5. Soil crimping imprinter. Larger seeds are covered with soil simultaneously with imprinting. Seedbed preparation and seeding can be accomplished during the same operation by attaching a seeder to the imprinter (after Dixon, R.M., unpub.).

general enough to be applicable. The accepted basis of payment for imprinting will be paid at the contract unit price according to the pay unit given in Table 5.4.

In-Service Performance

Performance records of the land imprinting indicated that the water holding capacity is approximately 2 inches and does not significantly deteriorate for at least 2 to 3 years. Infiltration rates may increase substantially depending on the site conditions. Imprint patterns can potentially persist for 10 to 12 years if the recommended conditions exist at the time of emplacement and vegetation is established. However, if imprinting is done in an arid region in dry clayey soil and no vegetation is established, the pattern will naturally be obliterated in 2 years.

5.5 Pitting

Design Information

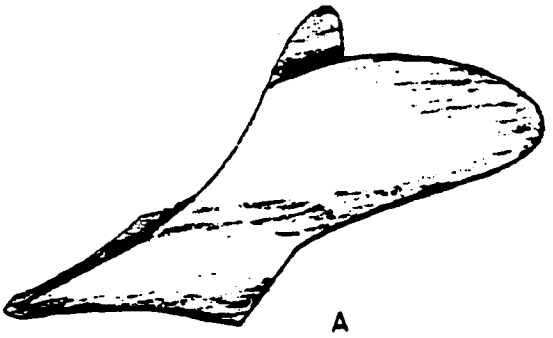
Pitting is a treatment which creates small basins to increase storage and infiltration, thereby increasing vegetative establishment (see Figure 5.6). Pits are generally 3 to 8 feet long, 8 to 12 inches wide and 4 to 8 inches deep.

Planning Considerations

As a water conservation and erosion control measure, pitting has been almost exclusively used on arid and semi-arid regions with varying degrees of success. Best results are received where annual precipitation exceeds 8 inches and where the pits are placed on the contour of less than 10 percent slopes in moderately dry, medium textured soil. It is not recommended for use on clayey, sandy, shallow or rocky soil.

Specifications - Pitting

This work shall consist of mechanically pitting in accordance with the specifications given in Table 5.5. These standard specifications are defined for disk, plow, and gouging type pitters; spike or rotary pitters do not meet these specifications. The accepted basis of payment for pitting will be paid for at the contract unit price according to the pay unit given in Table 5.5.



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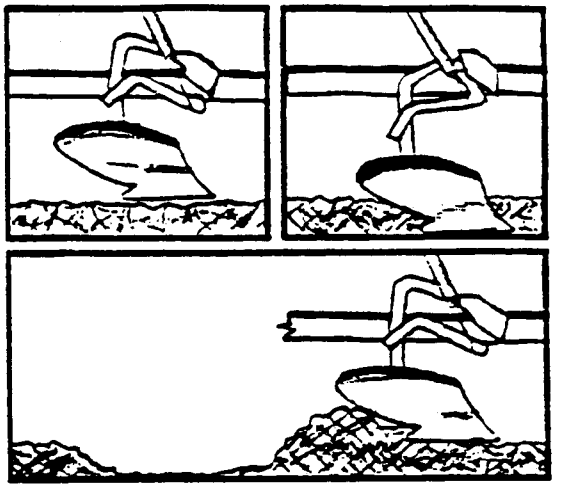

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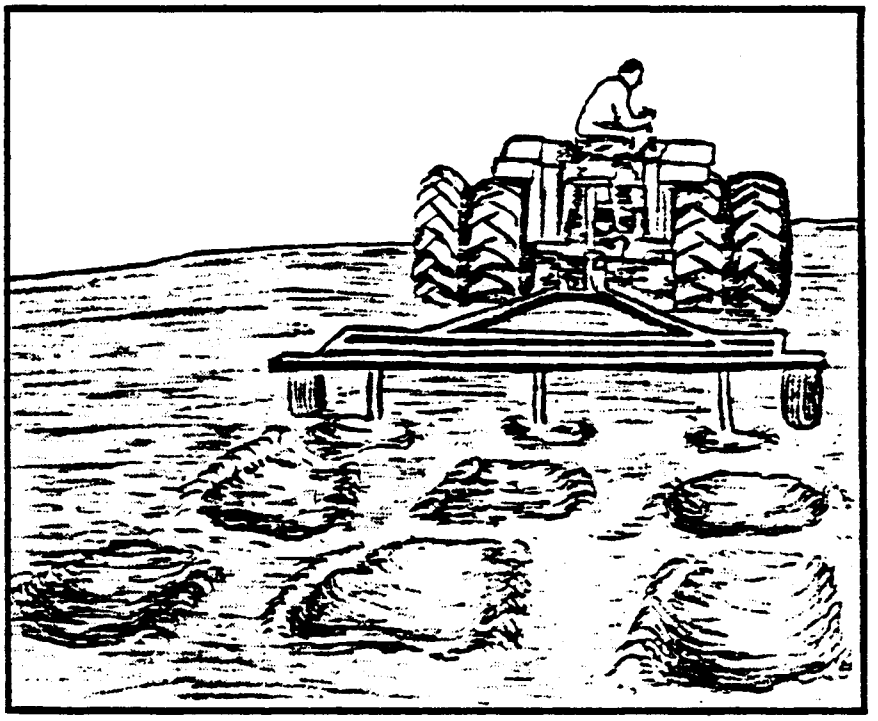

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Figure 5.6. Pitting implements and land surface pattern. A. A lister plow can be modified and rearranged for use in creating pits. B. Pits can be created by hydraulically raising and lowering a lister or other type of shank forming a pitted surface configuration. C. Land surface pattern. Hydraulically operated gouging machine creates elongated water traps 8-10 inches deep, 2 feet long and 1-1/2 feet wide. A seedbox with tubes can be fitted onto the implement to distribute seeds in depressions.

Table 5.5. Specifications for Pitting.

Item	Common Specifications
Equipment	Lister-type gouging pitters; eccentric cutaway, or cam shaped disk pitter; modified brushland, wheatland, standard disk, tandem disk, or moldboard plow
General Components	Pit former creating pit with ridges or check dams separating the pits; mechanical structure (eg. modified tripping action) or hydraulic device to control spacing (depending on equipment)
Number of Pits	3 to 5 depending on equipment
Pit Spacing	15" to 40"
Pits/Acre	Approximately 5,000
Width	8" to 18"
Depth	4" to 10"
Length	2' to 5' (8' maximum)
Power Requirement	30 to 45 HP
Pay Item	Per acre

In-Service Performance

Data collected in the northern Great Plains and southwest suggests that the water holding capacity of pits is relatively low, ranging from 0.03 to 0.6 inches the first year and decreasing to approximately 0.08 during the next 3 to 5 years. Infiltration was found to double and runoff decreased by 13 to 24 percent the first year, and by 4 to 16 percent the third year. The average longevity of pits is 4 years in the southwest although they have persisted for as long as 6 to 15 years in the northern Great Plains.

These performance values apply to disk-type (see Figure 5.7), modified plow and gouger pitters (see Figure 5.6). Spike tooth pitters have significantly lower performance records and are not recommended as a satisfactory treatment.

5.6 Ripping

Design Information

Ripping or deep chiseling is a subsoil mechanical treatment used to break or scatter compacted layers, heavy clays, or soil/minesoil interfaces (see Figure 5.8). Ripping will loosen and mix the subsoil and allow root penetration and moisture storage below the surface. The ripper shanks should be spaced 7 feet apart and create parallel slots 4 to 10 inches wide. Ripping depth varies from about 10 inches to 36 inches depending on the depth to the resistant layer.

Planning Considerations

Ripping as a land surface treatment is recommended for use in conjunction with other treatments. Ripping is best implemented on moderately dry, shallow mine soil which is medium or fine textured and underlain by a compacted spoil, hard pan or hardened caliche layers. Rippers should be operated on the contour of slopes less than 10 percent. Maximum benefit of subsoil moisture storage is received when precipitation is greater than 8 inches annually.

Three ripper or chisel points are recommended for use on mined land as illustrated in Figure 5.8. The standard point has the most general application and is suitable for nearly all ripping operations. Twisted points may be a viable tool for increasing the surface roughness and bringing clods to the surface. Spikes are thicker and more durable and have a special application

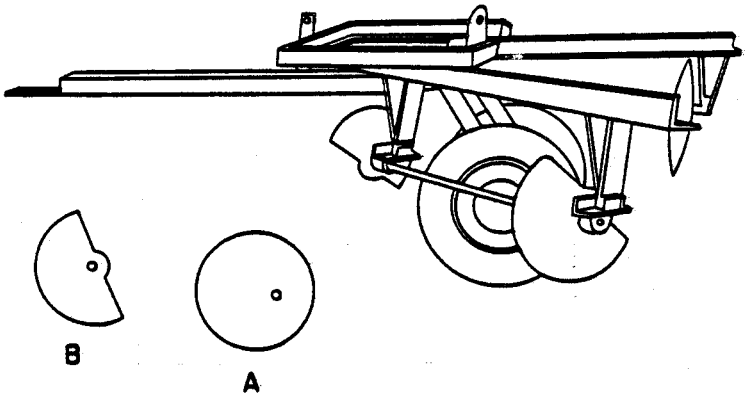
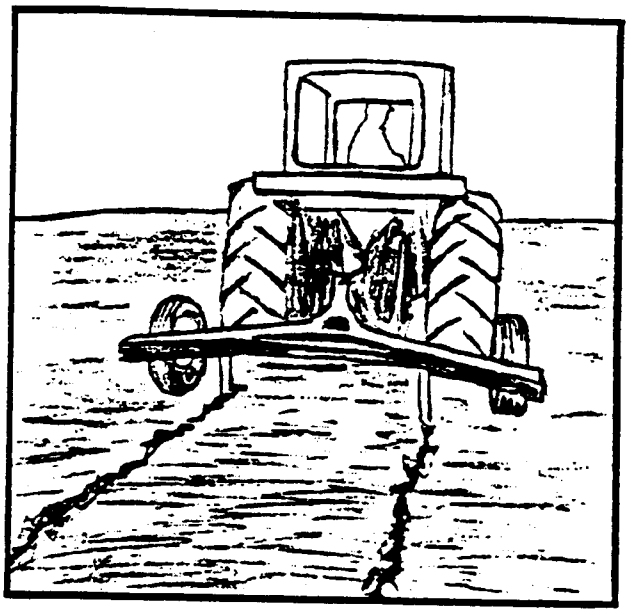


Figure 5.7. Disk-type pitting machine.
A. Eccentric (offset) disk;
B. Cutaway disk, (from Vallentine, 1971).



A

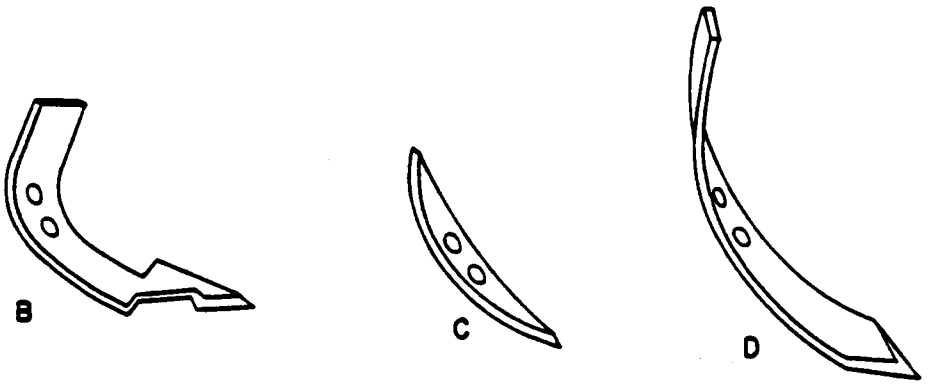


Figure 5.8. Soil ripping implement and land surface pattern. A. soil ripper is pulled through the soil and a temporary slot is formed; B. standard ripper (chisel) point; C. spike ripper point; D. twisted ripper point.

in extremely hard soil conditions. Commercially available construction ripper points are 3 to 4 inches wide and produce very satisfactory results.

Specifications - Ripping

This work shall consist of mechanically ripping in accordance with the specifications given in Table 5.6. The accepted basis of payment for ripping will be paid for at the contract unit price according to the pay unit given in the Table.

In-Service Performance

No data are available on the water holding capacity or changes in infiltration rates of ripped soil. Ripping produces a significant decrease in runoff and soil loss from small areas if applied under recommended conditions given above. These effects decrease, sometimes quite drastically, within the first three years because erosion from low intensity storms can fill the ripped surface slots. Ripping under optimum conditions will last 7 to 12 years.

Table 5.6. Specifications for Ripper.

Item	Common Specifications
Equipment	Ripper; deep chisel; subsoiler; subsoil chisel
Shanks	Rugged with general slope forward for maximum penetration and lift; curved to tapered end with replaceable chisel points
Number of Shanks	2 to 3 mounted shanks
Shank Spacing	Approximately 7 feet
Disturbed Band or Slot Width	4" to 10"
Ripper or Chisel Points	Standard; twisted; spike
Maximum Penetration	Approximately 36" depending on shank and soil conditions
Power Requirement	20 to 45 HP per shank depending on type of shank, depth of penetration, soil conditions (commonly the equivalent of a D6-D9)
Pay Item	Per acre

5.7 Example Problem

Problem: Compute the sediment yield from a disturbed mine site under baseline conditions outlined in Chapter IV, section 4.7, after an initial mechanical treatment of furrowing.

Input Data: As in baseline conditions (section 4.5) except CN = 81 (Table 5.2).

hydrologic soil group:	C
curve number, CN:	81 (from Table 5.2)
textural class:	Sandy loam
storm rainfall amount:	4 inches
percent ground cover:	zero percent
catchment area:	10 acres
slope:	9 percent
length:	660 feet

Step One: Particle size distribution as in baseline conditions (section 4.5).

Clay	P_1	P_2	P_3	P_4
5	25	20	20	30

Step Two: Roughness coefficient (K_g) and detachment coefficient (D_F).

K_e = 0.43 (Table 5.1)

K_g = 2700 (Table 5.1)

D_F = 1.000 (Table 5.1)

Step Three through Step Seven: see attached worksheets.

Step Eight: Mean concentration of settleable solids (C_S).

C_S = (35.57 + 1.51)+/(2.12 x 10) (8830)

C_S = 15,400 ppm

Discussion of Results

The mean concentration of settleable solids has been decreased by over a factor of 10, from 160,300 (baseline conditions) to 15,400 ppm (initial treatment of contour furrowing). Even though a large reduction in sediment yield occurred by furrowing the area, erosion of the soil is still high (15,400 ppm). To further decrease the sediment concentration, ripping the soil/subsoil interface before furrowing would effectively increase infiltration and vegetative establishment. Ripping would change the "C" hydrologic soil group to a "B" group and give a CN of 67. Without going into the details

of the calculations, the settleable solids would be reduced to 11,200 ppm. After one year, vegetation may become quickly established due to the ripped subsoil layer. Under the conditions of 55 percent vegetative cover over a one year reclamation period, the settleable solids are again reduced to 9,300 ppm. This is nearly half the sediment yield from the conditions of initial furrowing without ripping and zero percent cover. Sediment yield can be further reduced by one-third (from 9,300 ppm to 6,000 ppm) if the slope is reduced from 9 percent to 5 percent. The overall effect of these erosion control measures is a substantial reduction in sediment yield of 97 percent of the initial baseline conditions.

(1) Time (hr)	(2) Δt (hr)	(3) P/P_t	(4) P (inches)	(5) Pe (inches)	(6) ΔP (inches)	(7) ΔPe (inches)	(8) I (in/hr)	(9) Q (cfs)	(10) q (cfs/ft)
7.04		0.12	0.47	0.00					
	1.96				0.13	0.007	0.0667	0.035	5.34×10^{-5}
9.00		0.15	0.60	0.007					
	2.25				0.40	0.091	0.178	0.405	.000613
11.25		0.25	1.00	0.098					
	0.92				1.78	1.05	1.93	11.4	.0173
12.17		0.70	2.78	1.15					
	1.83				0.50	0.385	0.273	2.11	.00319
14.00		0.82	3.28	1.53					
	10.00				0.72	0.589	0.0720	0.589	.000893
24.00		1.00	4.00	2.12					

Small area characteristics:

Area = 10 acres

Length = 660 feet

Width = 660 feet

Example Problem 5.1. Step Three worksheet.

(1) Δt (hr)	(2) I (in/hr)	(3) G_r (tons)
1.96	0.0667	0.57
2.25	0.178	4.61
0.92	1.93	223.
1.83	0.213	8.85
10.00	0.0720	3.36

Area = 10 acres

$G_r = 6.48\ \Delta t\ I^2\ A_b$ (Eq. 4.7)

Ground Cover Ratio = 0.00

Width = 660 feet

$A_b = (1 - C_g)A$ (Eq. 4.8)

Example Problem 5.1. Step Four worksheet.

(1) Δt (hours)	(2) q (cfs/ft)	(3) g_{t1} (tons/ft/hr)	(4) g_{t2} (tons/ft/hr)	(5) g_{t3} (tons/ft/hr)	(6) g_{t4} (tons/ft/hr)	(7) G_{t1} (tons)	(8) G_{t2} (tons)	(9) G_{t3} (tons)	(10) G_{t4} (tons)	(11) G_t (tons)
1.96	5.34×10^{-5}	.00005	.000090	0.00	0.00	0.03	0.00	0.00	0.00	0.03
2.25	.000613	.00131	.00236	.000072	0.00	0.88	0.02	0.00	0.00	0.90
0.92	.0173	.113	.203	.00934	.000018	30.8	1.14	0.00	0.00	31.94
1.83	.00319	.0119	.0213	.000792	0.0	6.44	0.19	0.00	0.00	6.63
10.00	.000893	.00216	.00389	.000126	0.0	6.43	0.16	0.00	0.00	6.59

Roughness Coefficient, K_g = 2,700

Slope, S = 0.09

Width = 660 feet

Example Problem 5.1. Step Five worksheet.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Δt	G_t (tons)	G_r (tons)	G_f (tons)	G_s (tons)	G_{s1} (tons)	G_{s2} (tons)	G_{s3} (tons)	G_{s4} (tons)
1.96	0.03	0.57	0.00	0.57	0.14	0.11	0.11	0.17
2.25	0.90	4.61	0.00	4.61	1.15	0.92	0.92	1.38
0.92	32.03	223.	0.00	223.	55.8	44.68	44.68	67.0
1.83	6.63	8.85	0.00	8.85	2.21	1.77	1.77	2.66
10.00	6.59	3.36	3.23	6.59	1.65	1.32	1.32	1.98

Flow Detachment Coefficient = 1.00

$G_f = D_f(G_t - G_r)$ (Eq. 4.10)

where $G_t < G_r$

Example Problem 5.1. Step Six worksheet.

	(1)	(2)	(3)	(4)	(5)
	G_{y1}	G_{y2}	G_{y3}	G_{y4}	G_y
	0.03	0.00	0.00	0.00	0.03
	0.88	0.02	0.00	0.00	0.90
	30.8	1.14	0.00	0.00	31.94
	2.21	0.19	0.00	0.00	2.40
	1.65	0.16	0.00	0.00	1.81
TOTAL	**35.57**	**1.51**	**0.00**	**0.00**	**37.08**

Example Problem 5.1. Step Seven worksheet.

5.8. References

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VI. DIVERSION AND CONVEYANCE SYSTEMS

6.1 General

Diversions are used on sloping sites where it is necessary or desirable to intercept runoff and divert it from the site in a manner that the settleable solids concentration is minimized. Two general types of diversions are treated in this chapter. The first type is used to direct storm water away from the site to prevent undesirable erosion or interference with revegetation. The second type includes terraces and berms. The basic concept of terracing in this application is to break up the slope length by providing channels at predetermined intervals that are approximately perpendicular to the overland flow direction. The terraces intercept the runoff, slowing the flow velocity and allowing a percentage of the settleable sediment sizes to deposit. In most applications, the terraces are made with a relatively small longitudinal slope so that a minimal quantity of sediment is carried from the site. One effective variation of the terrace is the toe berm which is essentially a terrace having zero slope. Toe berms can be very effective on small sites as detention structures (see Chapter VII).

The conveyance channel is a stabilized drainageway used to collect water from the diversions and overland flow areas and deliver it from the site to the established disposal area. It is designed to pass the discharge from the specified storm without additional scour from the conveyance channel bed and banks.

Figures 6.1 and 6.2 show a diversion and conveyance system at typical sites using these concepts as part of the sediment control system.

6.2 Procedural Guide

The procedure for designing diversion structures and stable conveyance channels is nearly the same since the sediment transport process in response to a particular flow is the same. The performance objectives for each are different, however.

Diversions are intended to break up slope lengths, thereby reducing the sediment delivery from the overland flow areas. They may also be designed to trap the sediment from the overland areas in the diversion itself. Conveyance

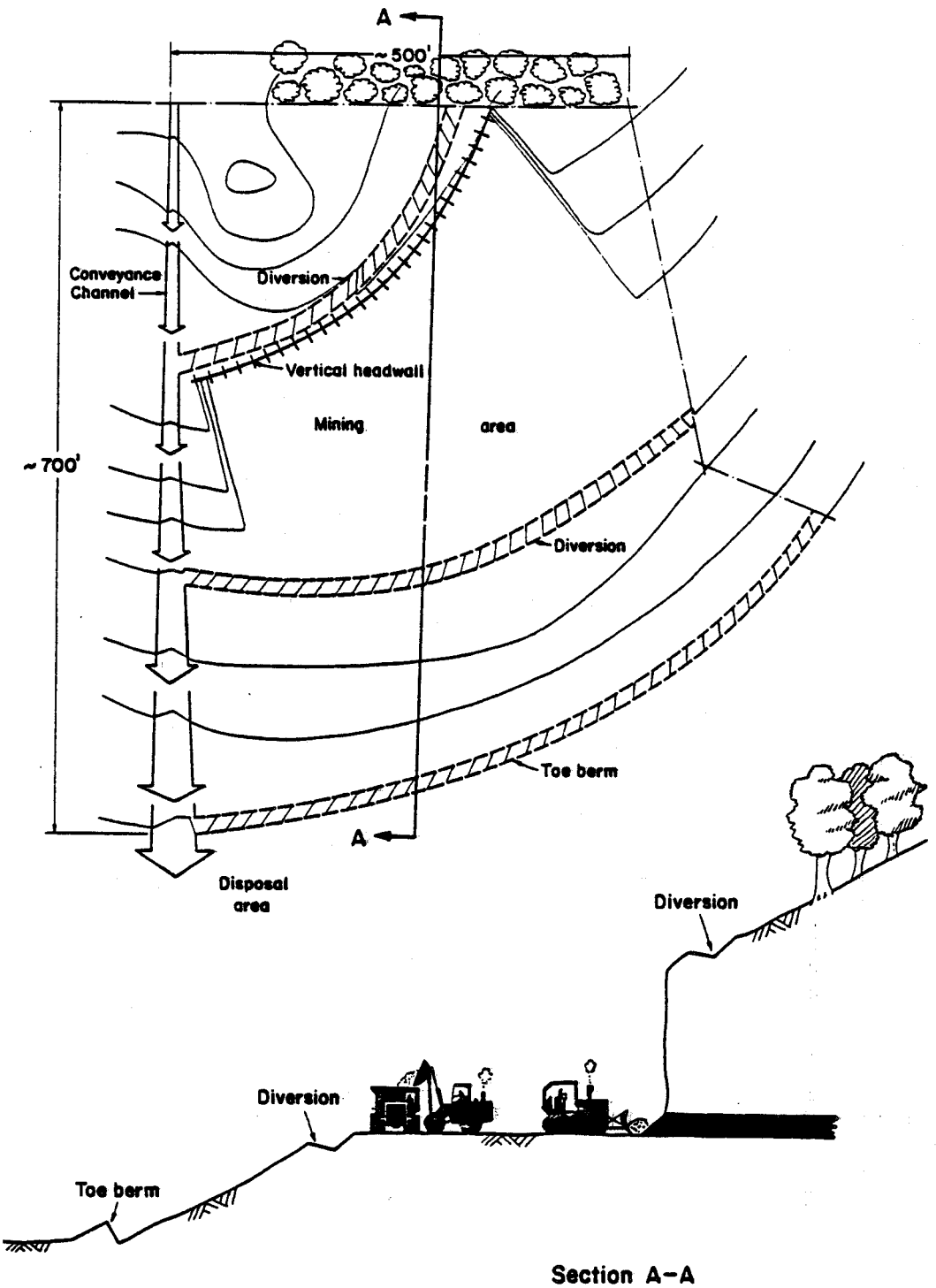


Figure 6.1. Typical mine site.

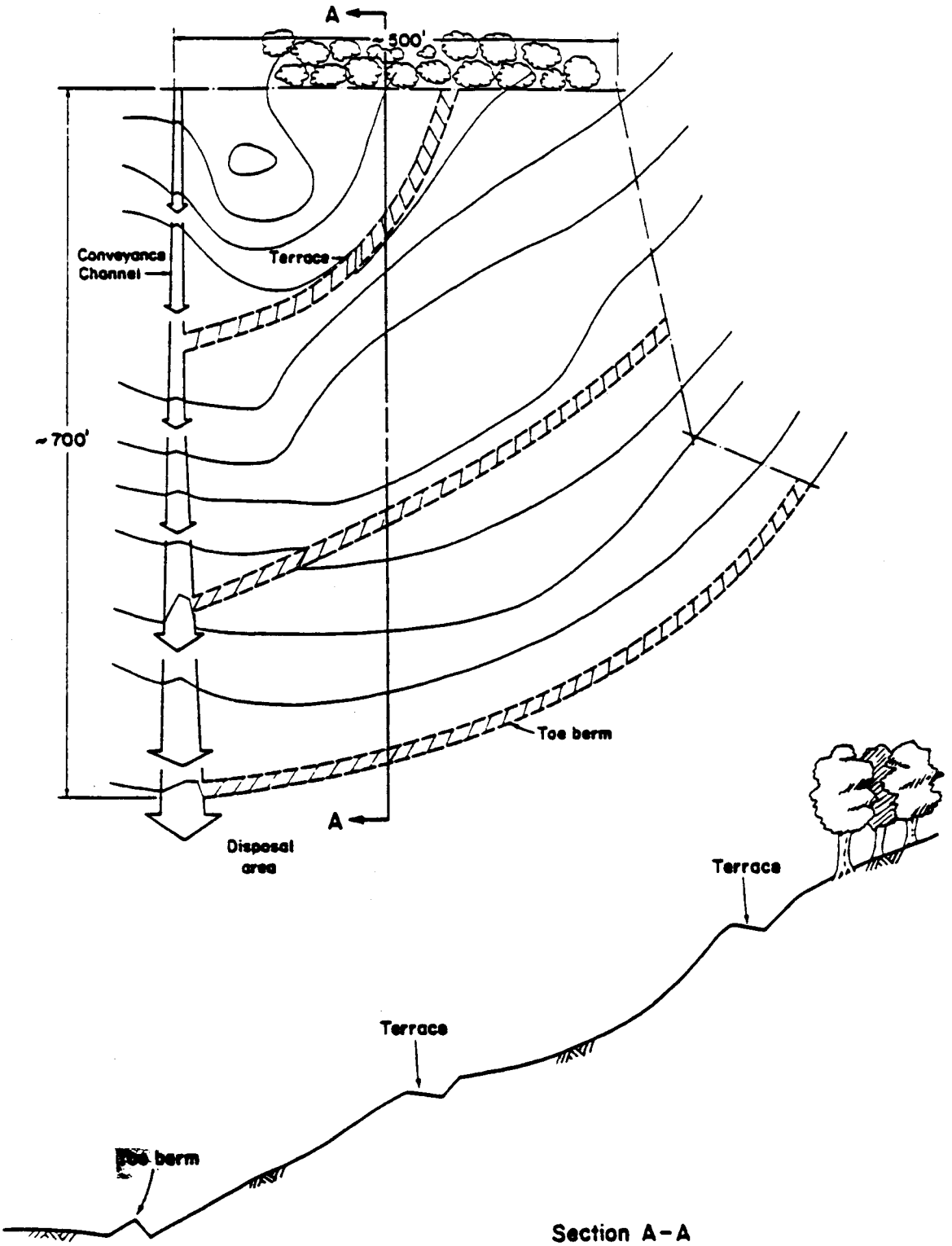


Figure 6.2. Typical reclaimed mine site.

channels are designed to provide an adequate cross section lined with nonerosive material to deliver the design flow without additional erosion from the channel bed and banks.

Design Steps for Diversion and Conveyance Channels

The specific steps to be followed in designing either of the channel types are as follows:

1. Determine the water and sediment delivery to the channel.
2. Estimate the required channel slope (S).
3. Choose an appropriate cross section and compute the velocity (V), flow depth (d) and topwidth (T) for each time increment of the runoff hydrograph.
4. Determine the sediment transporting capacity for each sediment size range and time increment.
5. Determine the total sediment yield from the channel and the average settleable solids concentration.
6. Compute the deposition depth (d_d) of sediment in the channel.
7. Size the channel based on the flow depth at peak flow plus the deposition depth (when appropriate) plus a minimum of 0.5 feet freeboard.

Step 1: Determine Water and Sediment Delivery to Channel

The inflow hydrograph for the design storm is required input for this design procedure. The inflow hydrograph is determined using the procedural guide in section 4.2. For either channel type, the watershed area is the actual overland area contributing to the channel. Although the discharge varies along the channel, the maximum discharge is used for design.

The sediment delivery to the diversions is the sediment yield from the overland flow areas determined using the procedural guide in section 4.2. The sediment yield from the diversions is the sediment supply to the conveyance channel.

Step 2: Estimate Required Channel Slope

Diversions. The estimated slope is based upon knowledge of the site, flow rate and soil type. A slope in the range of 0.5 percent to 1 percent is normally a good "first approximation."

Conveyance Channel. The slope for the conveyance channel is usually fixed within a limited range by the topographic constraints of the particular site and can best be determined from a topographic map or site survey.

Step 3: Choose an Appropriate Cross Section and Compute the Velocity (V), depth (d) and topwidth (T)

The majority of the channels used in the diversion and conveyance systems for small areas can be approximated by a triangular cross-sectional shape. Figures 6.3 and 6.4 are nomographs for determining the required flow parameters.

Procedures for solving Manning's equation for other channel shapes are readily available. For example, Chow (1959) presents detailed information on open channel flow including tables, charts and procedures for most channel shapes. Brater and King (1976) also provide complete tables and charts to aid in solving the open channel flow problems.

In using any of the above methods, a critical factor is the determination of a proper Manning roughness coefficient. Table 6.1 presents a listing of representative roughness values for the range of conditions encountered on small mine sites. Figure 6.5 presents roughness values for various manufactured channel linings for different flow depths.

For vegetative lined channels, the roughness values can vary significantly depending on the type of grass, condition of the grass cover, soil texture, channel slope and size and shape of the channel. The SCS has presented a method for determining the value of the roughness coefficient based on experimental measurements. This method is presented in the "Handbook of Channel Design for Soil and Water Conservation" (SCS, 1957). The procedure presented in this manual is based primarily on this method and is as follows:

1. Estimate the value of n for the intended type of grass lining using Table 6.1.

2. Determine the retardance classification for the grass lining from Table 6.2.

3. Determine the velocity and depth for the design discharge and slope.

4. Compute the value of VR noting that $R \approx 0.5\ d$ for a triangular channel.

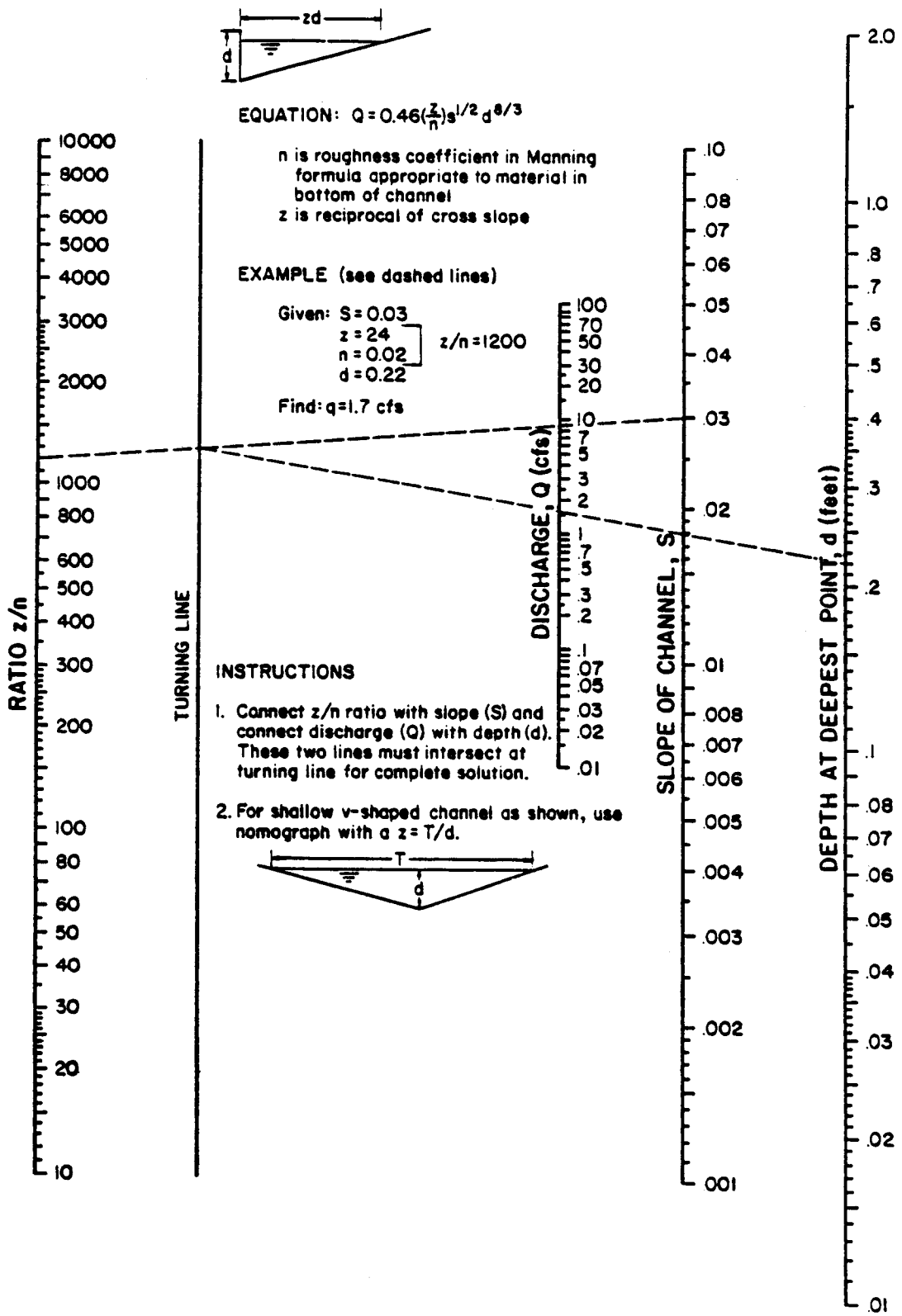
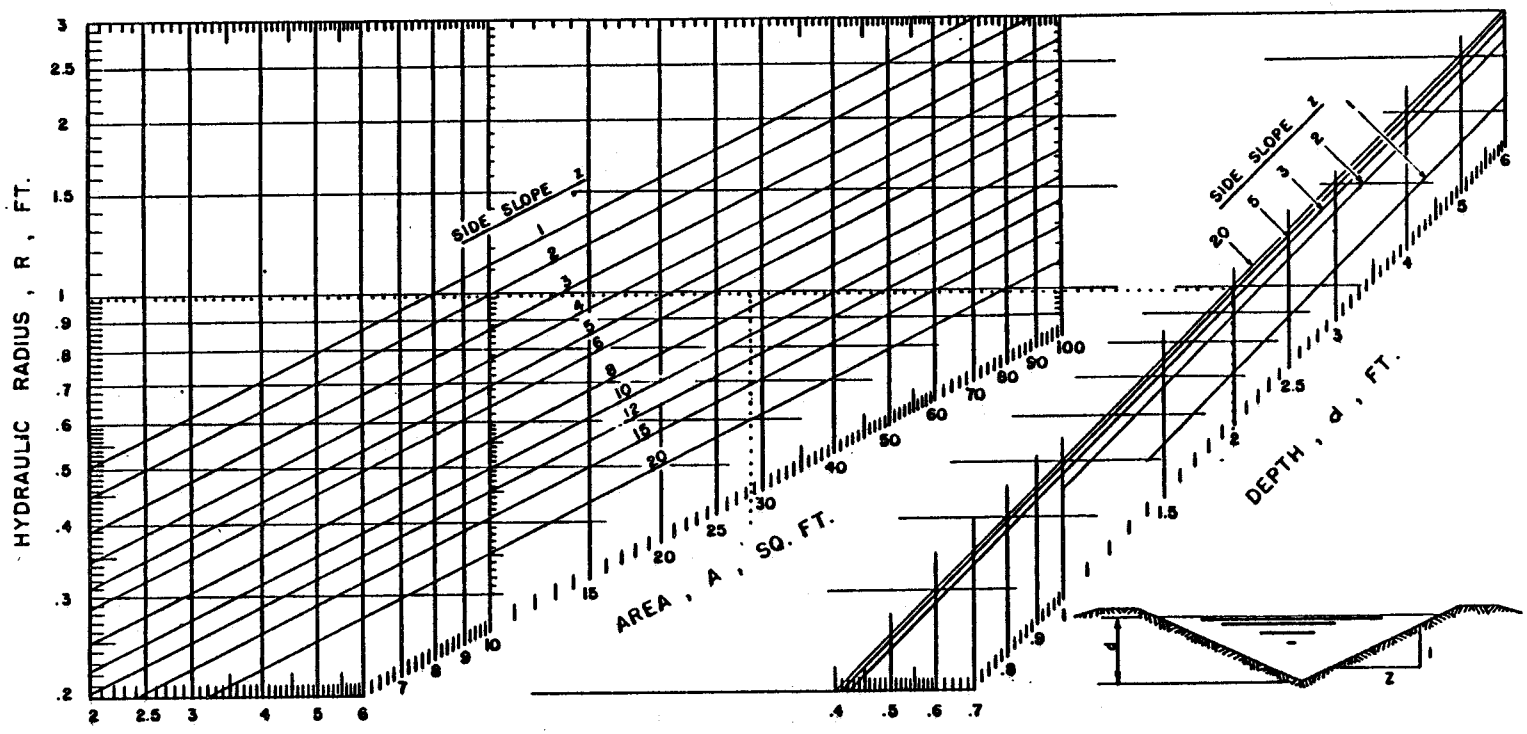


Figure 6.3. Nomograph for flow in triangular channels (from Simons, Li & Associates, Inc., 1982).



where: $A = zd^2$

$p = 2d\sqrt{z^2+1}$

$T = 2dz$

Figure 6.4. Dimension of triangular channels (from Chow, 1959).

Table 6.1. Manning Roughness Coefficients, n.

	Manning n range
I. Lined Open Channels:	
A. Gravel bottom, sides as indicated:	
1. Formed concrete	0.017-0.020
2. Random stone in mortar	0.020-0.023
3. Dry rubble (riprap)	0.023-0.033
II. Unlined Open Channels:	
A. Earth, uniform section:	
1. Clean, recently completed	0.016-0.018
2. Clean, after weathering	0.018-0.020
3. With short grass, few weeds	0.022-0.027
4. In gravely, soil, uniform section, clean	0.022-0.025
B. Earth, fairly uniform section:	
1. No vegetation	0.022-0.025
2. Grass, some weeds	0.025-0.030
3. Dense weeds or aquatic plants in deep channels	0.030-0.035
4. Sides, clean, gravel bottom	0.025-0.030
5. Sides, clean, cobble bottom	0.030-0.040
C. Dragline excavated or dredged:	
1. No vegetation	0.028-0.033
2. Light brush on banks	0.035-0.050
D. Rock:	
1. Based on design section	0.033
2. Based on actual mean section:	
a. Smooth and uniform	0.035-0.040
b. Jagged and irregular	0.040-0.045
E. Channels not maintained, weeds and brush uncut:	
1. Dense weeds, high as flow depth	0.08-0.12
2. Clean bottom, brush on sides	0.05-0.08
3. Clean bottom brush on sides, highest stage of flow	0.07-0.11
4. Dense brush, high stage	0.10-0.14
III. Channels and Swales with maintained vegetation (values shown are for velocities of 2 and 6 fps):	
A. Depth of flow up to 0.7 foot:	
1. Bermuda grass, Kentucky bluegrass, buffalo grass:	
a. Mowed to 2 inches (E Retardance)	0.13-0.024
b. Length 4 to 6 inches (D Retardance)	0.28-0.03
Good stand, any grass:	
a. Length about 12 inches (C Retardance)	0.30-0.032
b. Length about 24 inches (A Retardance)	0.38-0.06
3. Fair stand, any grass:	
a. Length about 12 inches (D Retardance)	0.28-0.03
b. Length about 24 inches (B Retardance)	0.32-0.04
B. Depth of flow 0.7-1.5 feet:	
1. Bermuda grass, Kentucky bluegrass, buffalo grass:	
a. Mowed to 2 inches	0.05-0.035
b. Length 4 to 6 inches	0.06-0.04

Table 6.1. (continued)

	Manning n Range
2. Good stand, any grass:	
a. Length about 12 inches	0.12-0.07
b. Length about 24 inches	0.20-0.10
3. Fair stand, any grass:	
a. Length about 12 inches	0.10-0.06
b. Length about 24 inches	0.17-0.09

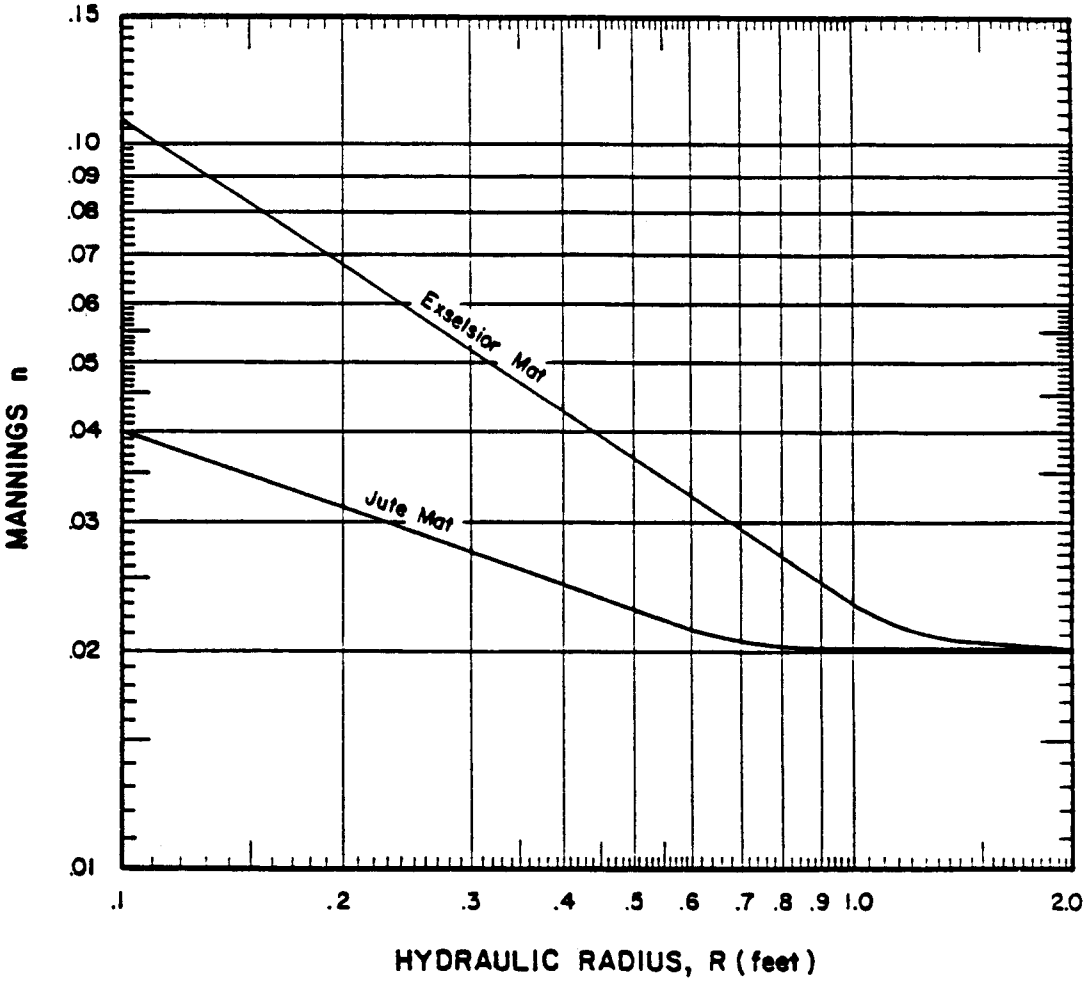


Figure 6.5. Manning's roughness coefficient versus hydraulic radius for manufactured channel linings (from Simons, Li & Associates, Inc., 1982).

Table 6.2. Classification of Vegetal Covers as to Degree of Retardance (SCS, 1957).

(Note: Covers classified have been tested in experimental channels. Covers were green and generally uniform.)

Retardance	Cover	Condition
A	Weeping lovegrass	Excellent stand, tall (average 30 inches)
	Yellow bluestem Ischaemum	Excellent stand, tall (average 36 inches)
B	Kudzu	Very dense growth, uncut.
	Bermuda grass	Good stand, tall (average 12 inches).
	Native grass mixture (little bluestem, blue grama, and other long and short midwest grasses)	Good stand, unmowed.
	Weeping lovegrass	Good stand, tall (average 24 inches).
	Lespedeza series	Good stand, not woody, tall 19 inches).
	Alfalfa	Good stand, uncut (average 11 inches).
	Weeping lovegrass	Good stand, mowed (average 13 inches).
	Kudzu	Dense growth, uncut
	Blue Grama	Good stand, uncut (average 13 inches).
C	Crabgrass	Fair stand, uncut (10 to 48 inches).
	Bermuda grass	Good stand, mowed (average 6 inches).
	Common lespedeza	Good stand, uncut (average 11 inches).
	Grass-legume mixture--summer (orchard grass, redtop, Italian ryegrass and common lespedeza)	Good stand, uncut (6 to 8 inches).
	Centipedegrass	Very dense cover (average 6 inches).
	Kentucky bluegrass	Good stand, headed (6 to 12 inches).

Table 6.2. (Continued)

Retardance	Cover	Condition
	Bermuda grass	Good stand, cut to 2.5-inch height.
	Common lespedeza	Excellent stand, uncut (average 4.5 inches)
	Buffalo grass	Good stand, uncut (3 to 6 inches.
D	Grass-legume mixture--fall, spring (orchard grass, redtop, Italian ryegrass, and common lespedeza	Good stand, uncut (4 to 5 inches).
	Lespedeza sericea	After cutting to 2-inch height. Very good stand before cutting.
	Bermuda grass	Good stand, cut to 1.5 inches height.
E		
	Bermuda grass	Burned stubble

5. Read the n value from Figure 6.6 for the appropriate VR and retardance classification.

6. Compare the new n with the original assumption. If it is not the same, repeat steps 2 through 5 using the new n until the two values are reasonably close.

The hydraulic parameters for the design storm are calculated by repeating the above procedure for each time increment of the storm hydrograph. Worksheet 6.1 is provided to facilitate these calculations.

Step 4: Determine Sediment Transport Capacity

Figures 6.7 through 6.10 and Worksheet 6.2 are provided for computing the sediment transport for the particle size distribution of the material comprising the channel bed. The procedure is as follows:

1. Using the velocity (V) and hydraulic depth (d_h) from columns 5 and 7 of Worksheet 6.1, read the sediment transport capacity per unit width of channel (g_t) for each particle size from Figures 6.7 through 6.10.

2. Determine the sediment transport for each size and time step by the following equation

$$G_t = g_t \, T \, \Delta t \, p \qquad (6.1)$$

where: G_t = sediment transport capacity, tons
g_t = sediment transport rate, tons/foot/hour
T = topwidth
Δt = incremental time in hours
p = decimal percentage of a particular particle size

Step 5: Determine Sediment Yield

Actual sediment yield will be controlled by either the supply of sediment available or by the transport capacity of the flow. If the available supply of sediment exceeds the transport capacity of the flow for a particle size, then the transport capacity will control the sediment yield and deposition will occur in the channel. If the transport capacity exceeds the available supply of sediment to the channel, then the supply of sediment will control the sediment yield and scour may occur in the channel. Diversion and conveyance structures should be designed so that transport capacity controls the yield of sediment.

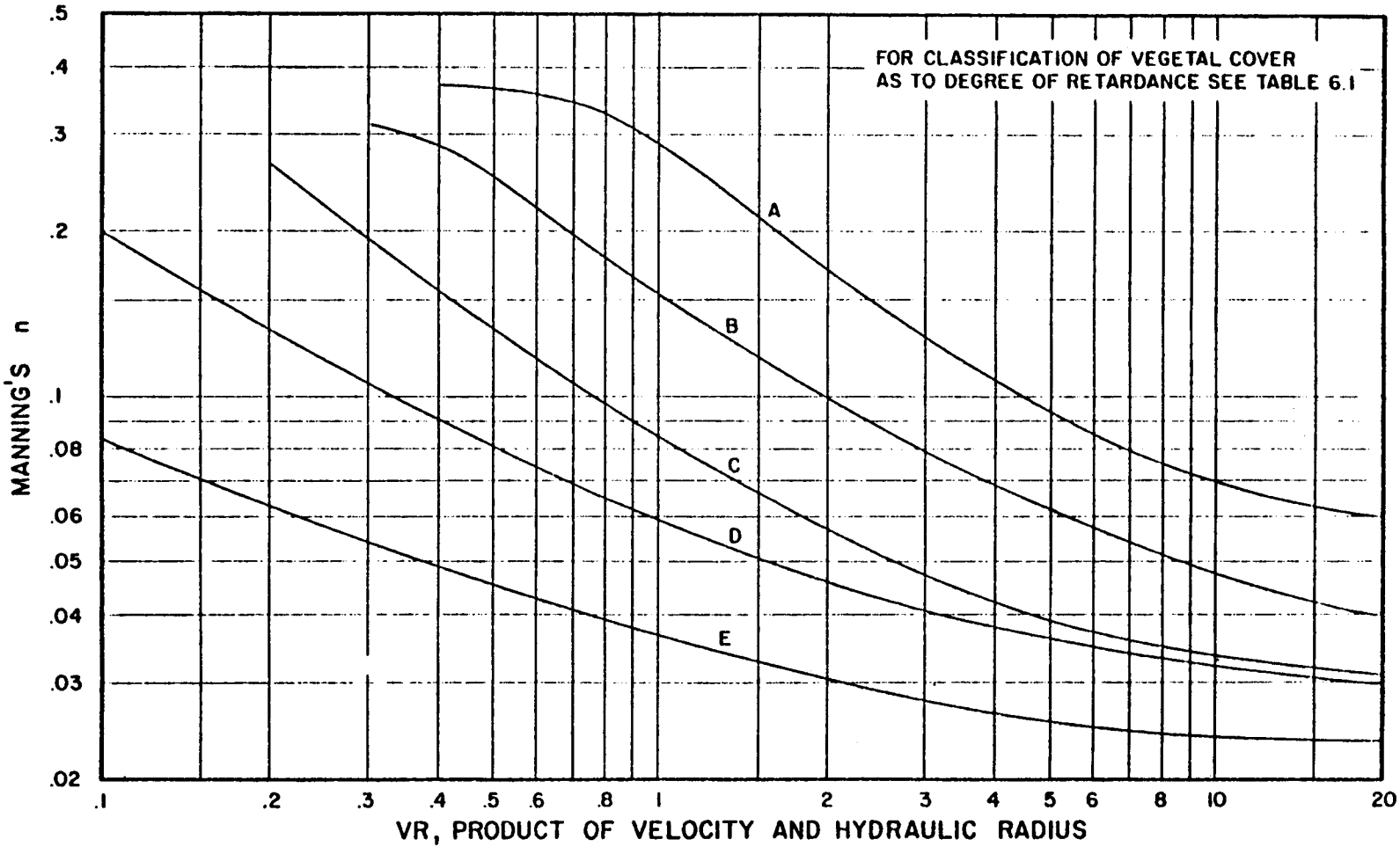


Figure 6.6. Manning's n for vegetal-lined channels (from handbook of channel design for soil and water conservation SCS-TP-61 revised June 1964).

1	2	3	4	5	6	7	8
Time Interval	Q (cfs)	n	d (ft)	A (ft2)	V (fps)	T (ft)	d_h=A/T (ft)

Worksheet 6.1. Step Three worksheet.

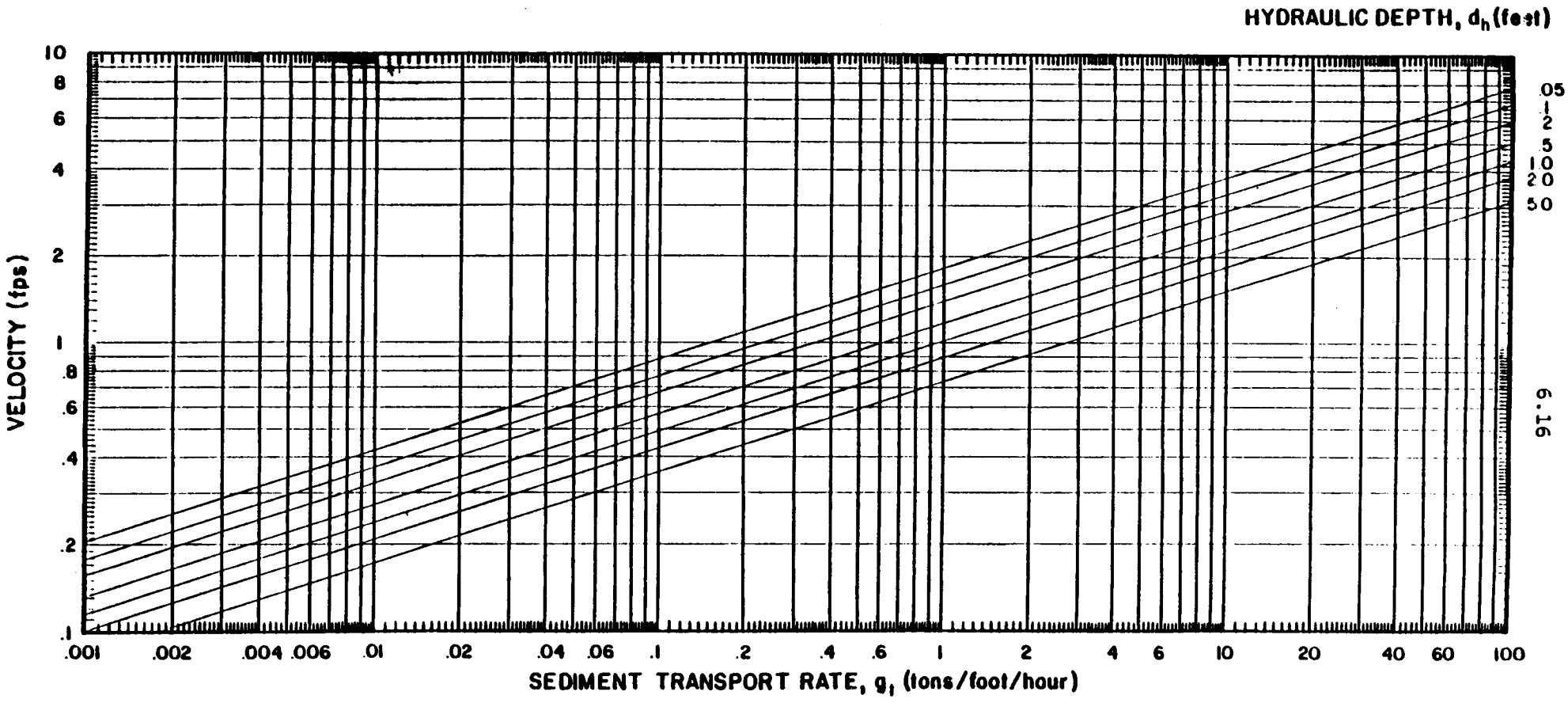


Figure 6.7. Sediment transport capacity for silt (0.002 mm - 0.05 mm) (from Simons, Li & Associates, Inc., 1982).

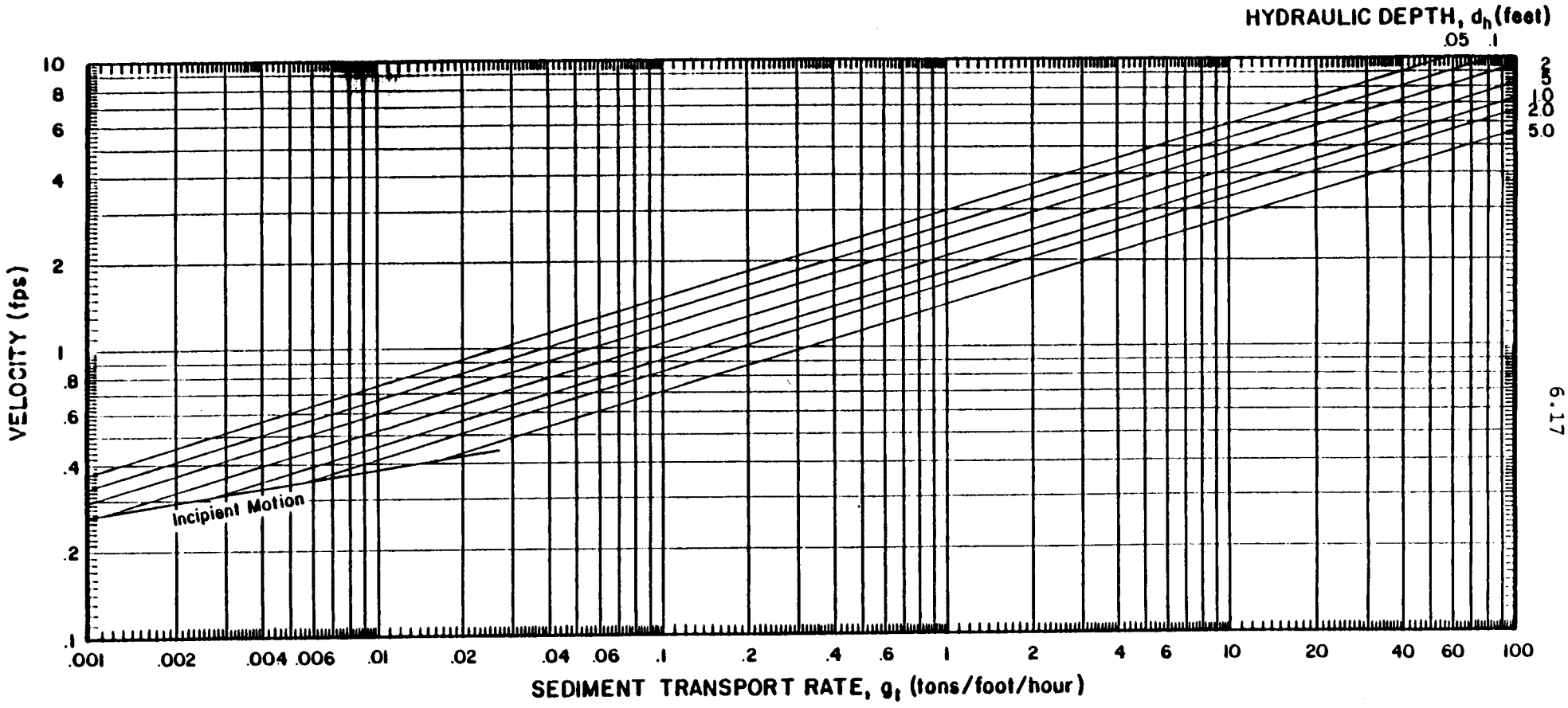


Figure 6.8. Sediment transport capacity for very fine sand (0.05 mm - 0.1 mm) (from Simons, Li & Associates, Inc., 1982).

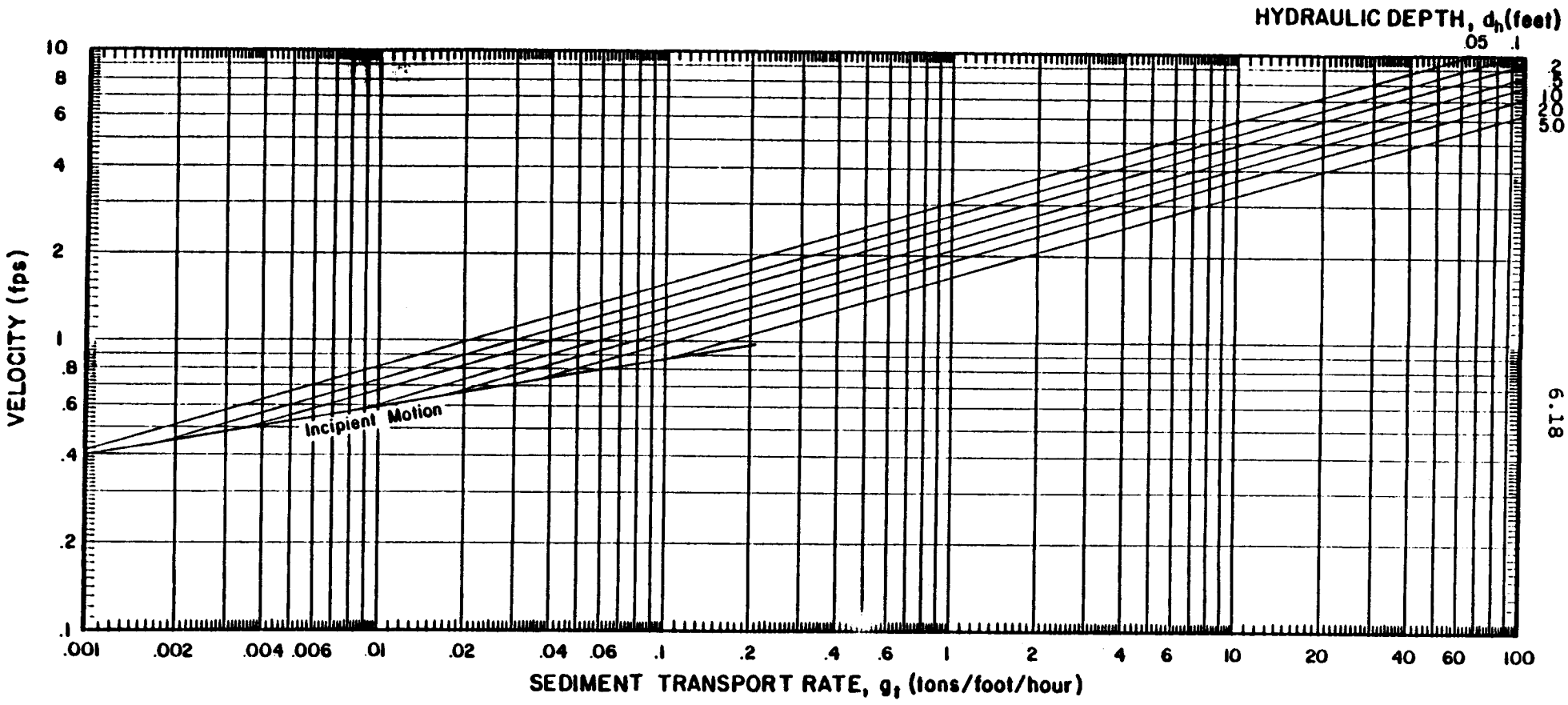


Figure 6.9. Sediment transport capacity for fine, medium and coarse sand (0.1 mm - 1.0 mm)(from Simons, Li & Associates, Inc., 1982).

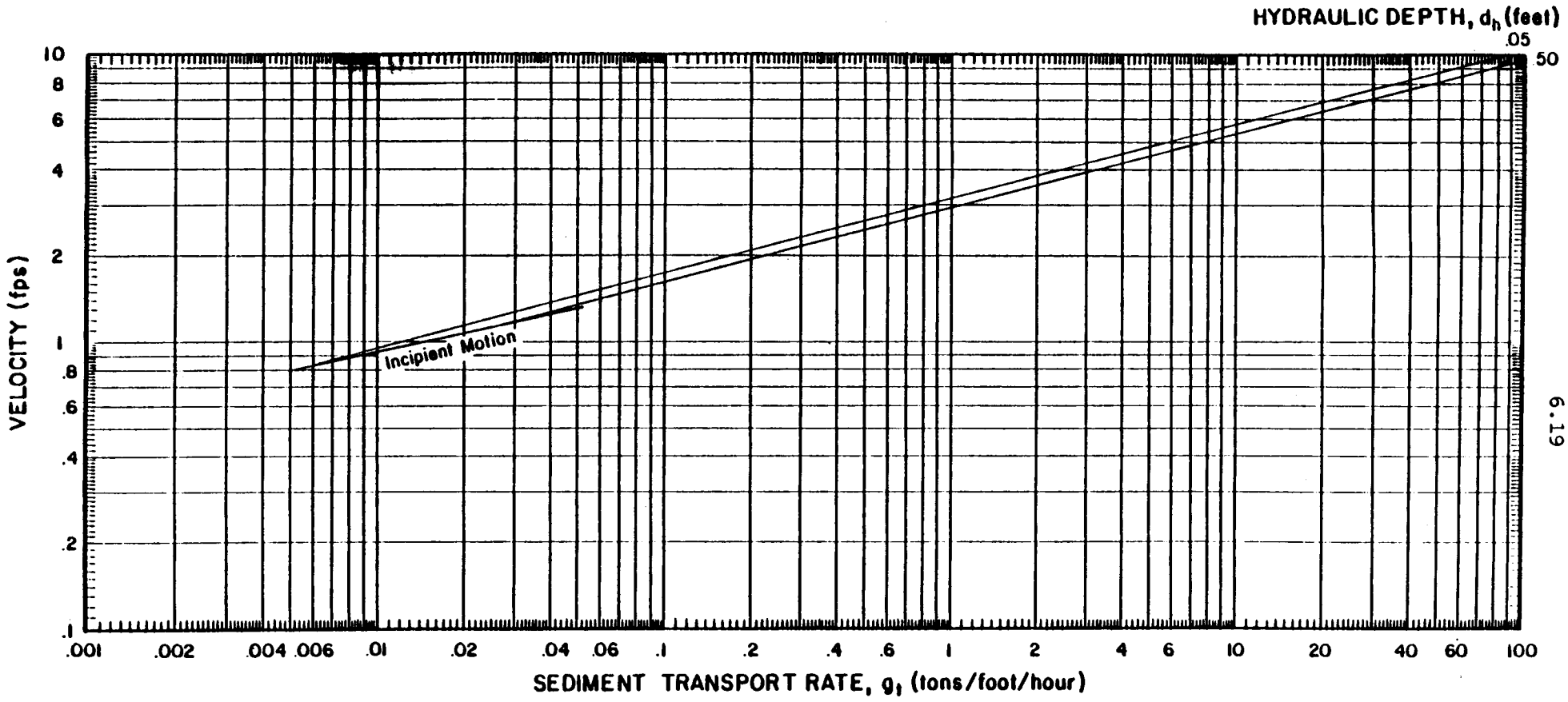


Figure 6.10. Sediment transport capacity for very coarse sand (1.0 mm - 2.0 mm)(from Simons, Li & Associates, Inc., 1982).

$p_1 =$ $p_2 =$ $p_3 =$ $p_4 =$

Time Interval	Δt (hrs)	T (ft)	g_t (tons/ft/hr)				G_t (tons)				
			1	2	3	4	1	2	3	4	Total
						TOTAL					

Worksheet 6.2. Step Four worksheet.

The sediment yield for each time step is given by making the following determinations:

$$G_y = G_s \quad \text{if} \quad G_t > G_s \tag{6.2}$$

and

$$G_y = G_t \quad \text{if} \quad G_t < G_s \tag{6.3}$$

where G_t = sediment transport capacity for a given time step, tons

G_s = sediment supply from overland flow to the channel, tons

G_y = sediment yield from the channel, tons.

Worksheet 6.3 is given for step five to aid in determining the sediment yield. Equation 6.3 indicates the sediment will deposit in the channel. For all sand sizes settling will occur quickly in the channel. For the silt size settling is slower, and even though deposition is indicated by Equation 6.3 some of the sediment supply may leave the channel before it can settle. NOTE: The actual sediment yield for the silt size must account for this short-circuiting affect. The actual sediment yield for silt is based on the following equation:

$$G_y = G_t + (G_s - G_t)(1 - p_s) \tag{6.4}$$

where p_s = the ratio of sediment settling to the volume of sediment available to settle.

Values of ρ_s are given in Figure 6.11 as a function of a settling parameter C_w, as given by the following equation,

$$C_w = \frac{2.2 \times 10^{-4} L_d}{V d_h} \tag{6.5}$$

where: L_d = structure length, feet

V = flow velocity, ft/sec

d_h = hydraulic depth, feet

The information in the Step Five worksheet is developed by repeated comparison between the sediment supply values from overland flow and the transport capacity of the channel flow for each particle size and time step. When transport controls the sediment yield, then the yield of silt sizes should be based on Equation 6.4.

1	2	3	4	5	6	7	8
Time Interval	C_w	P_s	Gy_1	Gy_2	Gy_3	Gy_4	Gy
Total Yield							

$$Cw = \frac{2.2 \times 10^{-4} L_d}{V d_n}$$ (Equation 6.5)

p_s (see Figure 6.11)

Worksheet 6.3. Step Five worksheet.

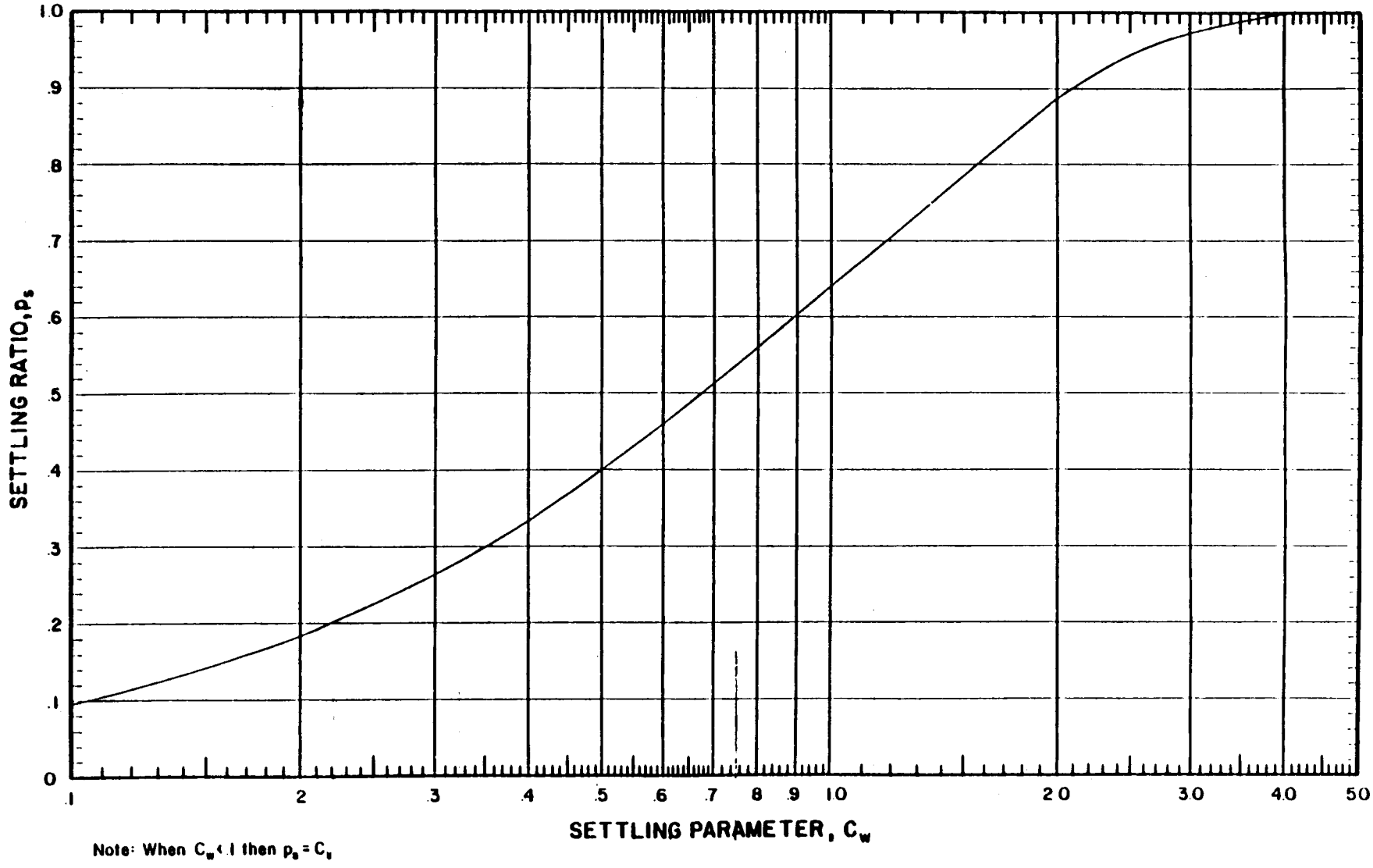


Figure 6.11. Settling ratio versus settling parameter (from Simons, Li & Associates, Inc., 1982).

The average suspended sediment concentration (C_s) in ppm is computed from the following equation

$$C_s = 8830 \frac{G_y}{P_e A} \tag{6.6}$$

where: G_y = total sediment yield, for all sizes, tons
P_e = rainfall excess at the end of the storm in inches (see Worksheet Three in Chapter IV procedure guide)
A = catchment area, acres

Step 6: Compute the Deposition Depth

The volume of deposition can be determined by the relation:

$$\forall_S = 20.15 (G_s - G_y) \tag{6.7}$$

where: $\forall_S$ = deposited volume, cubic feet
G_s = sediment supply from overland flow to the channel in tons
G_y = actual sediment yield from the channel in tons

$$d_d = \sqrt{\frac{\forall_s}{L_d z}} \tag{6.8}$$

where: d_d = deposition depth
L_d = channel length, feet
z = side slope of the channel

For other channel shapes, the deposition depth (d_d) is found by dividing the volume $\forall_s$ by the channel length to find the cross-sectional area of the deposition and using the relation between the area and depth for that particular channel to find d_d.

Step 7: Size the Channel

The design depth of the channel cross section is computed by:

$$d_c = d + d_d + 0.5 \tag{6.9}$$

where: d_c = design depth, feet
d = maximum flow depth during the storm, feet
d_d = deposition depth, feet
0.5 = freeboard, feet

Stable Channel Design

The objective in designing a stable channel is to provide hydraulic conditions and/or channel lining such that the bed and banks of the channel are not eroded. In many cases, it is not possible to reduce the erosive power of the flow through adjustments in the slope, roughness, etc. to prevent erosion of the natural bed material. In this case, a stable channel lining must be provided.

Figure 6.12 shows the relation between the critical particle size (D_c) (i.e., the smallest particle size that cannot be transported by the flow), the flow velocity, (V) and depth (d). Using this figure, the following steps are followed in designing a coarse gravel lining for a stable conveyance channel.

1. Choose an appropriate channel cross section and compute the velocity and depth as discussed in Step 3 for the maximum discharge.

2. From Figure 6.11 determine the critical particle size (D_c).

3. Select a coarse, well graded gravel mixture such as the American Association of State Highway Organizations (AASHTO) M147, Class 2 or M43, No. 3 or 4 gradation (see Table 6.3). Determine the percentage of material in the selected mixture that is finer than D_c. If the percent finer is less than 50 percent, the selected distribution should be acceptable.

4. Determine the required thickness of the lining to develop a protective layer using the relation:

$$t_a = \frac{2D_c}{(1-p_f)} \geq 6" \qquad (6.10)$$

where: t_a = thickness of the lining
D_c = critical particle size, mm
p_f = percentage of material finer than the critical size

NOTE: The lining thickness (t_a) should be a minimum of 6" to allow for irregularities in placement and material.

5. If the value of t_a is unreasonably large (greater than approximately 1.0 to 2.0 ft), the fraction of fine material in the selected size gradation is too high. In this case, a coarser gradation should be selected.

This procedure for designing a stable channel lining can be applied to flow conditions where the particle size at incipient motion does not exceed approximately 2.0 inches. This corresponds to design flows of 20 cubic feet

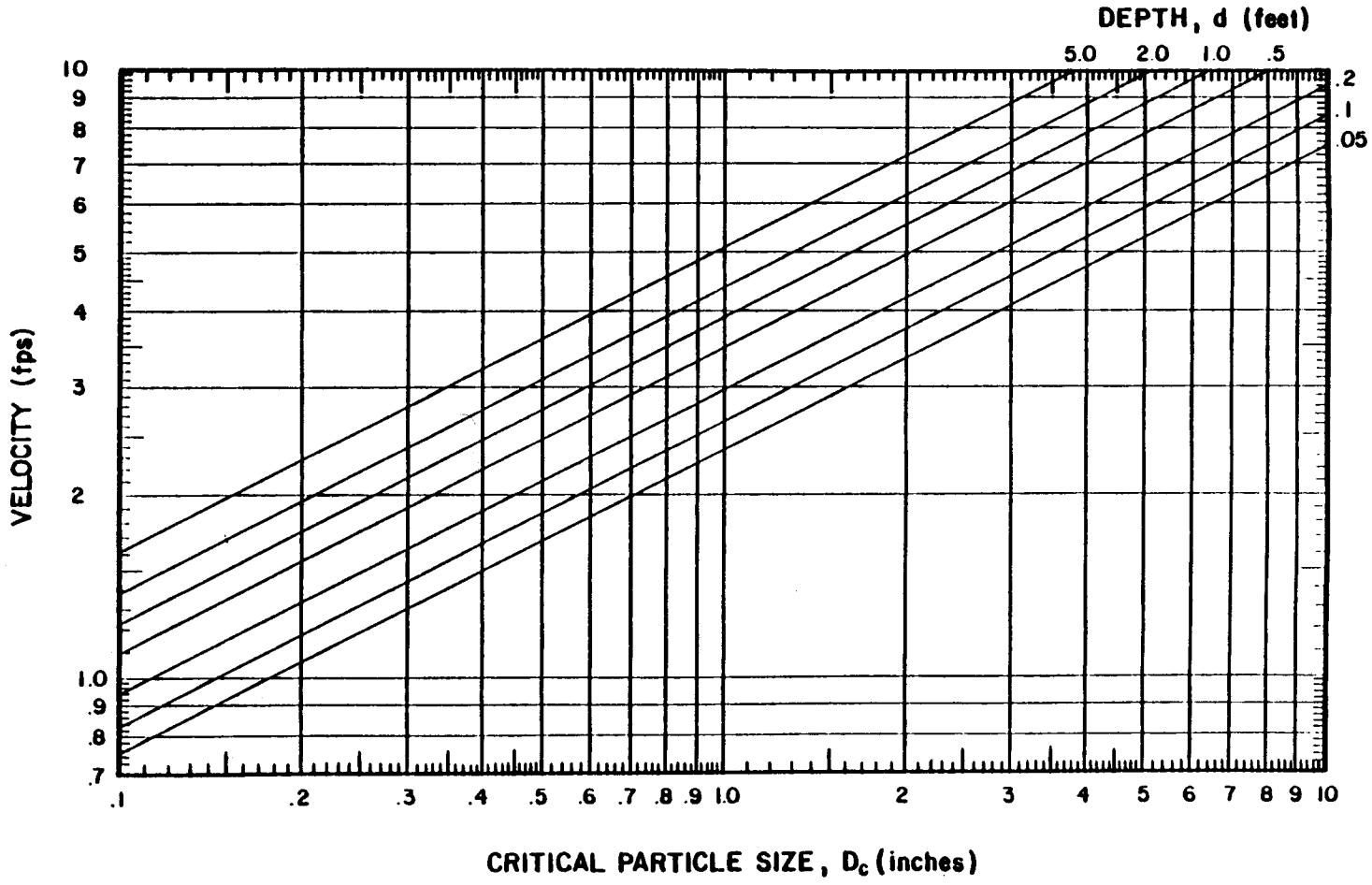


Figure 6.12. Critical particle size versus velocity and depth (from Simons, Li & Associates, Inc., 1982).

Table 6.3. Coarse Aggregate Gradation Table.

Sieve Size	Percentage Passing Designated Sieves		
	AASHTO M147	AASHTO M43	
	Class 2	No. 3	No. 4
	3" to 2"	2" to 1"	1-1/2" to 3/4"
4"	100		
3"	95-100		
2"		95-100	100
1-1/2"		35-70	90-100
1"		0-15	20-55
3/4"			0-15
1/2"		0-5	
3/8"			0-5
<No. 4	0-5*		

*AASHTO specifications allow 3 to 15 percent finer than No. 200 sieve. For channel linings, the percent finer than the No. 4 sieve shall not exceed 5 percent.

per second or less on slopes not exceeding 5 percent, and channels having side slopes no steeper than 4V to 1H. In practical terms, it applies to broad swales draining small sites. In the event that existing conditions are more severe than indicated above, a more detailed riprap design is required. Detailed information for design of riprap channels for a wide range of conditions may be found in the "Design Manual for Water Diversions on Surface Mine Operations," (OSM, 1981).

6.3 Planning and Design Information

For either channel type, if the computed sediment transport for any particle size exceeds the supply, degradation will occur within the channel. In this case, measures must be taken to reduce the transporting capacity.

For diversions, the effective slope can be reduced by adjusting either the actual channel slope or by using small checks in the channel. The effect of an adjustment is evaluated by repeating Steps 4 through 6 using the appropriate slope. These steps are repeated until the computed sediment yield from the channel does not exceed the supply. When terracing is used and an acceptable sediment yield cannot be obtained by adjusting the effective slope, additional terraces may be necessary. The entire procedure must be repeated using the water and sediment inflow from the reduced area when this condition exists.

For the conveyance channel, if the sediment transport exceeds the supply for the assumed conditions, several options are available. These include:

1. Lining the channel with aggregate sufficiently large to prevent erosion from the channel bed and banks.

2. Use of check dams to reduce the effective slope of the channel.

3. Lengthening the channel to reduce the slope if practical.

The procedure for designing a stable channel lining is presented in paragraph 6.2. Design of small check dams is discussed in paragraph 6.3.

Diversions

The general concept for the design of diversions for sediment control on small mine sites is to provide channels which run nearly perpendicular to the overland flow direction. Diversions are generally small wide channels having

a relatively flat slope. Depending upon their slope, roughness and the quality of sediment delivered to them, the diversion channels may provide a means of trapping the sediment eroded from the overland areas. On sites where the overland area has been treated with other erosion control measures, the sediment delivered to the diversions will be relatively small. In this case, the terrace should simply convey the excess runoff from the site without adding additional sediment to the flow. A variation of the diversions is the toe berm which is a terrace channel having zero slope. The berm acts as a sediment trap. Berms can be very effective on small sites with soils having large infiltration capacities.

The channel shape for diversions is dependent on the types of construction equipment available at the site and the method of constructing the channel. Triangular shaped channels are easily constructed; a recommended shape is to have side slopes of 3V to 1H on the upslope side and 5V to 1H on the downslope side (see Figure 6.13).

The number of channels required to provide an acceptable sediment yield depends upon the condition, size and length of the overland flow area contributing to each channel. For an area of 10 acres or less, one to three diversion channels are normally sufficient.

Diversion and terrace channels should be mulched and seeded to produce a good stand of vegetation as soon as possible after construction. In some cases, small checks may be necessary to slow the velocities to allow the vegetation to establish itself. Linings of jute mat or excelsior blanket (see Chapter IV) are useful temporary diversion channel linings.

Conveyance Channel

The general concept for designing the conveyance channel is to carry the excess runoff from the site without adding additional sediment from erosion of the bed and banks of the channel. Because of the small sediment yield to conveyance channels, the sediment transport capacity of the channel will most likely exceed the sediment supply from the overland flow areas and diversion structures unless a proper lining and/or grade control is provided. In cases where the channel slope is relatively small, a vegetative lining may be sufficient to stabilize the channel. If the sediment transport calculation indicates that vegetative lining is not sufficient, a coarse gravel lining should be used. The stable channel design procedure in section 6.3 should be used in

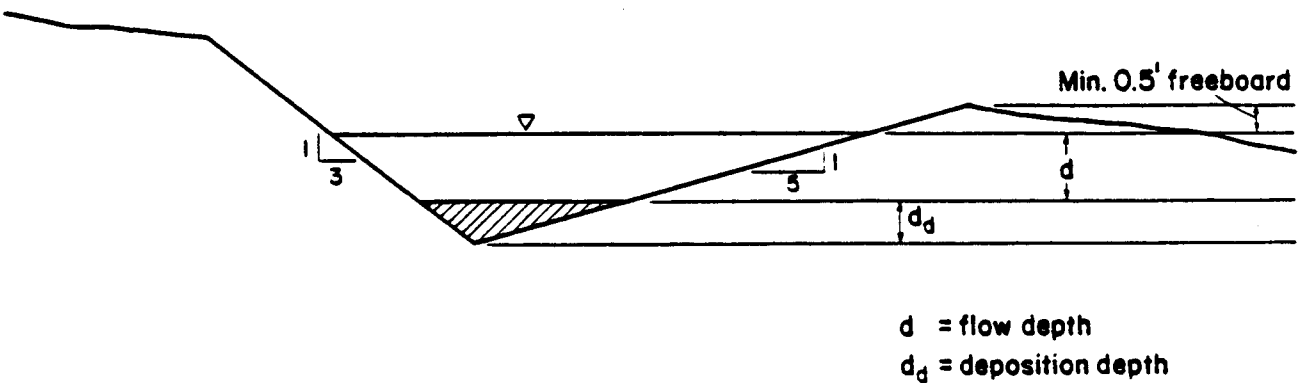


Figure 6.13. Typical diversion channel.

this application.

Because of the necessity for minimizing the sediment transporting capacity of the conveyance channel, a wide, shallow cross section is recommended. A V-shaped (triangular) swale will provide an easily constructed channel meeting this criteria.

Grade control

On steep sites where the required slope of the conveyance channel is excessively steep, a design using the stable channel design procedure alone may not provide sufficient protection. In these cases, small drop structures or check dams are a viable method of further stabilizing the channel by reducing its slope.

Drop Structures. The use of drop structures in this application is limited to locations where a locally steep slope would cause severe channel erosion to develop. Riprap drop structures are normally the most economical since the design flows and drop heights are relatively small. Figure 6.14 contains a sketch of a typical riprap drop structure for the range of conditions applicable to this manual. A formal design is not usually required, however, certain critical factors should be considered.

1. A short transition channel should be provided upstream of the structure to protect the channel from scour from the high approach velocities.

2. An apron must be provided downstream of the structure to prevent scour from the surging action and turbulence below the drop.

3. As a general rule of thumb, the length of the upstream transition channel (L_u) and the downstream apron (L_b) should be at least 6 times the flow depth in the channel. The length of the drop slope, L_a, is a minimum of 4 feet.

4. The bed and banks of the transition channel and apron should be constructed at zero slope and should be lined with riprap sufficient to withstand the velocity associated with critical flow conditions. The critical velocity (V_c) and flow depth (d_c) may be determined from Figure 6.15. To use this figure, divide the peak discharge by the topwidth of the structure to find the discharge per unit width (Q). Enter the figure using this value and read the corresponding V_c and d_c. Figure 6.12 can then be used to estimate the minimum size for the channel lining. If the slope of the face exceeds 3V to 1H, the indicated size from Figure 6.12 should be divided by the appropriate ratio of the critical shear on sides to critical sheer, K_2, from Figure 6.16.

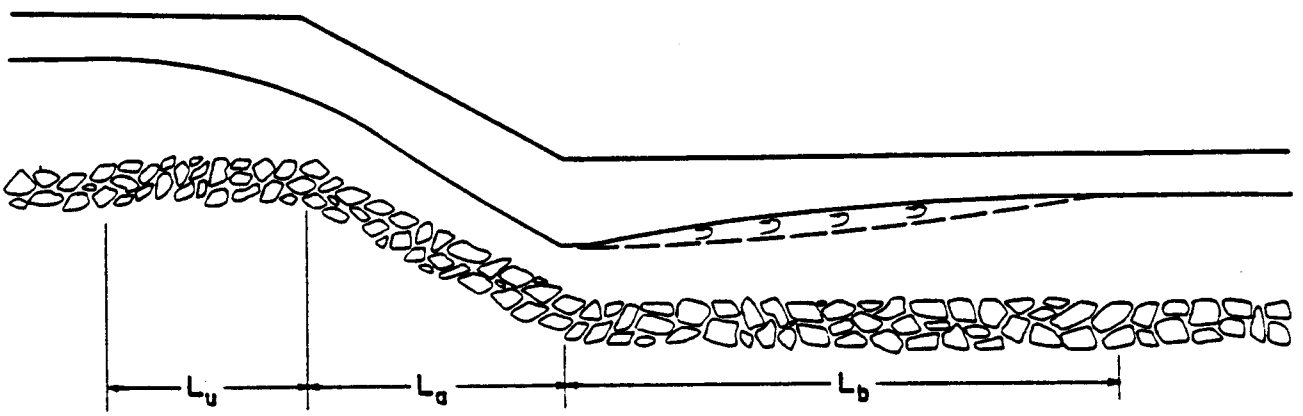


Figure 6.14. Definition sketch for a riprap drop structure.

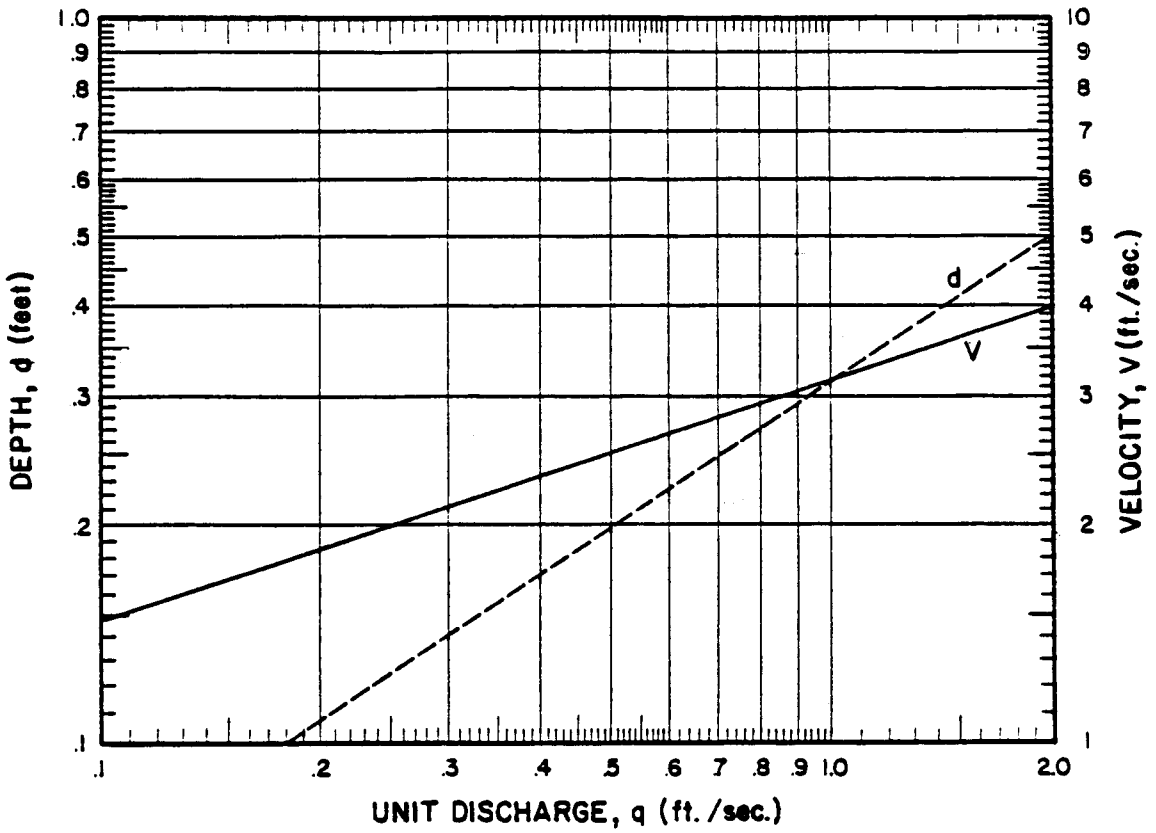
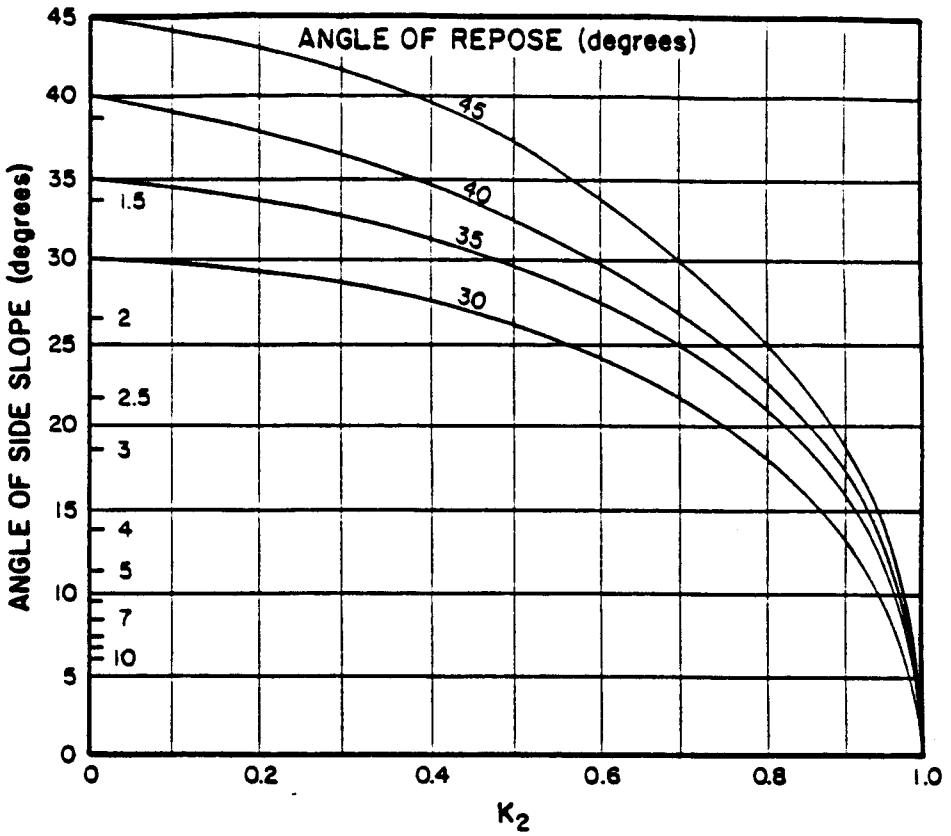


Figure 6.15. Critical flow (from Simons, Li & Associates, Inc., 1982).



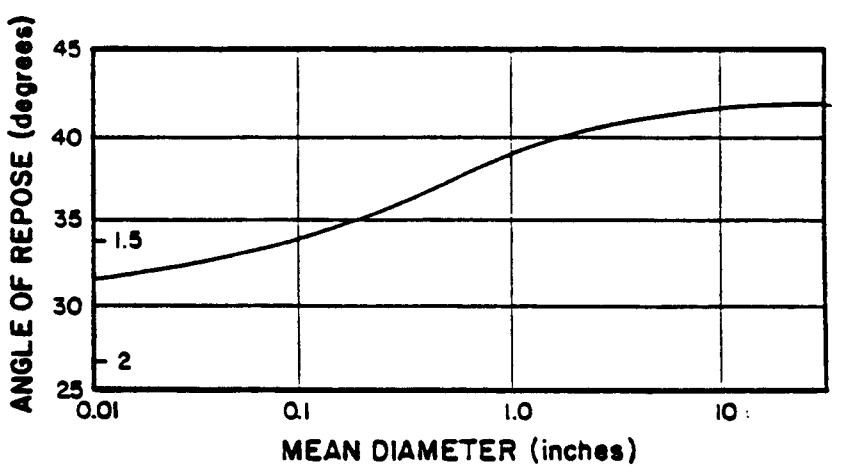


Figure 6.16. Graphs of angle of repose for riprap stones and ratio of critical shear on sides to critical shear (after Simons, 1957).

5. The sloping face of the structure should not exceed 2V to 1H.

6. Maximum drop height should not exceed 2 feet.

For cases where the grade control drop heights exceed 2 feet or the design flow exceeds approximately 2 cfs/ft of channel width, the above procedure should not be used. In these cases, a more rigorous design is required using more detailed drop structure designs which are beyond the scope of this manual (see OSM, 1981).

Check Dams. A check dam is a temporary barrier constructed across the channel which retards the flow and forms a small pool which reduces the flow velocity. Check dams trap some sediment, particularly the larger sediment sizes but do not make effective sediment traps. Their best use is for stabilization of the channel by reducing the effective gradient of the flow.

In specifying the check dams, a formal design is not required if the design discharge is less than 20 cfs, and the following criteria are met:

1. Maximum dam height should not exceed approximately 2 feet.

2. The dam spillway should be treated as a broad crested weir. The head of flow over the weir can be computed from the following relation:

$$H = \left(\frac{Q}{CL}\right)^{2/3} \qquad (6.11)$$

where: H = head, feet
Q = total channel discharge, cfs
L = effective length of weir
C = constant

Figure 6.17 shows the effective length of the weir and Figure 6.18 is a plot of this relation for C = 3.0 which is an averge value for small check dams.

3. The slope upstream of check dams normally varies from 0.5 to 0.7 times the original channel slope. This can vary widely depending upon a number of factors. As a rule of thumb, however, 0.5 should give a reasonably conservative estimate. It is recommended that the spacing of the check dams (Figure 6.19) be based on this value according to the following formula:

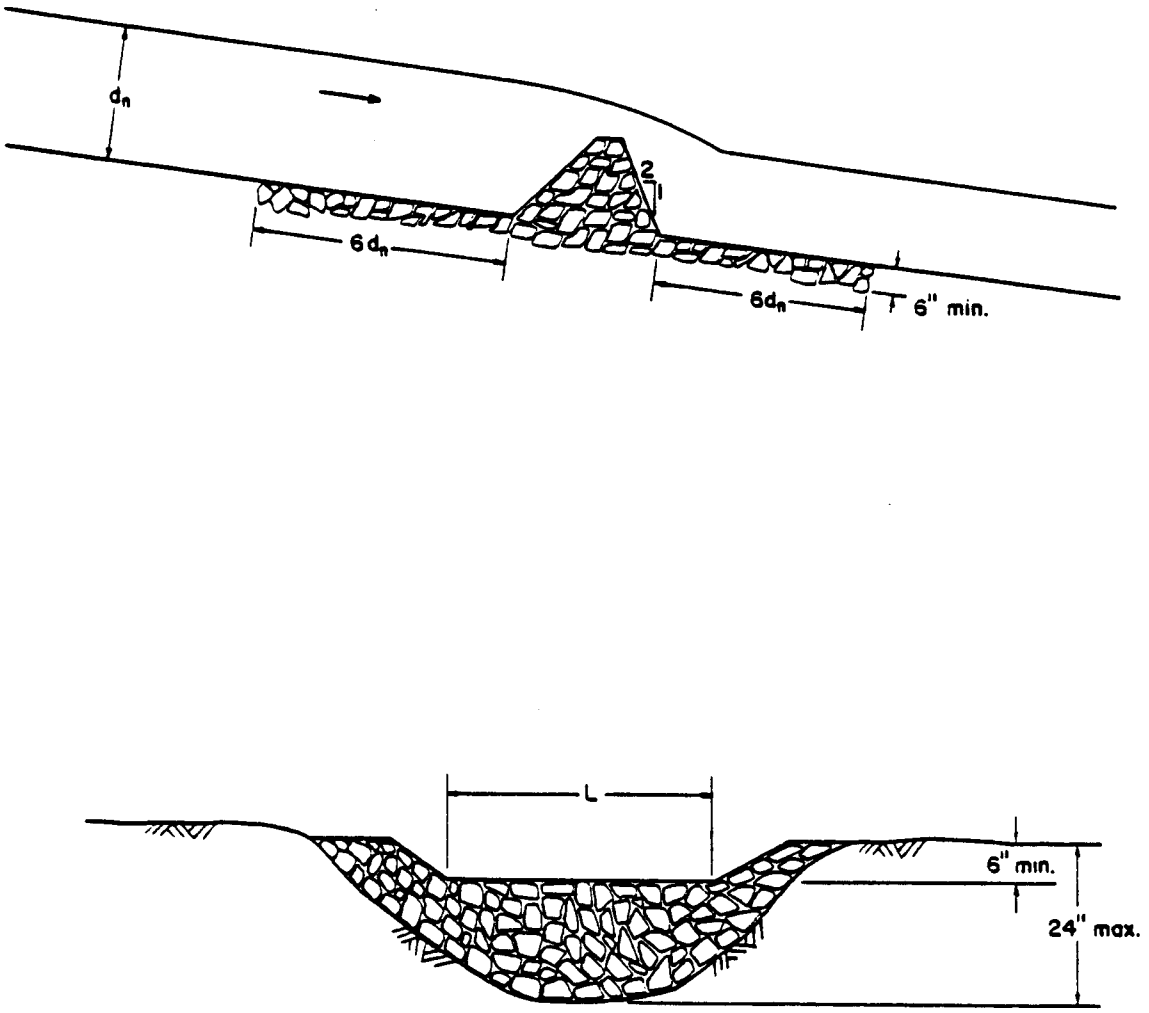


Figure 6.17. Rock check dam definition sketch.

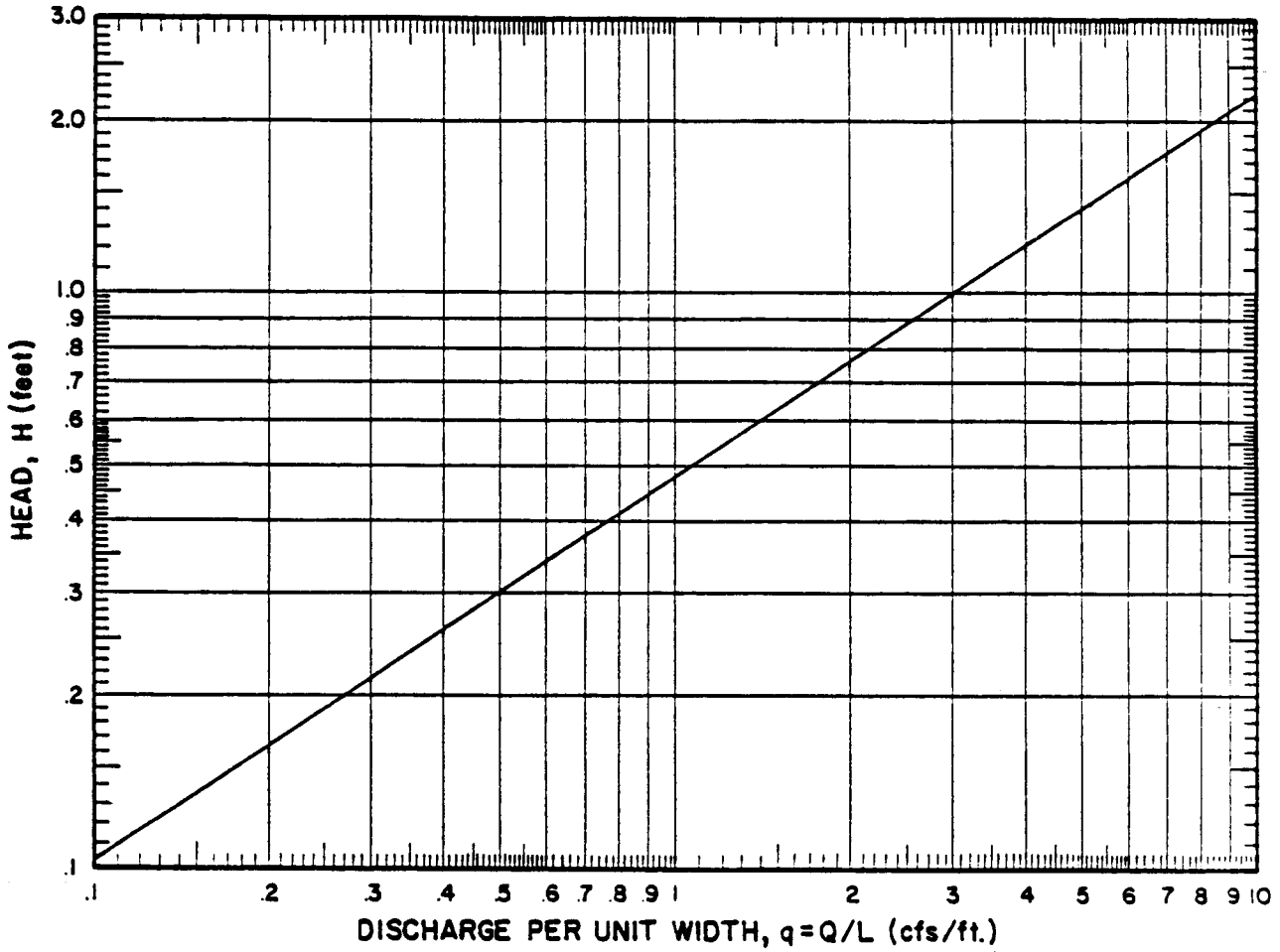


Figure 6.18. Plot of weir equation $Q/L = CH^{2/3}$ where C = 3.0 (from Equation 6.6) (from Simons, Li & Associates, Inc., 1982).

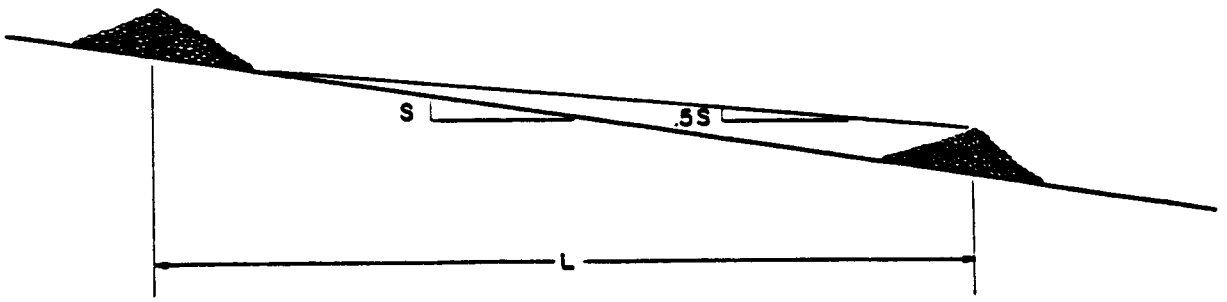


Figure 6.19. Spacing between check dams.

$$S_d = \frac{H_d}{0.5S} \tag{6.12}$$

where: S_d = spacing of dams
H_d = dam height
S = original channel slope

4. For the flow conditions applicable to this design, the aggregate used to construct the rock check dams should be a minimum of 2 to 3 inches.

5. The maximum side slope of the downstream face of the dam should not exceed 2H to 1V.

Figure 6.20 shows a suggested design for a log check dam.

6.4 In-Service Performance

Proper design and installation of the channels and structures as discussed in this chapter should provide sediment control devices which will perform their intended purpose throughout the life of the project with minimal maintenance. There are, however, certain key items which should be periodically checked to prevent failure of the system. The diversion and conveyance channels should be checked after each storm to insure that sediment deposition is not sufficient to cause overtopping of the channel and a possible breach during future storms. Cleaning of the channel may become necessary. All structures and the lining for aggregate or vegetative lined channels should also be inspected to insure that no damage has occurred.

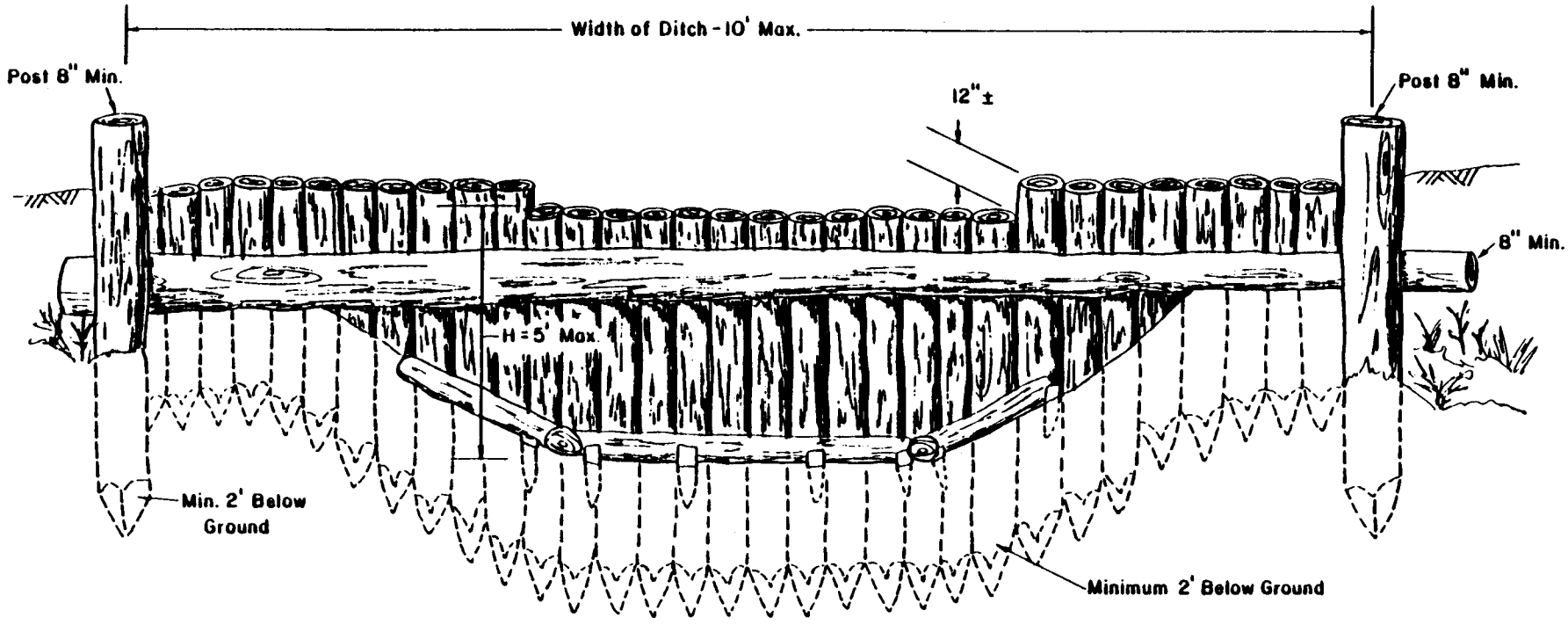


Figure 6.20. Log and brush check dam.

6.5 Example Problems

Example 6.1

Design a terrace system to intercept the excess runoff and sediment from the small mine site described in example problem 4.1 for the 10-year, 24-hour, Type II storm. The basic soils and hydrology data developed in that example will be used.

Required input data for the terrace design are summarized below.

Particle Size Distribtuion

	Decimal Percentage
Silt, p_1	0.25
Very fine sand, p_2	0.20
Fine-medium-coarse sand, p_3	0.20
Very coarse sand, p_4	0.30
	0.20

Area of mine site: 10 acres.

Solution:

The first solution to this problem assumes that one terrace is sufficient to meet the criteria. Therefore the area per terrace is equal to 10 acres. The terrace length is 660 feet.

Step One: Determine the Water and Sediment Delivery to the Terrace

Using the information from Example 4.1, the runoff and sediment yield by size fractions can be computed for each time increment of the storm hydrograph. Since only one diversion is to be used, the results of Example 4.1 can be used directly in this problem.

Storm hydrograph:

INFLOW HYDROGRAPH		
Time Interval	Time Increment (Hrs)	Discharge (Q) (cfs)
1	4.91	0.13
2	2.25	0.84
2	0.92	14.92
3	1.83	2.43
4	10.00	0.66

Total Excess Rainfall (P_e) = 2.71 inches from Example 4.1

Sediment supply to terrace from overland flow:

SEDIMENT INFLOW					
Time Interval	G_{s1}	G_{s2}	G_{s3}	G_{s4}	G_{s5}
1	2.81	0.62	0.18	0.00	3.61
2	15.2	3.50	0.55	0.00	19.25
3	276.	66.7	4.12	0.43	347.25
4	50.1	11.8	1.30	0.00	63.20
5	49.1	11.2	1.89	0.00	62.19
	393.21	93.82	8.04	0.43	495.50

<u>Step Two:</u> Estimate Required Slope

As a first approximation assume the channel slope to be 1%.

<u>Step Three:</u> Select an Appropriate Channel Shape and Compute the Velocity (V), Depth (d) and Topwidth (T)

Use a triangular cross section as shown in Figure 6.13 with side slope of 3:1 and 5:1.

Assume the channel will be lined with bermuda grass approximately 2 to 3 inches long. From Table 6.2, Manning's n is approximately 0.06. Using Figure 6.3 and 6.4, Step Three Worksheet is completed noting that the velocity (V) is simply the ratio of discharge to flow area or

$$V = Q/A \tag{6.13}$$

1	2	3	4	5	6	7
Time Interval	Q (cfs)	d (ft)	A (ft2)	V (fps)	T (ft)	d_h=A/T (ft)
4.91	0.13	0.24	0.22	0.58	1.88	0.12
2.25	0.84	0.48	0.91	0.93	3.81	0.24
0.92	14.92	1.40	7.81	1.91	11.18	0.70
1.83	2.43	0.71	2.00	1.21	5.66	0.35
10.00	0.66	0.43	0.75	0.88	3.47	0.22

Example Problem 6.1. Step Three Worksheet.

Step Four: Determine the Sediment Transport Capacity.

Using the results in Step Three Worksheet with Figures 6.6, 6.7, 6.8 and 6.9, the sediment transport capacity is determined and the Step Four Worksheet is completed.

Step Five: Determine the Sediment Yield.

Using the results in Worksheet 6.2 and the sediment supply from overland flow Step Five Worksheet is completed. Note that all the sediment yield from the terrace is transported controlled (Equation 6.3) and the silt yield (column 4) is determined using Equation 6.4.

The average sediment concentration is:

$$C_s = 8830\ G_y/P_e A = 8830\ (320.4)/(2.71)(10)$$

$$C_s = 104{,}400 \text{ ppm}$$

By using one terrace, the suspended sediment concentration from the overland flow area has been reduced by approximately 35 percent. The concentration is still very high, however. The procedure is therefore repeated assuming 4 terraces rather than 1 and reducing the channel slope to 0.5 percent. The results are summarized in the tables below and worksheets attached.

INFLOW HYDROGRAPH TO EACH TERRACE

Time Interval	Time Increment (Hrs)	Discharge (Q) (cfs)
1	4.91	0.03
2	2.25	0.21
3	0.92	3.72
4	1.83	0.61
5	10.00	0.17

$p_1 = .25 \quad p_2 = .20 \quad p_3 = .20 \quad p_4 = .30$

Time Interval	Δt (hrs)	T (ft)	g_t (tons/ft/hr)				G_t (tons)				
			1	2	3	4	1	2	3	4	Total
1	4.91	1.88	0.045	0.007	0.005	0.001	0.104	0.013	0.009	0.004	0.13
2	2.25	3.81	0.305	0.048	0.033	0.010	0.654	0.082	0.057	0.025	0.82
3	0.92	11.18	6.10	0.950	0.636	0.173	15.69	1.95	1.31	0.533	19.48
4	1.83	5.66	0.915	0.144	0.098	0.028	2.369	0.298	0.204	0.087	2.96
5	10.00	3.47	0.235	0.037	0.026	0.008	2.039	0.258	0.179	0.080	2.56
						TOTAL	20.86	2.60	1.76	0.73	25.95

Example Problem 6.1, Step Four Worksheet.

1	2	3	4	5	6	7	8
Time Interval	Cw	P_s	Gy_1	Gy_2	Gy_3	Gy_4	Gy
1	2.09	0.90	0.375	0.013	0.009	0.004	0.40
2	0.651	0.49	8.072	0.082	0.057	0.025	8.24
3	0.109	0.11	247.4	1.95	1.31	0.533	251.2
4	0.343	0.30	35.78	0.298	0.204	0.087	36.37
5	0.750	0.54	23.69	0.258	0.179	0.080	24.21
Total Yield			315.32	2.601	1.759	0.729	320.41

Example Problem 6.1. Step Five Worksheet.

1	2	3	4	5	6	7
Time Interval	Q (cfs)	d (ft)	A (ft^2)	V (fps)	T (ft)	d_h=A/T (ft)
4.91	0.03	0.16	0.10	0.32	1.28	0.08
2.25	0.21	0.32	0.41	0.51	2.58	0.16
0.92	3.72	0.95	3.58	1.04	7.57	0.47
1.83	0.61	0.48	0.92	0.66	3.83	0.24
10.00	0.17	0.29	0.35	0.48	2.35	0.15

Example Problem 6.1 (4 Terraces). Step Three Worksheet.

$p_1 = .25 \quad p_2 = .20 \quad p_3 = .20 \quad p_4 = .30$

Time Interval	Δt (hrs)	T (ft)	g_t (tons/ft/hr)				G_t (tons)				
			1	2	3	4	1	2	3	4	Total
1	4.91	1.28	0.005	0.001	0.001	0.000	0.008	0.001	0.001	0.000	0.010
2	2.25	2.58	0.035	0.005	0.003	0.001	0.051	0.006	0.004	0.002	0.063
3	0.92	7.57	0.670	0.101	0.066	0.016	1.167	0.140	0.091	0.033	1.431
4	1.83	3.83	0.100	0.015	0.010	0.003	0.175	0.022	0.014	0.005	0.216
5	10.00	2.35	0.025	0.004	0.003	0.001	0.147	0.019	0.013	0.005	0.184
						TOTAL	1.548	0.188	0.123	0.045	1.904

Example Problem 6.1 (4 Terraces). Step Four Worksheet.

1	2	3	4	5	6	7	8
Time Interval	Cw	P_s	Gy_1	Gy_2	Gy_3	Gy_4	Gy
1	5.67	1.0	0.008	0.0	0.0	0.0	0.01
2	1.78	0.85	0.406	0.01	0.0	0.0	0.42
3	0.30	0.26	33.034	0.14	0.09	0.03	33.29
4	0.92	0.61	3.250	0.02	0.01	0.01	3.29
5	2.02	0.89	0.988	0.02	0.01	0.01	1.03
Total Yield			37.69	0.19	0.11	0.05	38.04

Example Problem 6.1 (4 Terraces). Step Five worksheet.

SEDIMENT INFLOW TO EACH TERRACE					
Time Interval	G_{s1}	G_{s2}	G_{s3}	G_{s4}	G_{s5}
1	0.44	0.10	0.00	0.00	0.54
2	2.42	0.55	0.00	0.00	2.97
3	44.23	10.45	1.01	0.00	55.69
4	8.06	1.84	0.32	0.00	10.22
5	7.79	1.76	0.00	0.00	9.55
	62.94	14.70	1.33	0.00	78.97

Total sediment yield from each terrace is 38.04 tons or 152.16 tons for the entire 10 acre area. The average sediment concentration is

$$C_s = 8830(152.16)/(2.71)(10.) = 49{,}600 \text{ ppm}$$

The new assumption reduces the concentration compared to the untreated condition by 69 percent.

Step Six: Compute the Deposition Depth

For the condition of 4 terrace channels on a grade of 0.5 percent, the deposition volume is:

$$\forall_s = 20.15(78.97 - 38.04)$$

$$\forall_s = 824.7 \text{ ft}^3$$

The deposition depth is

$$d_d = \sqrt{\frac{834.6}{(660)(4)}}$$

$$d_d = 0.56 \text{ ft}$$

Step Seven: Channel Size.

The design depth of the terrace cross section is

$$d_c = 0.95 + 0.56 + 0.5$$

$$d_c = 2.01 \text{ ft}$$

Use 2.0 feet as the design depth for the terrace.

Discussion of Example Problem 6.1

In studying the results of the previous calculations, it becomes obvious that the terraces are quite effective in settling out the fine sand and larger particle sizes. For the case of one terrace with a slope of one percent, the percent of sediment in these size ranges settled out exceeds 99 percent. These channels are less effective in settling out the silts and smaller particle sizes, however.

Example Problem 6.2

Design a stable conveyance channel to pass the peak discharge for the 10-year, 24-hour Type II storm for the site discussed in example problem 6.1.

Step One: Determine the Water and Sediment Delivery to the Channel.

Assume that the conveyance channel will collect the water delivered from the 4 terraces design in Example 6.1. The channel will be designed to carry the runoff from all of the terraces. The sediment and water inflows to the conveyance channel are determined by multiplying the water and sediment discharges by the number of terraces. The result is summarized below:

INFLOW HYDROGRAPH

Time Interval	Time Increment (Hrs)	Discharge (Q) (cfs)
1	4.91	0.12
2	2.25	0.84
3	0.92	14.90
4	1.83	2.44
5	10.00	0.68

SEDIMENT INFLOW

Time Interval	G_{s1}	G_{s2}	G_{s3}	G_{s4}	G_{s5}
1	0.03	0.00	0.00	0.00	0.03
2	1.62	0.04	0.00	0.00	1.66
3	132.14	0.56	0.36	0.12	133.18
4	13.00	0.08	0.04	0.04	13.16
5	3.95	0.08	0.04	0.04	4.11
	150.74	0.76	0.44	0.20	152.14

Step Two: Estimate Channel Slope.

Because of the topography of the site, the conveyance channel will have a slope of 9 percent.

Step Three: Select an Appropriate Channel Shape and Compute the Velocity, Depth and Topwidth

A triangular channel with side slopes of 5V to 1H approximates the geometry of the natural swale where the channel will be placed. An unmaintained rough earth channel is planned which will have a Manning's n of 0.025 (Table 6.1). The hydraulic calculations for the design storm are summarized on the Step Three Worksheet.

Step Four: Determine the Sediment Transport Capacity.

See Step Four Worksheet.

Step Five: Determine the Sediment Yield.

Comparing the sediment transport capacity with the sediment inflow for each size fraction, it can be seen that the sediment transport capacity of the conveyance channel exceeds the sediment supply. The channel will be unstable in this condition. A stable lining will be required.

A coarse aggregate lining will be designed as described in section 6.2.

Stable Channel Design

Step One: Compute Velocity and Depth for Maximum Discharge.

Assuming a Manning's "n" of 0.25, the hydraulic conditions may be taken directly from Step Four above. From these calculations:

$V = 4.73$ ft

$d = 0.79$ ft

Step Two: Determine the Critical Particle Size.

From Figure 6.12,

$D_c = 1.6$ inches

1	2	3	4	5	6	7	8
Time Interval	Q (cfs)	n	d (ft)	A (ft^2)	V (fps)	T (ft)	d_h=A/T (ft)
1	0.13	0.025	0.134	0.090	1.45	1.34	0.067
2	0.84	0.025	0.270	0.364	2.31	2.70	0.135
3	14.92	0.025	0.794	3.15	4.73	7.94	0.397
4	2.43	0.025	0.402	0.808	3.01	4.02	0.201
5	0.66	0.025	0.247	0.304	2.17	2.47	0.123

Example Problem 6.2. Step Three Worksheet.

$p_1 = .25 \quad p_2 = .20 \quad p_3 = .20 \quad p_4 = .30$

Time Interval	Δt (hrs)	T (ft)	g_t (tons/ft/hr) 1	2	3	4	G_t (tons) 1	2	3	4	Total
1	4.91	1.34	0.575	0.107	0.089	0.013	0.95	0.14	0.12	0.03	1.24
2	2.25	2.70	4.005	0.740	0.603	0.123	6.10	0.90	0.73	0.22	7.95
3	0.92	7.94	79.80	14.60	11.50	3.692	145.75	21.33	16.80	8.09	191.97
4	1.83	4.02	12.09	2.23	1.792	0.431	22.25	3.28	2.64	0.95	29.12
5	10.00	2.47	3.085	0.571	0.467	0.091	19.05	2.82	2.31	0.68	24.86
						TOTAL	194.10	28.47	22.60	9.97	255.14

Example Problem 6.2. Step Four Worksheet.

1	2	3	4	5	6	7	8
Time Interval	Cw	P_s	Gy_1	Gy_2	Gy_3	Gy_4	Gy
1	2.42	0.94	0.03	0.00	0.00	0.00	0.03
2	0.698	0.51	1.62	0.04	0.00	0.00	1.66
3	0.076	0.076	132.14	0.56	0.36	0.12	133.18
4	0.292	0.26	13.00	0.08	0.04	0.04	13.16
5	0.838	0.58	3.95	0.08	0.04	0.04	4.11
Total Yield			150.74	0.76	0.44	0.20	152.14

Example Problem 6.2. Step Five Worksheet.

Step Three: Select an Available Coarse Aggregate.

An aggregate which has the particle size distribution, D_s, shown in Figure 6.21 is assumed to be readily available for this problem area. The D_{50} size for this mixture is 2.50 inches which is larger than the critical size indicating that it should provide an adequate

Step Four: Determine the Required Thickness of the Lining.

For the given aggregate mixture, approximately 3 percent of the material is finer than the critical particle size. The required thickness of the lining is:

$$t_a = \frac{2D_c}{(1-p_f)} \geq 26 \text{ inches}$$

$$= \frac{2(2.25)}{1 - 0.03}$$

$$= 4.64 \text{ inches}$$

A 6 inch lining of coarse aggregate will be used to provide a stable channel lining for the conveyance channel.

With a stable lining provided the sediment yield will equal the supply of sediment from the terraces. Sediment yield is summarized on the Step Five Worksheet.

Step Six: Compute the Deposition Depth.

Since sediment yield equals the sediment supply, no deposition will occur in the conveyance channel.

Step Seven: Channel Size.

The design depth of the conveyance channel is

$$d_c = 0.79 + 0.0 + 0.5$$

$$= 1.29 \text{ ft}$$

Rounding to the nearest half foot gives a conveyance channel depth of 1.5 feet.

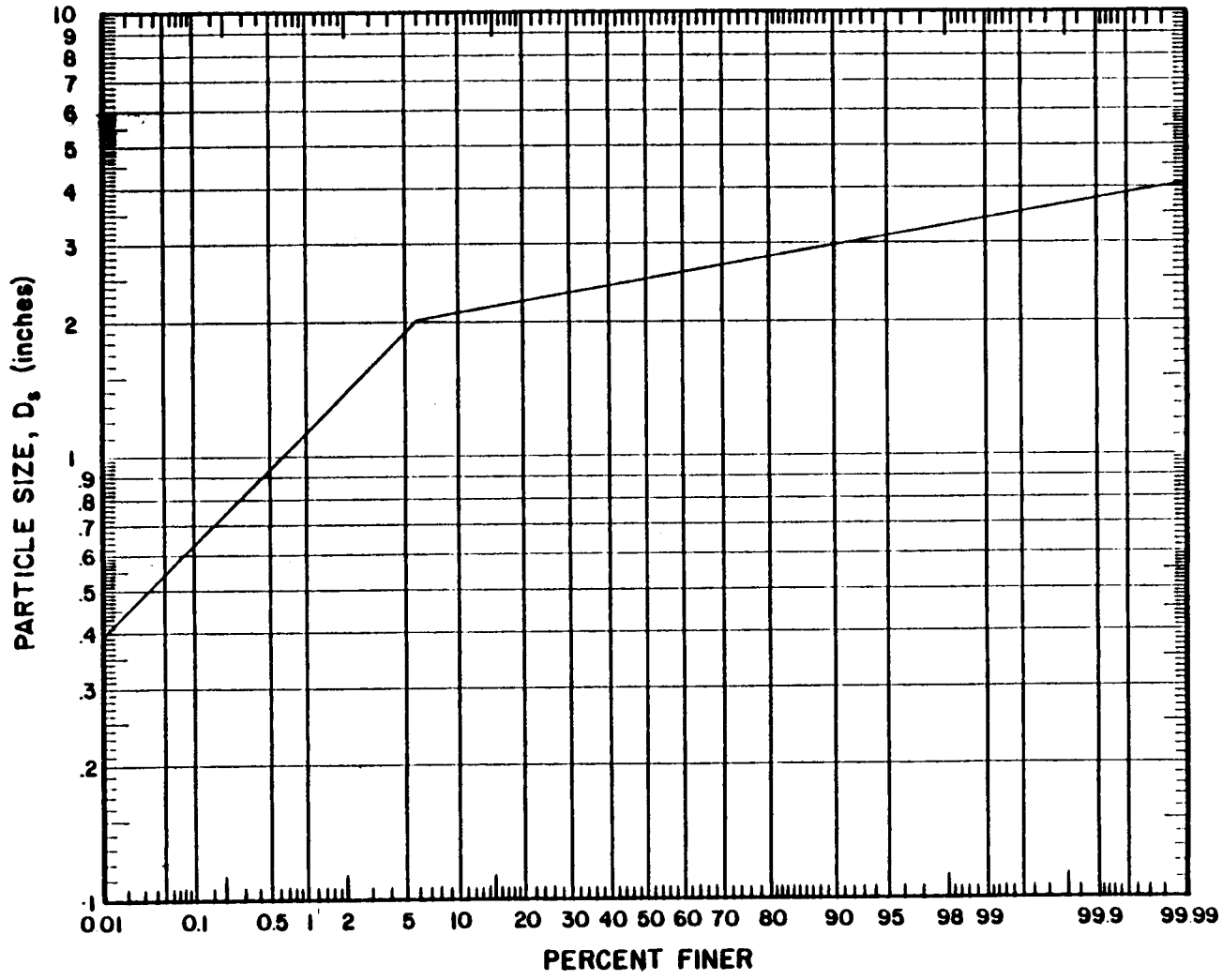


Figure 6.21. Aggregate mix particle size distribution.

6.6 Specifications

Specifications - Aggregate Channel Lining

Description. This item shall consist of furnishing and placing one or more courses of aggregate channel lining in reasonably close conformity with the lines, grades and typical cross sections shown on the plans or as designated by the engineer.

Materials. Aggregates for channel linings shall be crushed stone, crushed slag, crushed gravel, or natural gravel which conforms to the specifications (except as noted) as set forth in Table 7.4 unless otherwise specified by the engineer.

Construction Requirements. The aggregate channel lining shall be placed and compacted uniformly across the channel bed and banks to the thickness specified on the plans. Prior to placement of the aggregate channel lining, the channel cross section shall be formed as specified on the plans. If the required compacted depth of the aggregate lining exceeds 6 inches, it shall be constructed in two or more layers of approximately equal thickness.

Method of Measurement. Aggregate channel lining will be measured by the ton.

Basis of Payment. The accepted quantities of Aggregate Channel Lining of the class specified will be paid for at the contract price per ton.

Payment will be made under:

PAY ITEM	PAY UNIT
Aggregate Channel Lining	Ton

Haul for aggregate channel lining will be measured and paid for as a separate item.

Specifications - Excavation and Embankment for Channels

Description. This work shall consist of excavation, disposal, shaping or compaction of all material for construction of the diversion and conveyance channel in conformance with the specifications and in reasonably close conformity with the lines, grades and cross section shown on the plans or as stated by the Engineer.

Construction Requirements. Excavation operations for the construction of channels shall be conducted so that material outside the limits of the slopes will not be disturbed. Prior to beginning of excavation, all trees, brush, stumps, roots, obstructions, and other unsuitable material shall be removed and properly disposed of. The channel shall be excavated or shaped to the proper grade and cross section. All fills shall be well compacted to prevent unequal settlement. Any excess soil not required for the channel construction shall be removed and properly disposed of.

Embankment. Embankment construction shall consist of constructing dikes and built up channel banks as specified in the plans and the placing and compacting of approved material within areas where unsuitable material has been removed. Only approved material shall be used in the construction of embankments and backfills. Free running water shall be drained from the material before it is placed. Relative compaction required shall be as called for on the plans or as designated. All sod and organic matter shall be removed from the surface upon which the embankment is to be placed, and the cleared surface shall be completely broken up by scarifying or stepping to a minimum depth of 6 inches. This area shall then be recompacted. Sod not required to be removed shall be thoroughly disked before construction of embankment.

Method of Measurement. Excavation work shall be measured on a volume basis by cross sectioning the excavated areas. Volumes will be compacted from the cross section measurements of the original material by the average end area method. Embankment material will be measured in is final compacted position.

Basis of Payment. The accepted quantities will be paid for at the contract price for each of the pay items listed below that appear in the bid schedule.

Payment will be made under:

PAY ITEM	PAY UNIT
Excavation	Cubic Yard
Embankment	Cubic Yard

Excavated materials which require more than one handling prior to final placement will be paid for at the contract unit price for excavation or embankment as appropriate, for the first approved handling. Payment for the second approved handling will be made at the same unit price as the first handling except that material used in conjunction with any other pay item will be paid for in that pay item.

Haul, compaction and water for pay items which include the term (Complete in Place) will not be measured and paid for separately but shall be included in the work.

Haul and compaction for pay items including the term (Haul and Compaction) will not be measured and paid for separately but shall be included in the work.

Specifications - Haul

Description. Haul shall consist of transporting material from its original location to it final location in the work.

Method of Measurement. In determining what constitutes authorized haul, it will be assumed that material taken from excavation will be deposited in accordance with the plans in adjacent embankment after having been hauled the minimum possible distance. The haul distance for material moved from outside the roadway shall be measured along the shortest route determined by the engineer to be feasible and satisfactory. The haul distance for material obtained from the roadway and placed inside the roadway shall be measured along the centerline of the roadway.

Haul shall be the product obtained by multiplying the number of units of material removed from its original position by the mean distance in miles or fractions of miles such material is hauled. The distance between the center of volume of the material and the center of volume of its placement shall be the haul distance in the units specified.

Basis of Payment. The quantity of haul measured as provided above will be paid for at the contract price. Units of measurement will be as tabulated below:

PAY ITEM	UNIT OF QUANTITY	PAY UNIT
Haul	Cubic Yard	Yard Mile
Haul	Ton	Ton Mile

In case the Contractor, for his own experience, elects to use pits or a haul plan differing from the plan proposed by the Division, actual haul resulting from the use of the Contractor's plan will be paid for, except that haul in excess of that resulting from use of the Division's plan will not be paid for.

Haul for pay items including the term (Haul) will not be measured and paid for separately but shall be included in the work.

6.7 References

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VII. DETENTION AND FILTERING STRUCTURES

7.1 General

When sediment laden water is slowed or ponded, its ability to transport sediment is greatly reduced. Under these conditions, sediment will settle out of the water and deposit. The efficiency of a detention structure will depend on the amount of time the flow remains in the detention area. Larger size particles settle quickly while small size particles require a much longer time to settle. Figure 7.1 shows the settling distance for the different diameter particles used in this manual for a 30-minute time interval. Detention structures presented in this manual will only pond one to two feet of water and, as can be seen in Figure 7.1, the three largest sizes will quickly reach this depth while the smallest size will take several hours.

Filtering structures also pool water allowing sediment to settle out and deposit. In addition to detaining sediment laden water, a number of filter barriers are available for removing sediment from moving water. Filtering is accomplished by allowing the sediment laden water to flow slowly through the small pores of a filter material.

Synthetic fabrics have become the dominant material used in the design of filtering structures. The fabrics are permeable and have numerous small pores which trap sediments, both woven and nonwoven fabrics, are in use. These fabrics have a low permeability which means that water will pool behind a filter structure. Because of this low permeability filter structures will not be suitable for use where high concentrations of water occur such as channels or gullies. Filter fabrics will trap all sand size particles and 60 to 80 percent of silt and clay size particles. Large particle sizes will tend to settle out before they are filtered but the distinction is not necessary since all of these sizes will be removed in either case.

Detention and filtering structures are an effective means of reducing the sediment yield from an area. Several factors can decrease their performance over a short period of time, however, and maintenance of the structures is important. First, since these structures are very efficient sediment traps, they will accumulate large deposits of sediment after rainfall. These structures must be cleaned frequently or else their efficiency will be reduced. The structures must be accessible to maintenance equipment for cleaning and should not be installed in locations where maintenance equipment access is

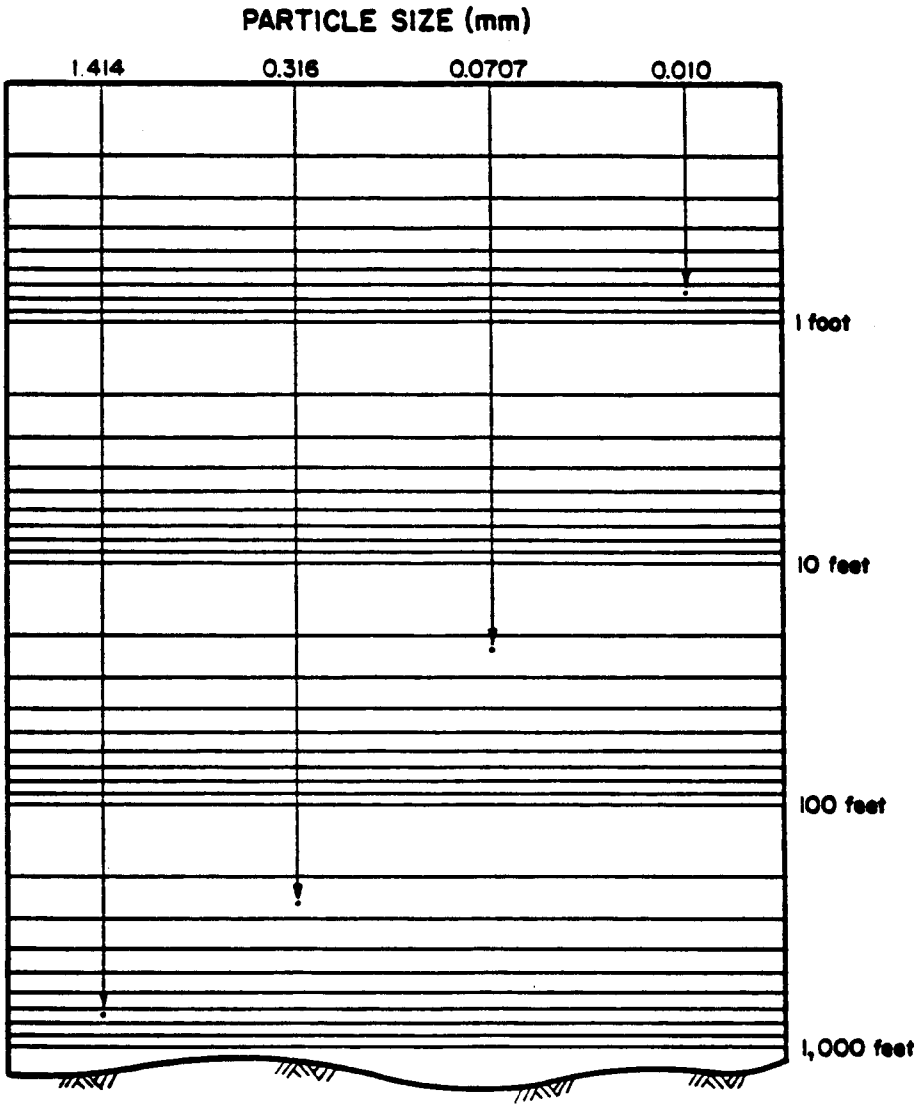


Figure 7.1. Settling distance for different diameter particles based on a 30-minute time interval.

limited. Second, erosion can jeopardize the effectiveness of these structures. Common problems are channels which form under or around structures and/or the clogging of filter materials. Synthetic filter fabric is also susceptible to deterioration from ultraviolet radiation. Structures should be inspected frequently and repairs made promptly when damage has occurred.

7.2 Procedural Guide

The sediment trapping efficiency of both detention and filtering structures can be evaluated using the following procedure. The height of ponded water is limited to two feet for both of these structures. This height reduces the possibility of various structural problems (undercutting or channeling around) and allows room for storage of sediment. Large sediment deposition behind these structures should be avoided since it greatly reduces the trapping efficiency of the structure. The procedure consists of the following five major steps:

1. Determination of total water and sediment yield to the structure.
2. Determination of structure length.
3. Determination of the amount of trapped sediment.
4. Determination of effluent settleable solids concentration.
5. Determination of the required structure height.

Worksheet 7.1 is provided to aid in executing the detention and filtering structure procedure.

Step One: Determine total water and sediment yield to the structure.

The procedure guide for Chapter IV computes water and sediment yield from an area. The step three worksheet gives total rainfall excess in inches (last value in column 4) and the step seven worksheet gives the total sediment yield in tons (sum of column 5). The total volume of water and sediment yield to the detention structure is given by the following equation:

$$V_{sw} = 3630\ P_e A + 20.2\ G_y \qquad (7.1)$$

where: V_{sw} = volume of sediment and water, cubic feet

P_e = rainfall excess, inches

Worksheet 7.1. Detention and Filtering Structures.

Step One: Volume of Water and Sediment Yield

Rainfall Excess, P_e = _____ inches

Catchment Area, A = _____ acres

Actual Sediment Yield, G_y = _____ tons

$$\Psi_{sw} = 3{,}630\ P_e A + 20.2\ G_y$$
$$=$$
$$= _____ \text{ cu.ft.}$$

Step Two: Minimum Structure Length

Maximum Allowable Ponded Depth, d_{max} = _____ feet

Duration of runoff, t_e = _____ hours

Flow rate per unit area, K_a = _____ ft/hr

Upland slope, S_x = _____

Detention Parameter

$$K_f = 1/2\ K_a\ t_e\ d_{max}$$
$$=$$
$$= _____$$

Structure Length Coefficient, C_f = _____

Minimum Structure Length

$$L_{min} = \Psi_{sw}/C_f$$
$$=$$
$$= _____ \text{ feet}$$

Actual structure length used, L_d = _____ feet

Worksheet 7.1. (continued).

Volume of sediment deposition

$\forall_s = 20.2\ G_d$

$=$ _____ cu.ft.

Depth of sediment deposition

$d_d = \sqrt{2\forall_s S_x / L_d}$

$=$

$=$ _____ feet

Step Four: Mean Concentration of Effluent

$C_s = 8{,}830\ (G_y - G_d)/P_e A$

$=$

$=$ _____ ppm

Step Five: Required Structure Height

If d_d is greater than 0.5 feet then add additional freeboard, d_f

$d_f = d_d - 0.5$

$=$ _____ feet

Total height

Structure Height, $H_d = \sqrt{\frac{L_{min}}{L_d}}\ d_{max} + 0.5 + d_f$

$=$

$=$ _____ feet

A = area in acres

G_y = total sediment yield in tons

Step Two: Determination of structure length.

The length of a detention or filtering structure will depend on the flow rate through the structure, the duration of runoff, and the height of the structure. The flow rates through straw bales, synthetic fabrics, and rock outlets are given in Table 7.1. The flow rate of synthetic fabrics can be determined by the Filtering Efficiency and Flow Rate Test (Test #1, developed by Virginia Highway and Research Council, 1980). These flow rates are generally not available from manufacturers. The permeability of the fabric as measured using either a fall head or constant head permeameter should not be used for flow rate.

The duration of runoff is determined by calculating the time of initial rainfall excess (see task three of step three in Chapter IV) and subtracting that time from the storm duration. The maximum depth of water which can pool behind a structure is 2.0 feet for detention structures and filter fence, 1.5 feet for brush filter barrier, and 1.0 feet for straw bale barrier.

Knowing the flow rate through the structure, the duration of runoff, and the structure height, a detention parameter, K_f, is determined from the following equation

$$K_f = 1/2\ K_a t_e d_{max} \tag{7.2}$$

where: K_a = flow rate per unit area for the structure in ft/hr

t_e = duration of runoff in hours

d_{max} = maximum allowable ponded depth in feet.

Using the detention parameter K_f and slope of the land surface above the structure, the structure length coefficient, C_f, is found using the nomograph in Figure 7.2. The minimum structure length is given by the following equation:

$$L_{min} = \frac{V_{sw}}{C_f} \tag{7.3}$$

The total amount of sediment trapped by the detention structure is given by summing the results of Equation 7.7 for each particle size. The volume of deposition is given by:

$$\forall_s = 20.2\ G_d \tag{7.8}$$

and the depth of deposition by:

$$d_d = \sqrt{\frac{2\ \forall_s\ S_x}{L_d}} \tag{7.9}$$

where: $\forall_s$ = deposited volume, cubic feet

d_d = deposition depth, feet

Step Four: Determine Settleable Solids Concentration

The concentration of settleable solids in the water leaving a detention structure is given by the following equation:

$$C_s = 8830\ \frac{(G_y - G_d)}{P_e\ A} \tag{7.10}$$

where: C_s = the mean concentration of settleable solids, ppm

G_y = actual sediment yield into the detention structure in tons

G_d = sediment trapped in the detention structure in tons

P_e = rainfall excess in inches

A = area above structure in acres

Step Five: Determination of the Required Structure Height

A detention structure should have at least 0.5 feet of freeboard above the depth of water and sediment. If the depth of sediment trapped is greater than 0.5 feet, then additional freeboard is recommended where the additional freeboard is given by:

$$d_f = d_d - 0.5 \tag{7.11}$$

where: d_f = additional freeboard in feet if the sediment deposition is greater than 0.5 feet

d_d = deposition depth, feet

The required height of the detention structure is:

$$H_d = \sqrt{\frac{L_{min}}{L_d}}\ d_{max} + 0.5 + d_f \tag{7.12}$$

Worksheet 7.1. Detention and Filtering Structures.

Step One: Volume of Water and Sediment Yield

Rainfall Excess, P_e = _____ inches

Catchment Area, A = _____ acres

Actual Sediment Yield, G_y = _____ tons

$$V_{sw} = 3{,}630\ P_e A + 20.2\ G_y$$
$$=$$
$$= _____ \text{ cu.ft.}$$

Step Two: Minimum Structure Length

Maximum Allowable Ponded Depth, d_{max} = _____ feet

Duration of runoff, t_e = _____ hours

Flow rate per unit area, K_a = _____ ft/hr

Upland slope, S_x = _____

Detention Parameter

$$K_f = 1/2\ K_a\ t_e\ d_{max}$$
$$=$$
$$= _____$$

Structure Length Coefficient, C_f = _____

Minimum Structure Length

$$L_{min} = V_{sw}/C_f$$
$$=$$
$$= _____ \text{ feet}$$

Actual structure length used, L_d = _____ feet

Worksheet 7.1. (continued).

Step Three: Sediment Trapping Efficiency

Sediment Size (mm)	Actual[1] Sediment Yield G_y (tons)	Fall[2] Velocity w(ft/sec)	Trap[3] Efficiency e_s	Sediment[4] Trapped G_d (tons)
0.010				
0.0707				
0.316				
1.414				
Total		/////////	/////////	

(1) From input data

(2) See Table 7.1 (Not needed for filter structures)

(3) For Filter Structures see Figure 7.2

For Detention Structures:

For Sand Sizes:

$e_s = 1 - 4\ (K_a/w)\ (L_f/L_d)\ S_x$

Rock outlet flow rate, K_a = _____ ft/sec

Rock outlet length, L_f = _____ feet

For the silt size:

$$C_w = \frac{2.2 \times 10^{-4}\ L_d}{K_a L_f S_x}$$

= _____

$e_s = p_s$ from Figure 6.11

(4) $G_d = e_s G_y$

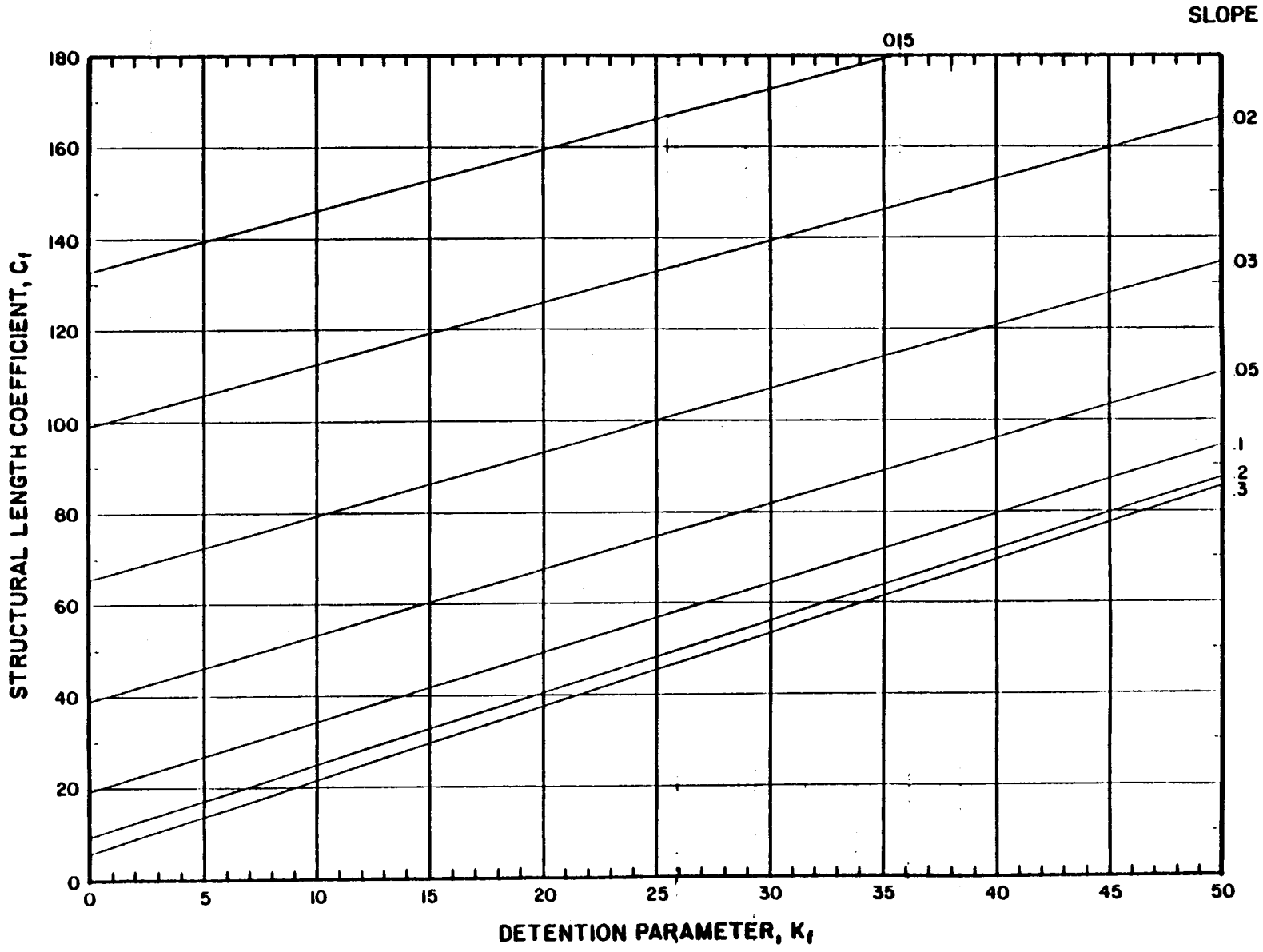


Figure 7.2. Structural length coefficient nomograph (from Simons, Li & Associates, Inc., 1982).

where: L_{min} = minimum structure length, feet

$\forall_{sw}$ = volume of sediment and water, cubic feet

C_f = structure length coefficient

If the topography of the site for the structure cannot accommodate the necessary minimum length, a new location should be selected. It is important to keep in mind that detention and filtering structures must be constructed parallel to the contours of a slope. The required structure length can be reduced by selecting a fabric with an increased unit area flow rate or by selecting a structure with increased height. The length can also be reduced by selecting a site with a flatter upland slope. The actual design length of the structure is denoted by L_d .

Permeable Rock Outlets

The flow rate through a permeable rock outlet is much greater than that for synthetic fabrics. Detention structures consist of an earth berm and a permeable rock outlet. The procedure for determining the length of a detention structure is as follows:

1. Divide the rock outlet flow rate (Table 7.1) by the estimated ratio of berm length to rock outlet length.

2. Use this flow rate to determine the detention parameter (Equation 7.2) and in determining the structure length coefficient (Figure 7.2).

3. Calculate the detention structure length using Equation 7.3. The rock outlet length can be found by dividing the structure length by the estimated ratio of berm length to rock outlet length.

The trapping efficiency of detention structures improves as the ratio of berm length to rock outlet length increases (see next step). The rock outlet length can be varied to find the most efficient outlet size for a site.

Step Three: Sediment Trapping Efficiency

Flow through a detention structure is controlled by a permeable rock outlet. The rate at which the pool drains can be controlled by varying the length of the rock outlet or the type of rock used (riprap or gravel). The faster the pool drains, the fewer fine sediment sizes will be trapped.

Trapping efficiency of a detention structure for a sand size material is given by the following equation:

$$e_s = 1 - 4 \frac{K_a}{w} \frac{L_f}{L_d} S_x \qquad (7.4)$$

where: e_s = trap efficiency for a given sediment size

K = flow rate of the rock outlet in ft/sec

w = fall velocity of the particle in ft/sec

L_f = rock outlet length, feet

L_d = structure length, feet

If e_s from Equation 7.4 is negative, then the trapping efficiency will be zero for that sediment size. Table 7.1a gives of fall velocity for each particle size and Table 7.1b flow rates for rock outlets.

For silt size sediment, the trap efficiency is based on the procedure in Chapter VI for determining silt yield from diversion structures (Step 5). This procedure is simplified for diversion structures.

First, the settling parameter is given as,

$$C_w = \frac{2.2 \times 10^{-4} L_d}{K_a L_f S_x} \qquad (7.5)$$

Second, the trap efficiency will equal the ratio of sediment settling to the volume of sediment available to settle, or

$$e_s = p_s \qquad (7.6)$$

For filtering structures, the trapping efficiency of the structure for the sand sizes equals 1.0 (100 percent) and will vary for the silt size (0.010 mm) depending on the percentage of silt in the incoming sediment yield to the filter structure. Figure 7.3 gives the trapping efficiency (for synthetic fibers and straw bales) for silt size particles as a function of the percent of silt.

The amount of sediment trapped for a particular size is:

$$G_d = e_s G_y \qquad (7.7)$$

where: G_d = amount of sediment trapped in tons

G_y = sediment yield for a particle size (sum of colums 1-4, respectively from the Step Seven worksheet, Chapter IV) in tons

Table 7.1a. Particle Fall Velocity and Rock Outlet and Structure Flow Rates.

Particle Size (mm)	Fall Velocity (ft/sec)
0.010	4.40×10^{-4}
0.0707	.0115
0.316	.129
1.414	0.391

Table 7.1b. Unit Area Flow Rates for Various Structure Types.

Synthetic Fabrics (ave) Structure Type	Flow Rate (ft/sec)	Flow Rate (ft/hr)
Rock Outlet:		
Riprap	0.061	220.0
Coarse Aggregate	0.044	158.0
Synthetic Fabrics (ave)	--	2.4
Straw Bales	--	45.0

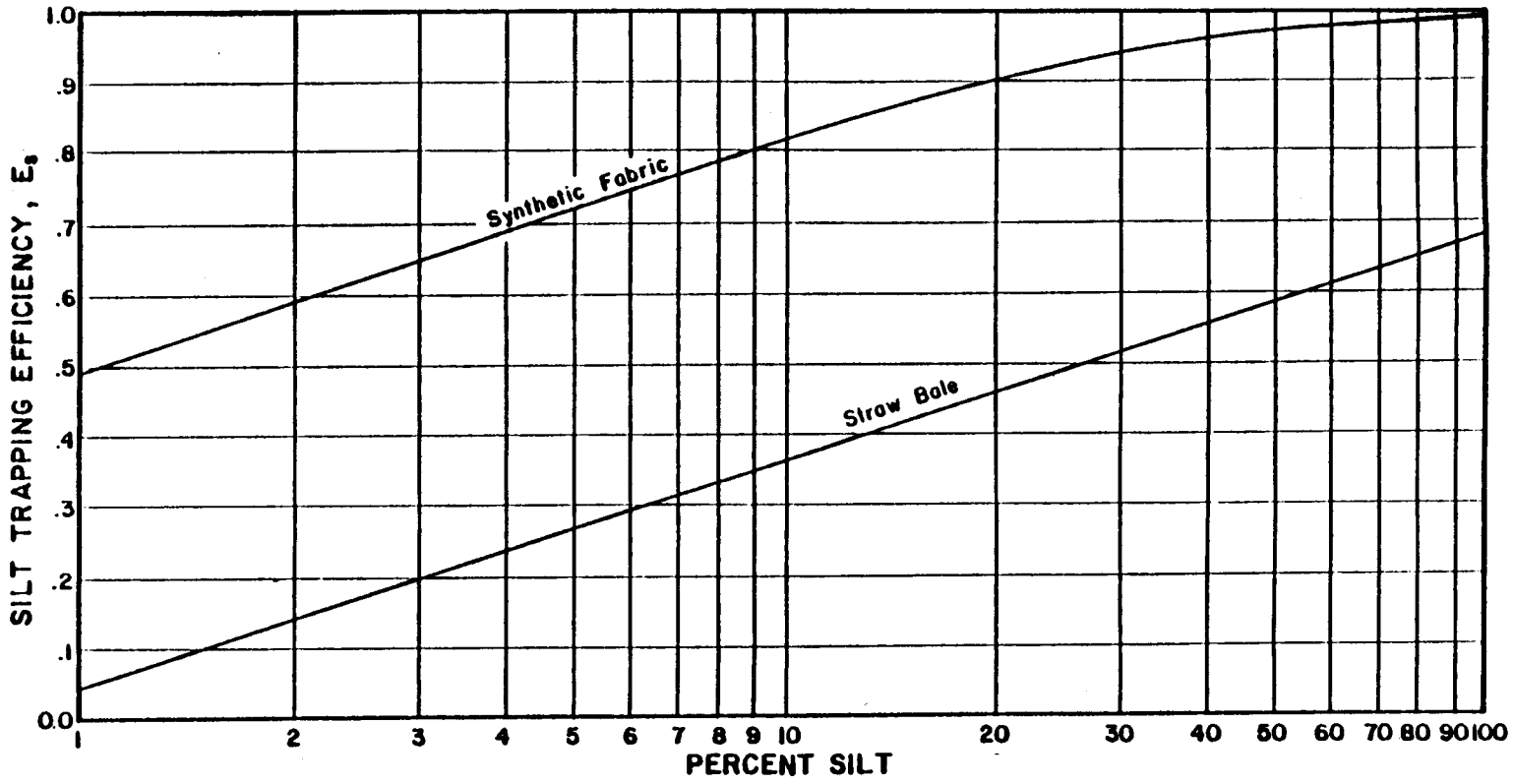


Figure 7.3. Silt trapping efficiency (from Simons, Li & Associates, Inc., 1982).

where: H_d = structure height, feet

The height of the rock outlet for the detention structure should equal the structure height without freeboard.

7.3 Design of Detention Structures

A detention structure is a temporary ridge of compacted soil located at the base of a disturbed area. It is constructed on the contour of a slope and provides a linear sediment trapping area. Water is discharged from the detention structure through a permeable rock outlet to a stabilized outlet channel. Detention structures are easily combined with diversion and conveyance structures to form a complete sediment trapping system (see Figure 7.4). These structures are designed to retain the entire storm volume which is then released slowly. Fairly long detention times can be developed in these structures which result in a high sediment trapping efficiency.

Design Information

A detention structure consists of two components: 1) a perimeter berm of compacted soil, and 2) a permeable rock outlet. General design criteria for the perimeter berm are given in Table 7.2, and Figure 7.5 shows a typical cross section of a perimeter berm. General design criteria for a permeable rock outlet are given in Table 7.3. Figure 7.6 shows a typical permeable rock outlet.

Planning Considerations

A detention structure is intended to collect sediment laden sheet flow and provide adequate sediment settling time. These structures are generally used at the base of a slope to trap sediment and protect adjacent downslope land.

If the perimeter berm is to remain in place for longer than 30 days, the berm should be stabilized with temporary or permanent vegetation. The lateral slope of the berm should be nearly zero for maximum ponding length to develop. It is desirable to maintain a slight gradient toward the rock outlet to facilitate drainage.

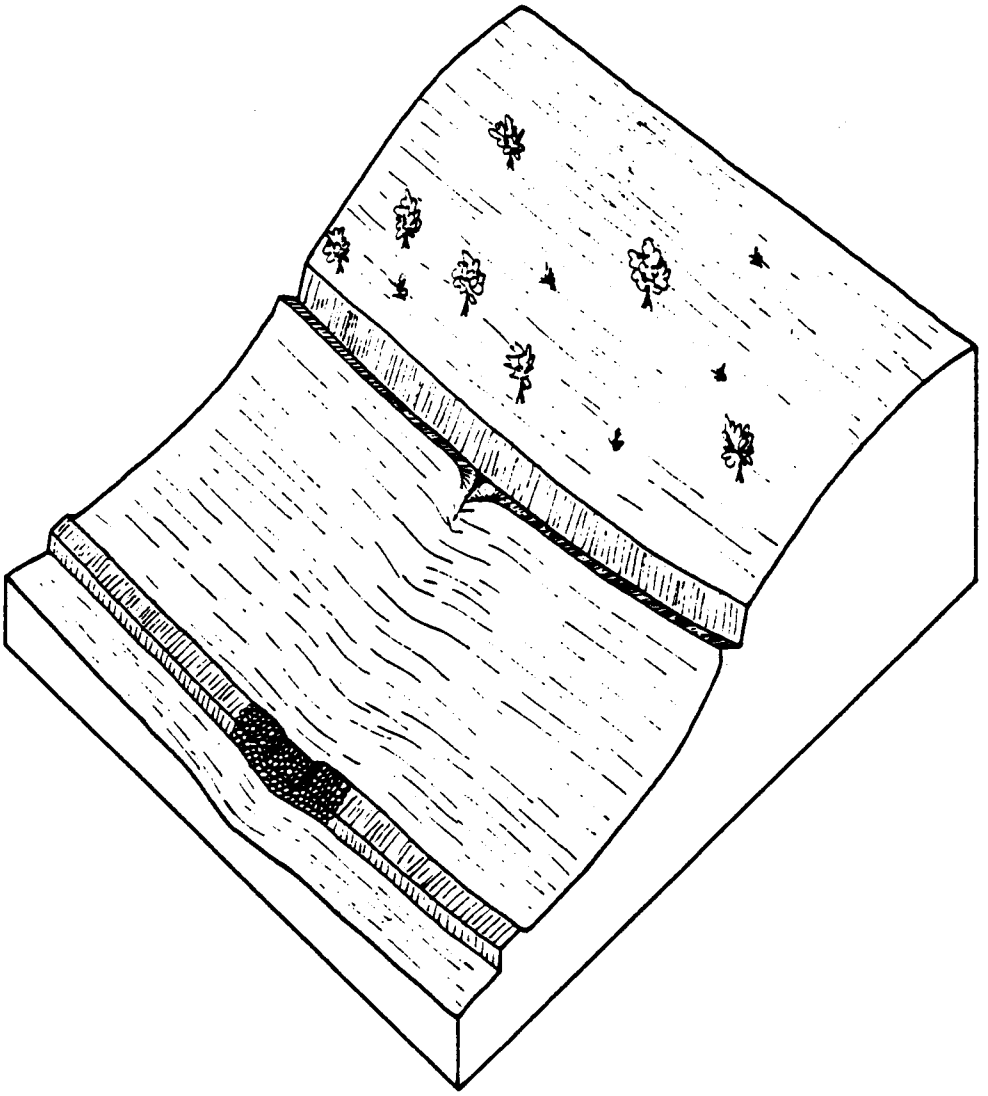


Figure 7.4. Detention berm with rock outlet.

Table 7.2. General Design Criteria for a Perimeter Berm.

Height:	1.5 feet minimum measured from upslope side of berm
Topwidth:	2.0 feet minimum
Side Slopes:	2:1 or flatter
Compaction:	Required. Compaction using the wheels or tracks of heavy equipment is adequate.
Grade:	Zero. Perimeter berm should be constructed parallel to the contour of the upland slope.

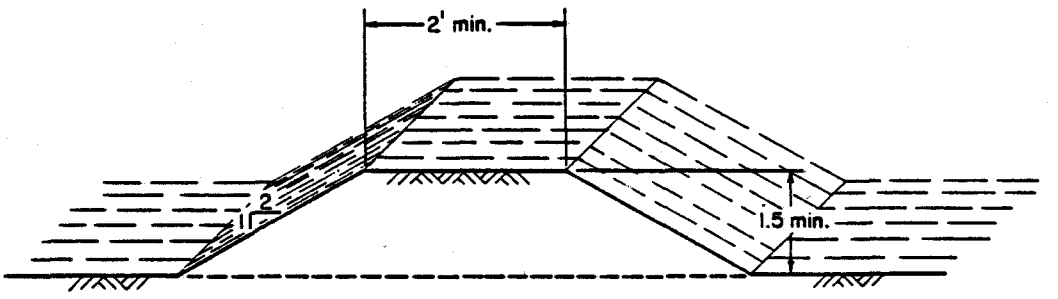
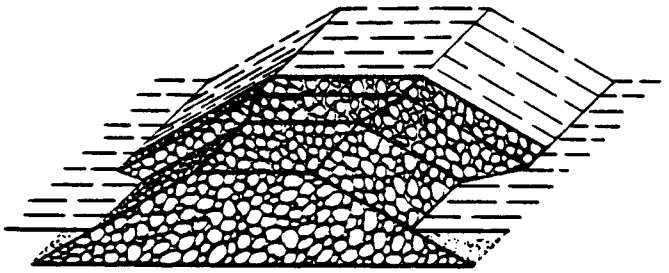


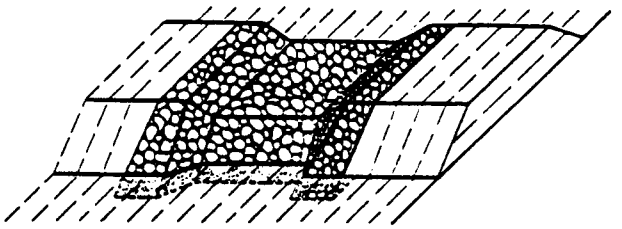
Figure 7.5. Typcial cross section of a perimeter berm.

Table 7.3. General Design Criteria for a Rock Outlet.

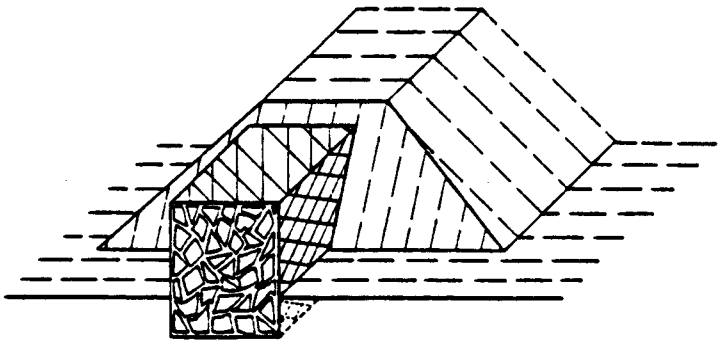
Height:	Minimum of 0.5 feet lower than the top of the perimeter berm
Topwidth:	2.0 feet minimum
Side Slopes:	2:1 or flatter
Material:	Riprap, 6 to 12 inches in diameter when high flows are possible, or crushed stone 2.0 inches or larger when only low flows are expected.



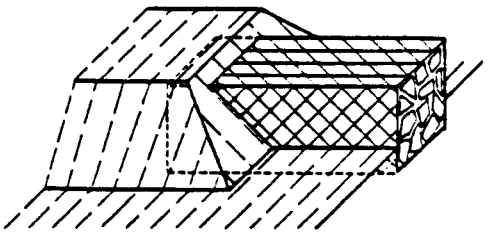
Typical riprap or gravel cross section



Riprap or gravel outlet



Typical gabion cross section



Gabion outlet

Figure 7.6. Rock outlet types.

Whenever possible, the detention structure should be built before other construction begins. The berm should be adequately compacted to prevent failure and stabilized with mulch and vegetation. The detention structure should be located in active mining areas to minimize possible damages by mining and reclamation operations. Deposited sediment should be removed from behind the structure after major storms or when one-third of the pond volume has been filled with sediment.

Rock outlets used with detention structures are permeable and should be expected to leak. They are not intended to trap sediments in the pore openings of the rock. The outflow rate can be greatly reduced by adding synthetic filter fabric over the rock (see Figure 7.7). Filter fabric will clog rapidly under these conditions and therefore must be inspected frequently and replaced when clogging is evident. Filter fabric should never be incorporated within a rock outlet since maintenance and inspection would be difficult.

In-Service Performance

Deposited sediment should be removed from behind the detention structure after major storms or when one-third of the pond volume has been filled with sediment. The detention structure should be designed with adequate room behind the structure to allow for easy access by equipment for cleaning. Detention structures should not be installed in locations where access by maintenance equipment is difficult.

When sediment is removed from a detention structure, the berm and rock outlet should be clearly marked to prevent damage to these areas by equipment. Flagged stakes should be placed along the inside edge of the berm (see Figure 7.8) so that the equipment operator can clearly gage the location of the berm and rock outlet.

If filter fabric is used in conjunction with a rock outlet, it should be replaced when sediment is removed from the pond. Filter fabric should be inspected after major storms for clogging.

Specifications

Materials used in the construction of detention structures are earth embankment, gravel, riprap, or gabions. Specifications for embankment for

berm construction and gravel for rock outlets are given in section 6.6. Specifications for riprap and gabions used for constructing rock outlets are given on the following pages.

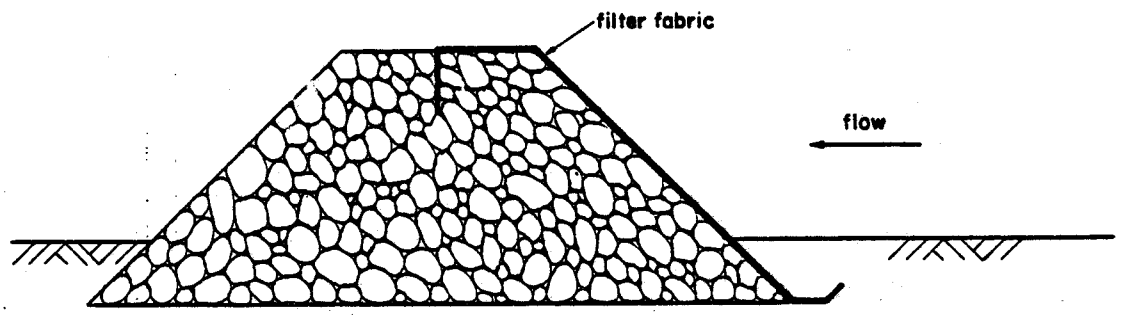


Figure 7.7. Rock outlet with filter fabric.

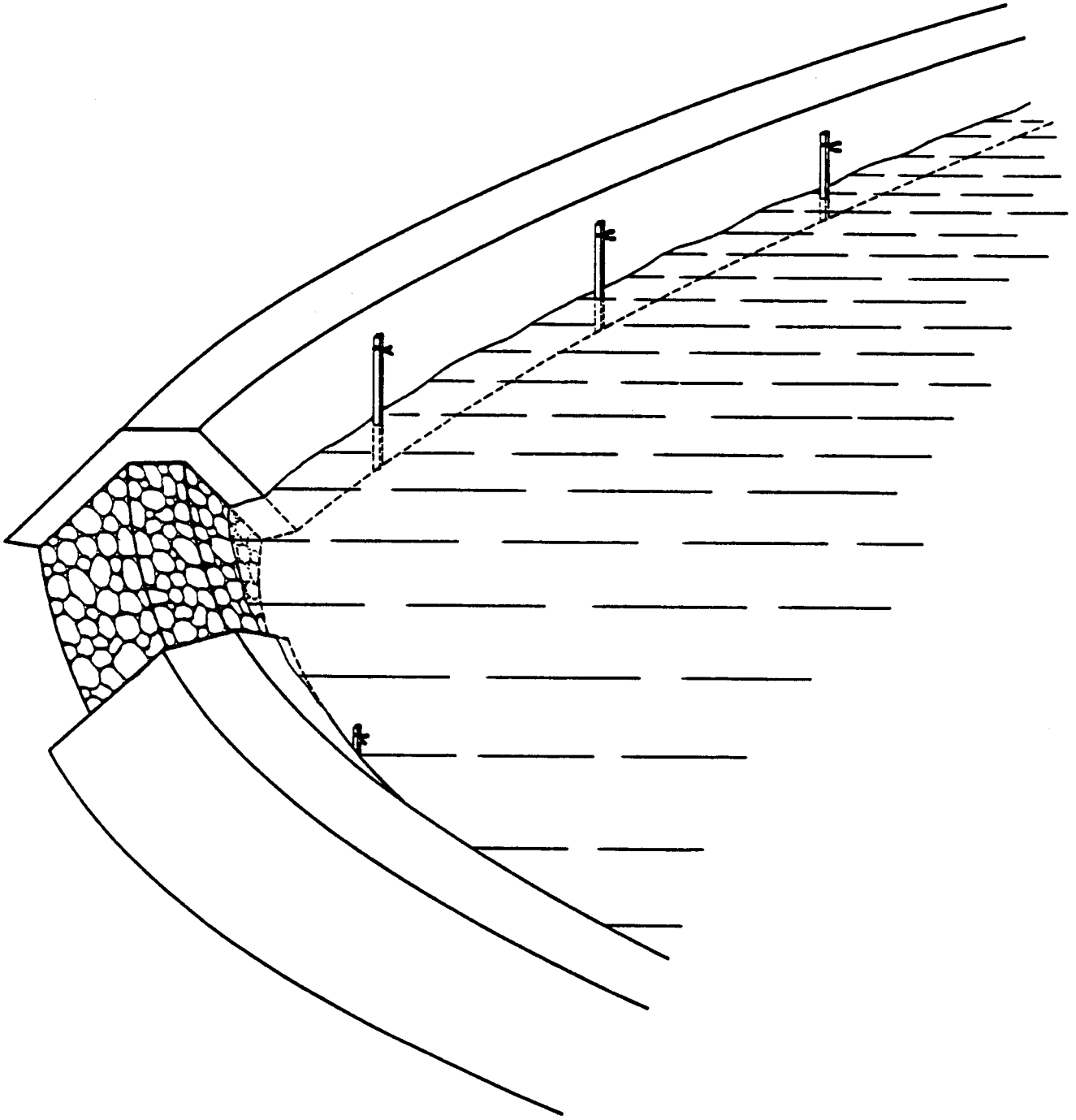


Figure 7.8. Flagging to protect berm and rock outlet during maintenance.

Specification - Riprap for Rock Outlets

Description. This work shall consist of construction of riprap in accordance with these specifications as shown on the plans or as directed.

Materials. Riprap shall consist of hard, dense, sound, rough fractured stone as nearly cubical as parcticable. Thin slab type stones and flaking rock shall not be used. The stone shall have a specific gravity of at least 2.25. Removed concrete may be used for riprap provided it meets the other requirements of this section and if approved. The size requirements for the two items of riprap are as follows:

Guide for Size Determination

Stone Size*	Volume (cu.ft.)	Weight (lbs)
6 in.	0.065	10
9 in.	0.22	30

*equivalent spherical diameter

Size of stone and arrangement of riprap shall be as shown on plans. Stone shall be well graded in order that the voids can be filled, and at least 50 percent of the mass shall be stones equal to or larger than the stone size called for on the plans. Stone size shall not be larger than twice the mean diameter of the riprap.

Construction Requirements. Riprap shall be placed to conform to the plan details. The spaces between the larger stones shall be filled with smaller stone of a suitable size. Riprap may be machine-placed with sufficient hand work to accomplish requirements of this specification.

Method of Measurement. Riprap will be measured by the cubic yard by the method of average end areas based on dimensions shown on the plans or ordered.

Basis of Payment. The accepted quantities will be paid for at the contract unit price for each of the pay items listed below that appear in the bid schedule.

Payment will be made under:

PAY ITEM	PAY UNIT
Riprap	Cubic Yard

Structure excavation will be measured and paid for separately.

Specification - Gabions

Description. This work shall consist of the construction of riprap in wire mesh gabions in accordance with these specifications as shown on the plans or directed.

Materials. Wire - All wire used in the manufacture and assembly of the mesh shall equal or exceed Federal Specification QQ-W-461G, Wire, Steel, Carbon (Round, Bare and Coated) including the following specific requirements: finish 5, class 3 weight of zinc coating. Wire mesh for Gabions (cage thickness 12 inches and greater) shall be 11 gage (U.S.), soft temper.

Tie and connecting wire shall be supplied for securely fastening all edges of the gabions and diaphrams. Gabions shall be provided with 4 cross connecting wires in each cell 1/2 unit high and 8 in each cell one unit high. Gabions shall also have inner tie wires connecting the front face to the rear face at approximate spacing of 12 inches in both vertical and horizontal dimensions. Tie wire shall meet the same specifications for wire used in the mesh except that tie wire for gabion cages shall not be more than 2 gages lighter.

All wire used, including tie and connecting wire, shall be certified by mill test report(s) showing compliance with specificatin requirements.

Riprap - Riprap shall consist of hard, dense, sound, rough fractured stone or local sandstone, as nearly cubical as practicable. Thin slab type stones and flaking rock shall not be used. Stone shall have a specific gravity of at least 2.25 and shall be resistant to the action of air and water. Flaking or fragmental rock will not be permitted.

The sizes of riprap stone for gabions and slope mattresses shall conform to the following:

	Stone Size
Gabions (cage thickness 12 inches or greater)	4 to 8 inches

Construction Requirements: Gabions shall be placed to conform with plan details. Riprap material shall be placed in close contact in the unit so that maximum fill is obtained. The units may be filled by machine with sufficient hand work to accomplish requirements of this specification.

Where the length of the unit exceeds its horizontal width, the gabion is to be equally divided by diaphragms, of the same mesh and gauge as the body, into cells whose length does not exceed the horizontal width. The unit shall

be furnished with the necessary diaphragms secured in proper position on the base section in such a manner that no additional tying at this juncture will be necessary.

All perimeter edges of gabions are to be securely bound so that the joints formed by tying have approximately the same strength as the body of the mesh.

All gabion units shall be tied together each to its neighbor along all contacting edges in order to form a continuous connecting structure.

Method of Measurement. The quantity to be measured under this item will be the number of cubic yards of riprap required to fill the gabions in accordance with the dimensions shown on plans, or as ordered, completed and accepted.

Basis of Payment. The accepted quantity measured as provided above will be paid for at the contract unit price per cubic yard for gabions.

Payment will be made under:

PAY ITEM	PAY UNIT
Gabions	Cubic yards

Structure excavation and structure backfill will be measured and paid for separately.

7.4 Design of Filter Structures

Filter structures are temporary sediment barriers consisting of synthetic filter fabric or straw bales placed along the contour of a slope. Several designs are in common use and are presented in this manual. Filter fence is a linear filter barrier constructed of synthetic filter fabric, posts and, depending on the strength of the fabric used, wire fence. Brush barrier is a linear filter barrier which makes use of residue materials available from clearing and grubbing operations covered by synthetic filter fabric. A straw bale barrier consists of a row of entrenched and anchored straw bales.

Filter structures can be easily combined with other sediment control practices to form a complete sediment control system. These structures are very effective at reducing the amount of suspended sediment from an area. Filter fabrics have a low permeability and are limited to situations where unconcentrated, overland flows are expected. Filter structures are not able to handle the volumes of water generated by channel flows.

Design Information

Improperly constructed filter structures will have poor sediment trapping efficiency and high failure rates. Undercutting and end flow are two major problems with this type of structure. Careful installation and adequate maintenance are essential to the effectiveness of these sediment filters. Improper installation can result in increased erosion and damage from sediment. In general synthetic filter structures are easier to install correctly compared to straw bale barriers and may be preferable in many cases.

Installation procedures are presented for both synthetic fabric structures (filter fence and brush filter barrier) and straw bale barriers. All installations should be carefully inspected for defects after construction.

Installation Procedure - Filter Structures

In most cases the fabric should not extend to a height greater than 36 inches; higher heights may back up volumes of water sufficient to cause failure of the structure.

The procedure for installing filter fences are given below.

1. Set wood or steel posts securely at intervals no greater than 10 feet apart. Wood posts should be at least 3 inches in diameter; with steel, only the T-shaped posts should be used.

2. Fasten fence wire securely to the upstream side of the posts. Wire should extend into the soil a minimum of 2 inches, and be a minimum of 36 inches in height.

3. Excavate a trench 6 inches wide by 6 inches deep along the upstream base of the fence.

4. Staple or wire the filter fabric to the fence, allowing the fabric to extend into the trench as shown in Figure 7.9. The fabric should not extend over 36 inches above the original ground on the wire fence.

5. Backfill and compact the soil over the fabric extending into the trench.

6. If a filter fence is to be constructed across a ditch line or drainageway of low flow, the barrier should be of sufficient length to contain the design storm volume from the upland area.

7. The fence should be constructed parallel to the contours of the slope. The ends of the fence should bend upslope a sufficient distance to eliminate end flow as shown in Figure 7.10.

The procedures for installing brush filter barriers is similar to that for filter fence and is illustrated in Figure 7.11.

Installation Procedure - Straw Bale Barrier

The installation procedures for straw bale barriers are given below and are illustrated in Figure 7.12.

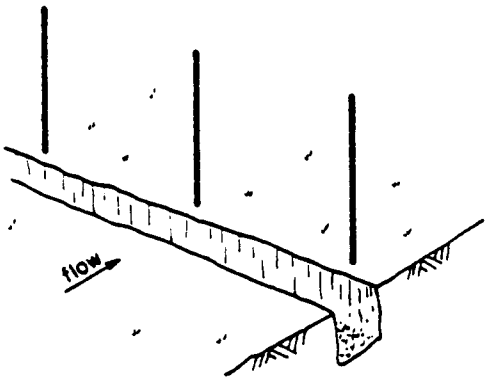
1. Excavate a trench the width of a bale and the length of the proposed barrier to a minimum depth of four inches.

2. Place bales tightly together in the trench. Drive two sturdy wooden stakes or steel rods through each bale and into the ground to a depth sufficient to securely anchor the bales.

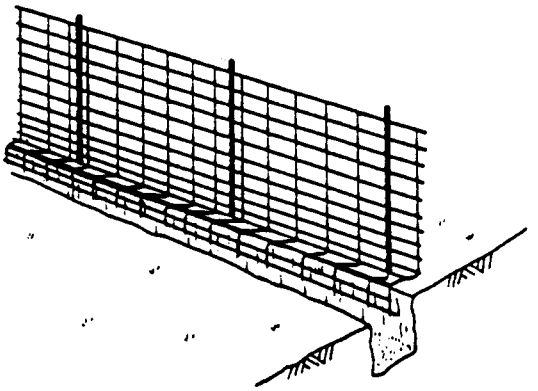
3. Wedge loose straw tightly between bales after staking.

4. Backfill and compact the excavated soil against the barrier. Backfilled soil should conform to ground level on the downstream side and should be built up to 4 inches against the upstream side of the barrier.

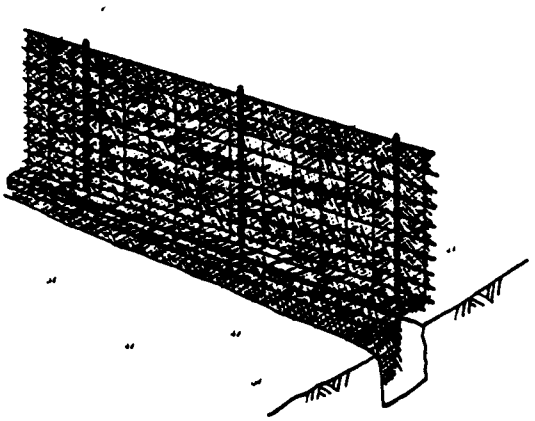
5. The straw bale barrier should be constructed parallel to the contours of the slope. The ends of the barrier should bend upslope a sufficient distance to eliminate end flow.



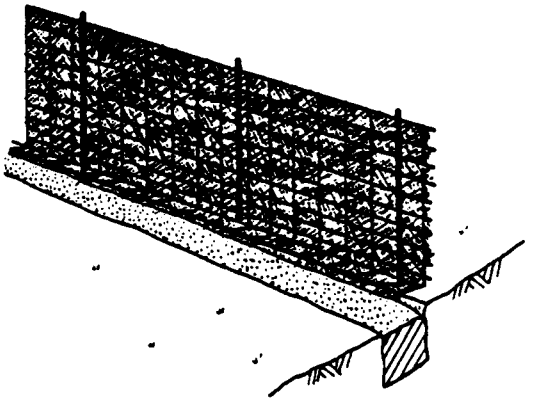
1. Set posts and excavate trench.



2. Tie wire fencing to posts



3. Attach filter fabric to wire fence, allowing extension into trench as shown.



4. Backfill and compact excavated soil.

Figure 7.9. Building a filter fence (after Virginia Soil and Water Conservation Commission, 1980).

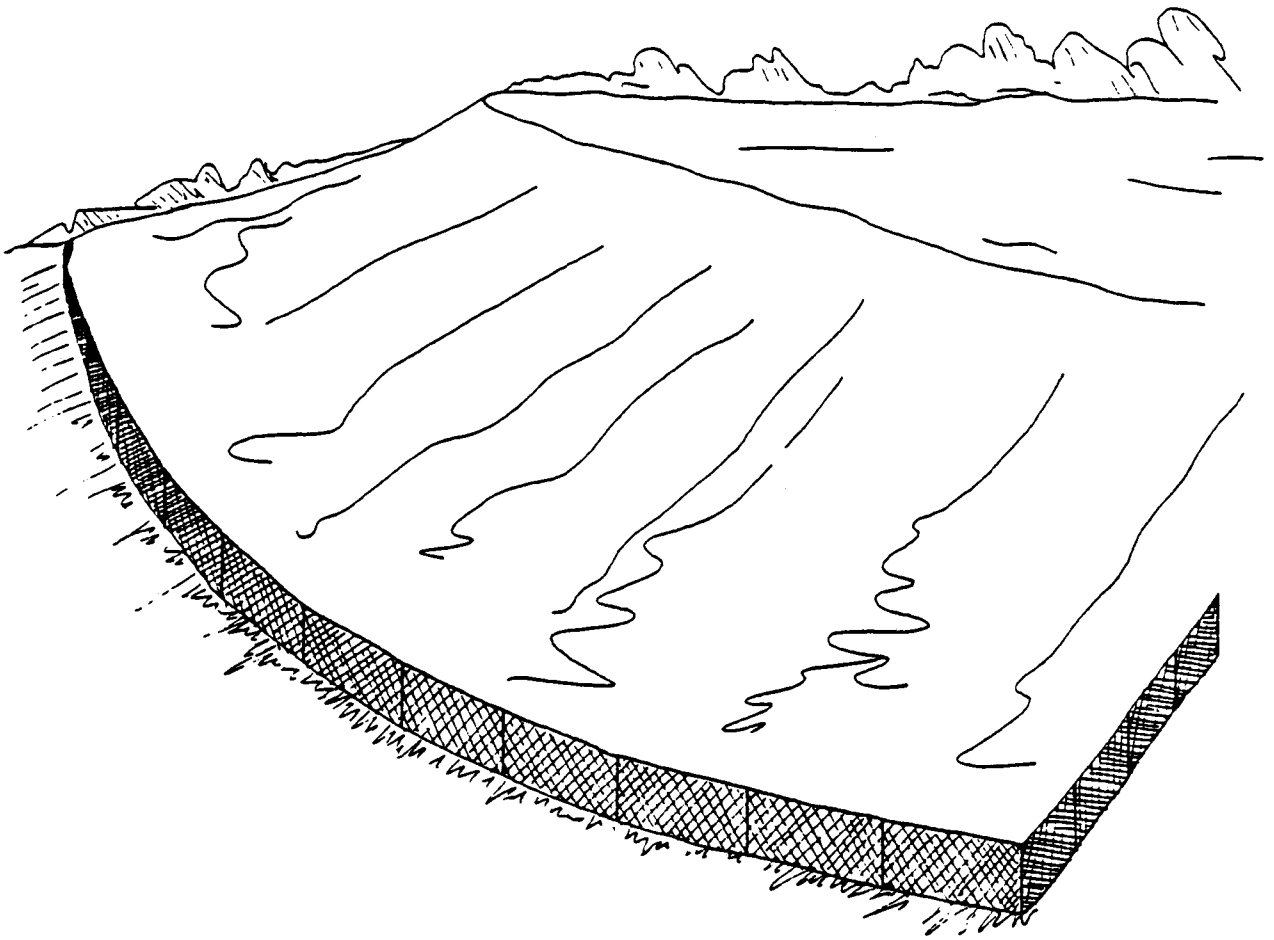
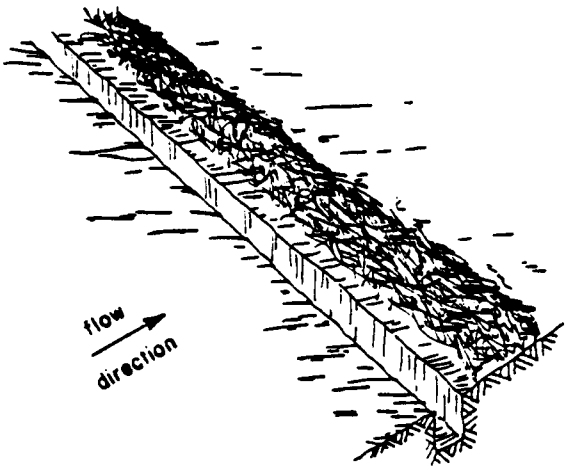
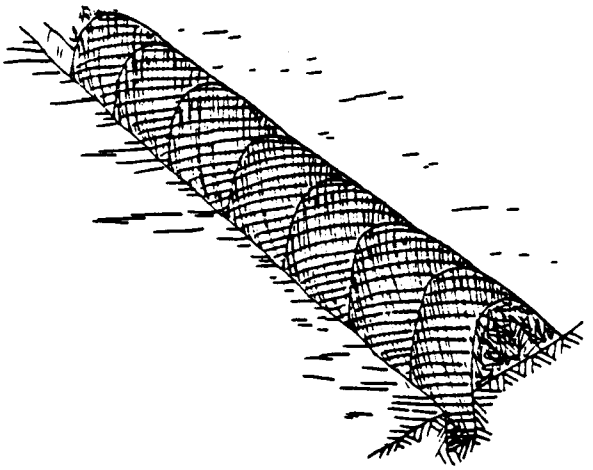


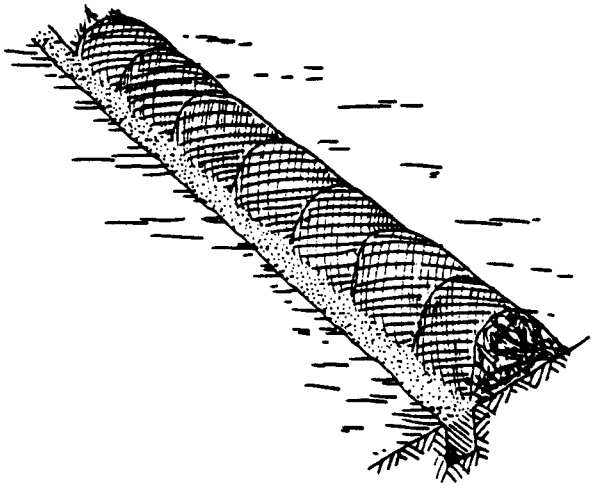
Figure 7.10. Filter fence application showing proper termination to prevent end flow.



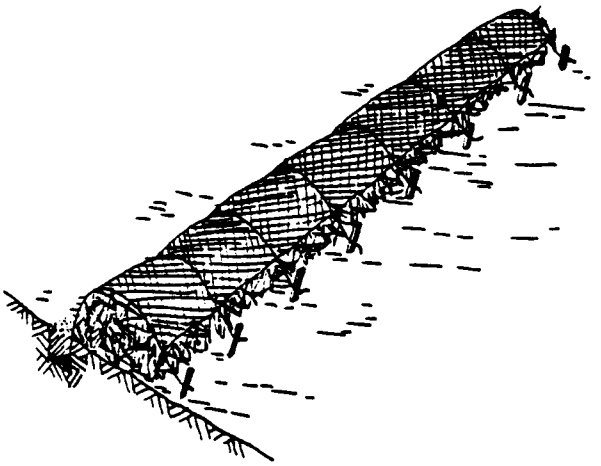
1. Excavate trench along uphill edge of brush barrier.



2. Drape filter fabric over brush barrier and into the trench.

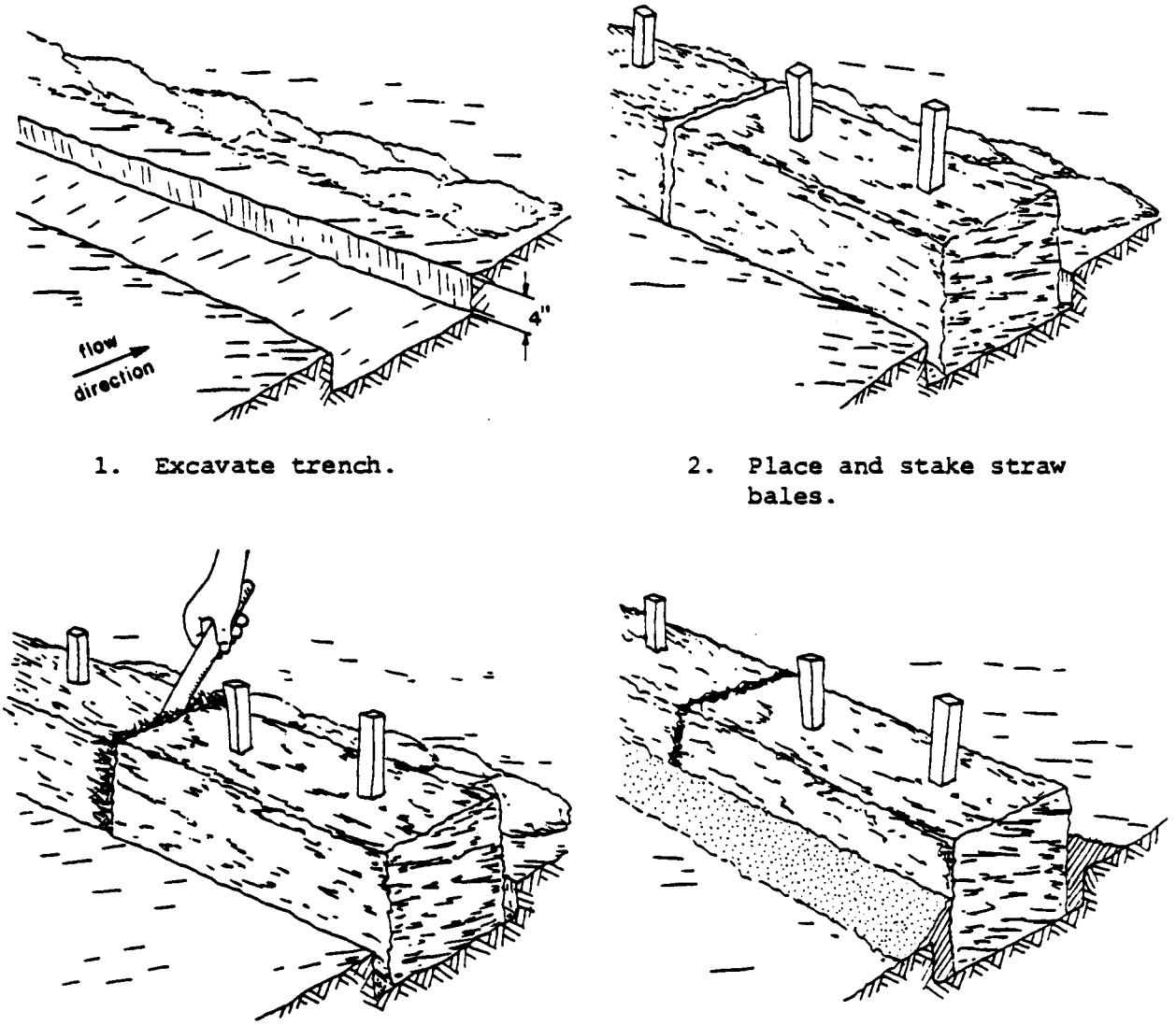


3. Backfill and compact excavated soil.



4. Set stakes and tie down filter fabric along the downhill edge of the brush barrier.

Figure 7.11. Building a brush filter barrier (after Virginia Soil and Water Conservation Commission, 1980).



1. Excavate trench.

2. Place and stake straw bales.

3. Wedge loose straw between bales.

4. Backfill and compact excavated soil.

Figure 7.12. Installation of straw barrier (after Virginia Soil and Water Conservation Commission, 1980).

Planning Considerations

The use of filter structures must be limited to situations in which only low or moderate flows are to be intercepted. Use of these structures is specifically excluded for situations in which water is to be concentrated in a channel or drainageway. Experience has shown that use of straw bales as check structures in ditches has resulted in high failure rates. Rock check structures are recommended (see Chapter VI). It must be emphasized that while these structures are efficient sediment filters, they require more inspection and maintenance than most sediment control structures.

The filtering efficiency of straw bales is lower than that for synthetic fabric (see Figure 7.3). Filter structures may be preferable to straw bales because they are capable of ponding sediment laden water to a greater depth, therefore reducing the required length of the structure. Failure rates are lower for synthetic fabric structures compared to straw bale barriers, but poorly constructed fabric structures are not uncommon. Installation procedures must be followed carefully.

In-Service Performance

Deposited sediment should be removed from behind a filter structure after major storms or when one-third of the sediment trapping volume has been reached. Filter structures should not be installed in locations where access by maintenance equipment is difficult. Filter fabric should be checked after major storms for clogging and damage. Filter fabric will deteriorate from exposure to ultraviolet radiation and should be checked at regular intervals for reduced strength or tears.

During cleaning operations, care should be taken with equipment to prevent damage to the filter structure. If damage occurs, it should be repaired promptly. Repaired sections of filter fabric should be overlapped and bonded to existing sections to prevent leakage.

Specifications

This section gives specifications for filter fabric structures. The specification for synthetic fabric requires that fabric pass two tests developed by the Virginia Department of Transportation to determine filtering efficiency, flow rate, and strength. Since these are nonstandard tests, the procedures for conducting the test are given. Manufacturers are currently aware

of these tests and some give the results in their published performance data or will comply with requests for this information.

No detailed specification is given for straw bales since these may vary with the type of machinery and straw used to form the bale. General guides to selecting a durable straw bale are: 1) the bale should be wire-bound around the sides, and 2) old or water logged bales should be avoided. Straw bales should be secured with wooden stakes (2 inches x 2 inches minimum) or rebar.

Specification - Filter Fence and Brush Filter Barrier

Description. This work shall consist of furnishing and installing filter fences and brush filter barriers in accordance with this provision and in reasonably close conformity with the lines, grades and details shown on the plans or established by the Engineer.

Materials. Filter cloth fabric shall be a pervious sheet of propylene, nylon, ester or ethylene yarn and shall be certified by the manufacturer or supplier as conforming to the following requirements:

PHYSICAL PROPERTY	TEST	REQUIREMENTS
Filtering Efficiency	Test 1	90% (Min.)
Flow Rate	Test 1	0.3 Gal./Sq.Ft./Min. (Min.)
*Tensile Strength @ 20% (Max.) Elongation	Test 2	Extra Strength 50 Lbs. per Linear Inch (Min.) Standard Strength 30 Lbs. per Linear Inch (Min.)

*Requirements reduced by 50% after 6 months of installation.

Filter cloth fabric for above ground use shall contain ultraviolet ray inhibitors and stabilizers to provide a minimum of 6 months of expected usable construction life at a temperature range of 0°F to 120°F.

Posts for filter fence shall be rough or finish 4 inches by 4 inches wood, 3 inches (minimum) diameter wood, or 1.33 pounds per linear foot (minimum) steel with a minimum length of 5 feet.

Wire fence reinforcement for filter fence using standard strength filter cloth fabric shall be a minimum of 36 inches in height, a minimum of 14-1/2 gage and shall have a mesh spacing of 6 inches or less.

Construction Requirements. Filter Fence shall be erected at locations shown on the plans or as approved or determined by the Engineer. The Contractor shall have the option to provide extra strength filter cloth fabric or to provide standard strength filter cloth fabric with a wire fence reinforcement. When standard strength filter cloth fabric is used for filter fence, the filter cloth fabric shall be reinforced with wire fence, and the post spacings shall not exceed 10 feet. When extra strength filter cloth fabric is

used for filter fence, the post spacings shall not exceed 6 feet and the wire fence will not be required. Posts shall be uniformly installed with not less than 2° and not more than 20° inclination toward the potential silt load area. The attachment of fence fabric to existing trees will not be permitted unless approved by the Engineer. The filter fence shall be maintained in an effective condition at all times while in use.

Filter cloth fabric shall be a minimum of 45 inches wide and shall be secured to the post or fence by suitable staples, tie wire or hog rings in such a manner as to prevent tearing of the fabric. The bottom of the filter cloth shall be entrenched into the ground a minimum of 8 inches to prevent water from flowing under the fence. Filter cloth fabric shall be spliced together only at support posts with a minimum of 6 inch overlap and securely sealed. The top of the filter cloth fabric shall be installed with a 1 inch tuck or with a reinforced to end section.

In the event the filter cloth fabric has decomposed or becomes ineffective prior to 6 months after installation, the filter cloth fabric shall be replaced at the Contractor's expense to original design. In the event the filter cloth fabric has decomposed after 6 months from the installation date and the filter fence is still required as determined by the Engineer, the filter cloth fabric shall be replaced with equal material and will be paid for at one-half the contract unit price for the filter fence. Filter fence materials shall be removed when no longer required, as determined by the Engineer, and shall be disposed of by the Contractor.

Brush Filter Barriers: Brush barriers used along the down hill side of slopes shall have standard strength filter cloth fabric attached at specified locations to form a brush filter barrier. The bottom of the filter cloth shall be entrenched into the ground a minimum of 8 inches and the top of the filter cloth shall be installed with a 1 inch tuck or with a reinforced top end section.

Brush for brush filter barriers shall be installed prior to any major earth-disturbing activity and shall be trimmed sufficiently to prevent tearing or puncturing of the filter cloth. The top of the filter cloth shall be tied, stapled or otherwise secured to the top or slope of brush barrier such that the integrity of the silt barrier will be sound. Intermediate attachment of the filter cloth shall be with suitable ties or staples. A 6 inch overlap of

cloth for vertical and horizontal splicing shall be maintained and tightly sealed.

The filter cloth fabric shall be maintained in accordance with the requirements for filter fence. When brush filter barriers are no longer required, as determined by the Engineer, the fabric shall be cut at ground height and disposed of by the Contractor.

Inspection and Maintenance: All filter fences and brush filter barriers shall be inspected immediately after each rainfall and at least daily during prolonged rainfall. Any deficiencies shall be immediately corrected. In addition, a daily review of the location for filter fences and brush filter barriers shall be made in areas where construction activity changes the earth contour and drainage runoff to ensure that the filter fences or brush filter barriers are properly located for effectiveness. Where deficiencies exist, additional filter fences or brush filter barriers shall be installed as approved or directed by the Engineer.

Sediment deposits shall be removed when the deposit reaches approximately one-third of the volume capacity of the filter fence or brush filter barrier as approved or directed by the Engineer and disposed of as directed by the Engineer. Any sediment deposits remaining in place after the temporary filter fence or brush filter barrier is no longer required shall be dressed to conform with the existing grade, prepared and seeded.

Method of Measurement. Filter fences will be measured in linear feet, complete-in-place. When the filter cloth fabric is required to be replaced after 6 months from the installation date, the replacement filter cloth fabric will be measured in linear feet of filter fence and paid for at one-half the contract unit price for filter fence.

Brush filter barriers will be measured in square yards of filter cloth complete-in-place, excluding laps. The brush filter barrier will not be measured for payment under this provision, but will be paid for separately.

Basis of Payment. The accepted quantity measured as provided above will be paid for at the contract unit price.

Payment will be made under:

PAY ITEM	PAY UNIT
Filter Fence	Linear foot
Brush Filter Barrier	Square yard

When silt cleanout is approved or directed by the Engineer, silt removal will be measured in cubic yards of vehicular measurement of haul and paid for separately.

Seeding materials will be measured and paid for separately.

TEST 1 - FILTERING EFFICIENCY AND FLOW RATE TEST

LABORATORY

1. Scope

This method is used to determine the filtering efficiency and flow rate of a filter fabric in the laboratory.

2. Apparatus

a. A flume 48 inches long by 32 inches wide by 12 inches high with a gutter attached to one side (see Figures 7.13 and 7.14).

b. Two 20-gallon containers.

c. A stirrer on a 1/4 inch portable drill.

d. Stopwatch.

e. A DH-48 integrated water sampler with ten 500 ml bottles.

3. Procedure

a. Stretch a sample of the fabric 39 inches long by 12 inches wide across the flume opening 32 inches wide and fasten securely in place to assure that all the sediment-laden water passes through the sample. Note: The flume opening is the standard length of a straw bale.

b. Elevate the flume to an 8 percent slope.

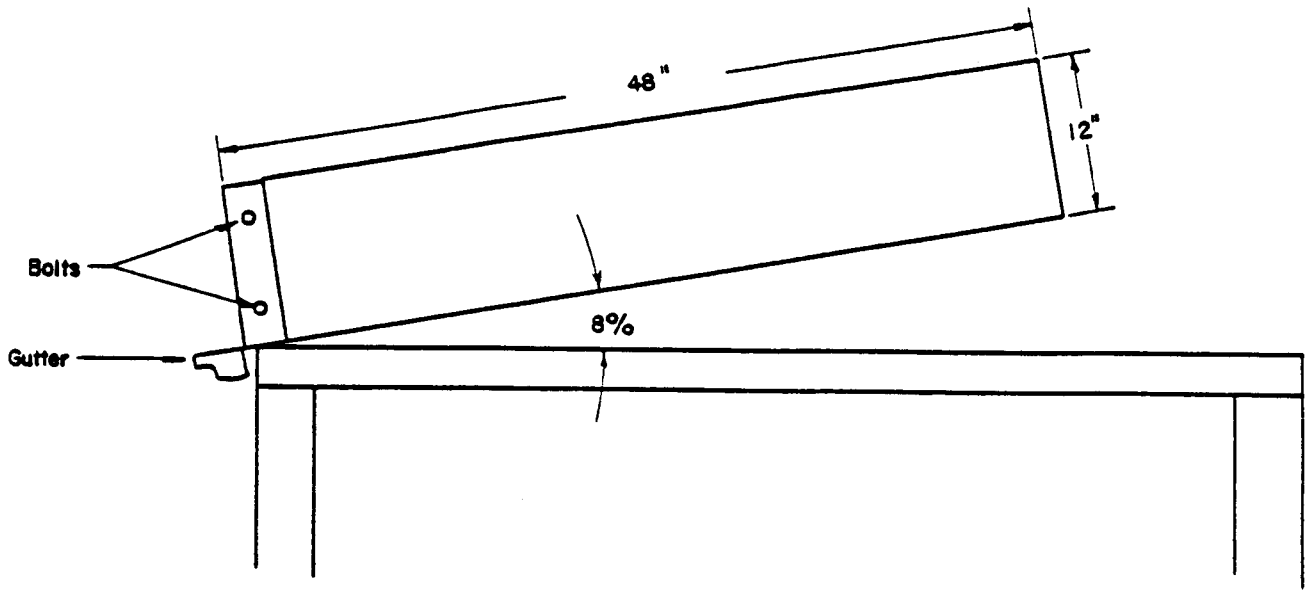
c. Take a depth integrated, suspended solids sample from an untreated, fairly sediment-free water supply. Continuously agitate the supply for uniformity during the sampling process.

d. Prewet the fabric by passing 50 litres of untreated, fairly sediment-free water through it.

e. Mix 150 grams of minus 10 material of a silty soil (see gradation curve, Figure 7.15) in 50 litres of the untreated water placed in one of the 20-gallon containers. Thoroughly agitate the solution with the stirrer on the 1/4 inche portable drill to obtain a uniform mix.

f. After uniformly mixing the solution, quickly dump the solution behind the fabric sample in the flume. Start the timer at dumping.

g. Rinse the mixing container with 1 to 2 litres of the filtrate and dump into the flume.



Note: All dimensions are inside measurements.

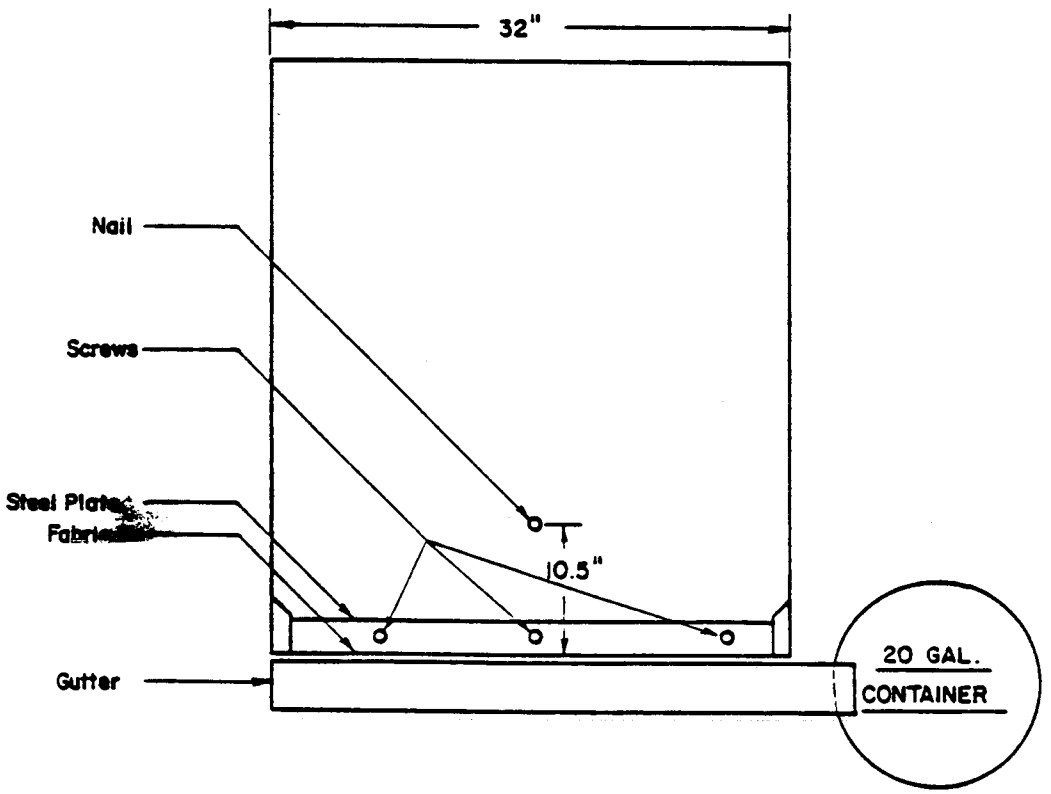
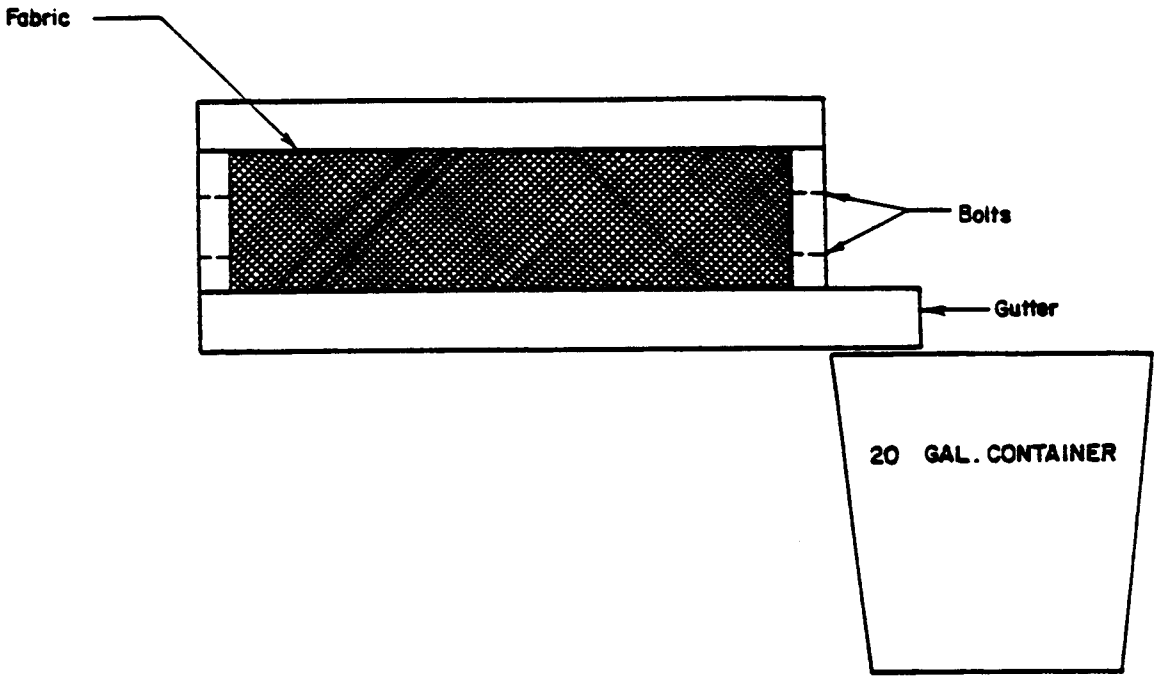


Figure 7.13. Side view (upper sketch) and top view of flume (after Virginia Soil and Water Conservation Commission, 1980).



Note: 2 Side plates and a bottom plate are used to fasten the sample of fabric in place.

Figure 7.14. End view of flume (after Virginia Soil and Water Conservation Commission, 1980).

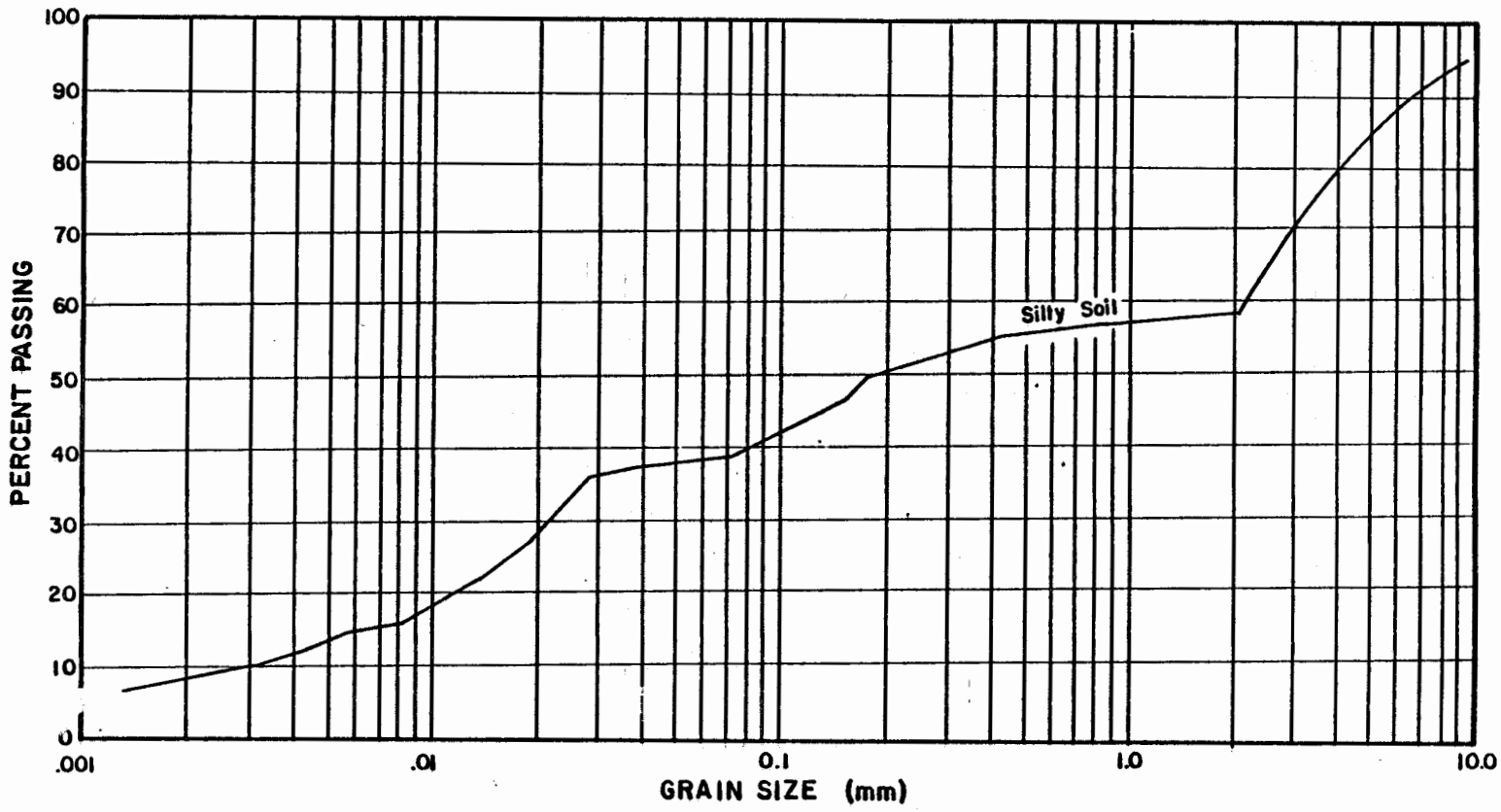


Figure 7.15. Gradation curve for soil used (after Virginia Soil and Water Conservation Commission, 1980).

h. Time the flow of water through the fabric until the water level drops to a point 10.5 inches behind the fabric. At this point the flow has essentially ceased.

i. Collect all filtrate in a second mixing container.

j. At the completion of the test, agitate the collected filtrate until the mixture is uniformly mixed. Obtain a depth integrated, suspended solids sample from the mixture during agitation.

k. Process the two suspended solids samples by the "nonfilterable residue" procedure described by the American Public Health Association, et al. (1981.

l. Calculate the filtering efficiency (FE) of the fabric as follows:

$$FE\ (\%) = \frac{(SS_{bg} + 3{,}000) - SS_{after}}{(SS_{bg} + 3{,}000)} \times 100,$$

where SS_{after} and SS_{bg} are the suspended solids value after filtration and the background level, respectively.

m. Calculate the flow rate of the fabric as follows:

$$\text{Flow rate (gal./ft.}^2\text{/min)} = 14.85/\text{time (min.)}$$

n. Repeat steps e through l for the same fabric sample twice more.

TEST 2 - STRENGTH TEST

1. Scope

This test determines the stress-strain relationship of a filter fabric.

2. Apparatus

A tensile test device with a capacity of approximately 2,500 lb. equipped with a dial that can be read in increments of 10 lb. or less. The device should have a rate of travel of 13 percent ± 2 percent of the gage length of the fabric per minute. The device shall have a travel distance of 20 inches minimum and hold a 7 inch wide sample.

3. Procedure

a. Cut a sample of the fabric in the direction perpendicular to the axis of the roll. The sample should be 27 inches long by 7 inches wide.

b. Securely fasten the sample of the fabric in the clamps of the testing device so the length of the fabric between the clamps is 14 inches.

c. Place the secured sample in the testing device.

d. Start the testing device and stopwatch simultaneously.

e. Take load and elongation readings every 15 seconds up to 2-1/2 minutes, or until failure has occurred, whichever comes first.

f. Plot the load on the vertical axis versus its corresponding elongation on the horizontal axis.

g. Determine the peak load value, if it occurs prior to 20 percent or 2.8 inches elongation. If the peak load does not occur before 20 percent elongation, then record the load at 20 percent elongation.

h. Repeat steps a through g for a sample cut in the direction perpendicular to the axis of the roll with a 1/2 inch long tear crossways in the middle of the sample.

i. Repeat steps a through g for a sample cut in the direction parallel to the axis of the roll.

7.5 Example Problems

Example Problem 7.1

Design a detention structure to control the sediment yield from the mechanically treated slope given in Example Problem 5.7. The topography of the area will allow a maximum detention structure length of 660 feet. The slope of the area immediately uphill of the planned structure location is 0.030. A ratio of berm length to rock outlet length of 100 will be used for a riprap rock outlet. All computations for this example problem are carried out on the attached worksheet.

Example Problem 7.1. Worksheet - Detention Structure.

Step One: Volume of Water and Sediment Yield

Rainfall Excess, P_e = 2.12 inches

Catchment Area, A = 10 acres

Actual Sediment Yield, G_y = 37.1 tons

$$\forall_{sw} = 3{,}630\ P_e A + 20.2\ G_y$$
$$= 3{,}630(2.12)(10) + 20.2(37.1)$$
$$= 77{,}705 \text{ cu.ft.}$$

Step Two: Minimum Structure Length

Maximum Allowable Ponded Depth, d_{max} = 2.0 feet

Duration of runoff, t_c = 17.0 hours

Flow rate per unit area, K_a = 2.20 ft/hr

Upland slope, S_x = 0.03

Detention Parameter

$$K_f = 1/2\ K_a\ t_e\ d_{max}$$
$$= 1/2(2.2)(17.0)(2.0)$$
$$= 37.4$$

Structure Length Coefficient, C_f = 118

Minimum Structure Length

$$L_{min} = \forall_{sw}/C_f$$
$$= 77{,}705/118$$
$$= 659 \text{ feet}$$

Actual structure length used, L_d = 660 feet

Example Problem 7.1. (continued)

Step Three: Sediment Trapping Efficiency

Sediment Size (mm)	Actual[1] Sediment Yield G_y (tons)	Fall[2] Velocity w(ft/sec)	Trap[3] Efficiency e_s	Sediment[4] Trapped G_d (tons)
0.010	35.6	0.000227	0.75	26.7
0.0707	1.5	0.0115	0.99	1.5
0.316	0.0	0.129	1.00	0.0
1.414	0.0	0.391	1.00	0.0
Total	37.1	/////////	/////////	28.2

(1) From input data

(2) See Table 7.1 (Note needed for filter structures)

(3) For Filter Structures see Figure 7.2

For Detention Structures:

For Sand Sizes:

$e_s = 1 - 4\ (K_a/w)\ (L_f/L_d)\ S_x$

Rock outlet flow rate, K_a = 0.061 ft/sec

Rock outlet length, L_f = 6.6 feet

For the silt size:

$$C_w = \frac{2.2 \times 10^{-4}\ L_d}{K_a L_f S_x}$$

$$= \underline{\quad 12.0 \quad}$$

$e_s = P_s$ from Figure 6.11

(4) $G_d = e_s G_y$

Example Problem 7.1. (continued)

Volume of sediment deposition

$$\forall_s = 20.2\ G_d$$

$$= \underline{\quad 570 \quad} \text{ cu.ft.}$$

Depth of sediment deposition

$$d_d = \sqrt{2\forall_s S_x / L_d}$$

$$= \sqrt{2(570)(0.03)/660}$$

$$= \underline{0.228} \text{ feet}$$

Step Four: Mean Concentration of Effluent

$$C_s = 8{,}830\ (G_y - G_d)/P_e A$$

$$= 8{,}830(37.1 - 28.2)/(2.12)(10)$$

$$= \underline{3{,}560} \text{ ppm}$$

Step Five: Required Structure Height

If d_d is greater than 0.5 feet then add additional freeboard, d_f

$$d_f = d_d - 0.5$$

$$= \underline{\quad 0.0 \quad} \text{ feet}$$

Total height

$$H_d = d_{sw} + 0.5 + d_f$$

$$H_d = \sqrt{\frac{L_{min}}{L_d}}\, d_{max} + 0.5 + d_f$$

$$= 2.0 + 0.5 + 0.0$$

$$= \underline{2.5} \text{ feet}$$

Example Problem 7.2

Design a filter fence structure to control sediment yield from the mechanically treated slope given in Example Problem 5.1. The topography of the area will allow a maximum filter fence length of 660 feet. The slope of the area immediately uphill of the planned structure location is 0.03. Computations for this example are given on the attached worksheet.

Example Problem 7.2. Detention and Filtering Structures.

Step One: Volume of Water and Sediment Yield

Total Rainfall Excess, P_e = 2.12 inches

Catchment Area, A = 10 acres

Total Sediment Yield, G_y = 37.1 tons

$$\forall_{sw} = 3{,}630\ P_e A + 20.2\ G_y$$
$$= 3{,}630(2.12)(10) + 20.2(37.1)$$
$$= 77{,}705 \text{ cu.ft.}$$

Step Two: Minimum Structure Length

Maximum Allowable Ponded Depth, d_{max} = 2.0 feet

Duration of runoff, t_c = 17.0 hours

Flow rate per unit area, K_a = 2.4 ft/hr

Upland slope, S_x = 0.03

Detention Parameter

$$K_f = 1/2\ K_a\ t_c\ d_{max}$$
$$= 1/2(2.4)(17.0)(2.0)$$
$$= 40.8$$

Structure Length Coefficient, C_f = 122

Minimum Structure Length

$$L_{min} = \forall_{sw}/C_f$$
$$= 77{,}705/122$$
$$= 636 \text{ feet}$$

Actual structure length used, L_d = 660 feet

Example Problem 7.2. (continued).

Step Three: Sediment Trapping Efficiency

Sediment Size (mm)	Actual[1] Sediment Yield G_y (tons)	Fall[2] Velocity w(ft/sec)	Trap[3] Efficiency e_s	Sediment[4] Trapped G_d (tons)
0.010	35.6	---	0.98	34.9
0.0707	1.5	---	1.00	1.5
0.316	0.0	---	1.00	0.0
1.414	0.0	---	1.00	0.0
Total	37.1	/////////	/////////	36.4

(1) From input data

(2) See Table 7.1 (Note needed for filter structures)

(3) For Filter Structures see Figure 7.2

For Detention Structures:

For Sand Sizes:

$e_s = 1 - 4\ (K_a/w)\ (L_f/L_d)\ S_x$

Rock outlet flow rate, K_a = ___---___ ft/sec

Rock outlet length, L_f = ___---___ feet

For the silt size:

$$C_w = \frac{2.2 \times 10^{-4}\ L_d}{K_a L_f S_x}$$

= ___---___

$e_s = P_s$ from Figure 6.11

(4) $G_d = e_s G_y$

Example Problem 7.2. (continued).

Volume of sediment deposition

$$V_s = 20.2\ G_d$$

Depth of sediment deposition

$$d_d = \sqrt{2V_s S_x / L_d}$$

$$= \sqrt{2(570)(0.03)/660}$$

$$= \underline{0.18} \text{ feet}$$

<u>Step Four: Mean Concentration of Effluent</u>

$$C_s = 8{,}830\ (G_y - G_d)/P_e A$$

$$= 8{,}830(37.1 - 36.4)/(2.12)(10)$$

$$= \underline{292} \text{ ppm}$$

<u>Step Five: Required Structure Height</u>

If d_d is greater than 0.5 feet then add additional freeboard, d_f

$$d_f = d_d - 0.5$$

$$= \underline{0.0} \text{ feet}$$

Total height

$$H_d = \sqrt{\frac{L_{min}}{L_d}}\ d_{max} + 0.5 + d_f$$

$$= \sqrt{\frac{636}{660}}\ (2.0) + 0.5$$

$$= \underline{2.46} \text{ feet}$$

Discussion of Example Problem Results

The sediment yield for the two previous problems was primarily in the silt size range. The gravel rock outlet reduces outflow from the detention structure and provides a silt detention efficiency of 24 percent. The filter fence traps silt in the pore openings of the fabric and provides a 62 percent filter efficiency. The five-foot long gravel rock outlet used in Problem 7.1 is the smallest size outlet structure which could be realistically constructed and properly maintained.

In general, the cost of a detention structure will be less than that of a filter structure since materials for construction are readily available. Sediment trapping efficiency of filter structures, however, is much higher.

7.6 References

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VIII. OVERVIEW OF SEDIMENT CONTROL STRUCTURES FOR SMALL AREA DISTURBANCES

8.1 General

Control of sediment yield using small structures and treatments is limited by two key factors: (1) the ability to handle incoming runoff without sustaining damage, and (2) adequate performance to reduce sediment and meet the design objective. The first criterion is a function of the type of structure or treatment selected for use. The design procedures in this manual allow for a significant factor of safety to avoid damage to a structure or to the integrity of an erosion control treatment. However, there is no specific limit on the catchment area which can be treated with structures and treatments. As the size of the catchment area increases, small structures will not be capable of controlling the volume of water and sediment which will reach them. Also, as the size of the catchment increases, the amount of sediment yielded will increase. The problem is compounded for catchments with steep slopes because the sediment yield increases rapidly, and it becomes difficult to find adequate locations for the sediment control structures. Likewise, treatments, e.g. mulches and mechanical treatments, can be damaged by large volumes of runoff from large drainage areas. As runoff is concentrated, rilling and gullying develop on the slopes and alter the coherence and form of these treatments, thereby greatly reducing their efficiency. Damage by rilling will be limited, however, if sediment yield objectives can be met and if adequate maintenance is provided. Maintenance is essential for the effective performance of all structures and treatments.

The second criteria is that the performance of the structure be adequate to meet the design water quality object. Typical design objectives are as follows:

- The sediment concentration (usually in ppm or mg/l) is set below a given level for a storm of a specified return period (e.g., 10-year, 24-hour precipitation event).

- The expected sediment yield (usually in tons per acre) on a yearly basis is set below a given level.

The previous design chapters have shown how to calculate the sediment concentration for an individual storm event. This chapter will also give a procedure for estimating the mean annual sediment yield. Meeting the design water quality objective will require a design process which entails,

1) selecting structures or combinations of structures which seem likely alternatives for further analysis based on conditions present in the catchment, 2) analyzing each alternative to determine whether or not it is capable of meeting the design objective, 3) assessing the cost, and maintenance requirements for the alternatives which meet the design objective, and 4) selection of the best alternative.

8.2 Guide to Selecting Erosion Control Structures

The first step in the design process is to select structures which are suitable for the site. Four groups of erosion and sediment control structures have been identified in this manual. Each group produces a different effect since they control different physical processes. Figure 8.1 compares how typical structures from each group would respond to changes in slope and silt content for a site. Surface protection measures are effective for large areas with mild slopes and low silt content in the soil. Mechanical treatment measures perform in a similar fashion but for smaller areas. (Diversion and conveyance systems are relatively ineffective.) When used alone on an area, this type of design is usually used in combination with other treatment measures (see section 8.4). Detention and filtering structures are very effective for moderate sized areas. They are relatively insensitive to the amount of silt in the soil and to the slope of the area. The height of these structures is limited to two feet which restricts the size of the area which can drain to the structure. Heights of more than two feet could be used but a detailed structural design would be required.

Table 8.1 provides a ranking of structures and treatments for individual groups based on the maximum area for the structure, cost and maintenance requirements. A qualitative selection of alternatives for further investigation can be made by using Figure 8.1 and Table 8.1. For example, if a site had mild slopes and sandy soils, alternatives would be selected from the surface protection or mechanical treatment groups. For a site that was steep or had silty soils, alternatives would be selected from the detentions and filtering group. A small area with a moderate slope or moderately silty soils, would have alternatives based on the surface protection, and detention and filtering groups.

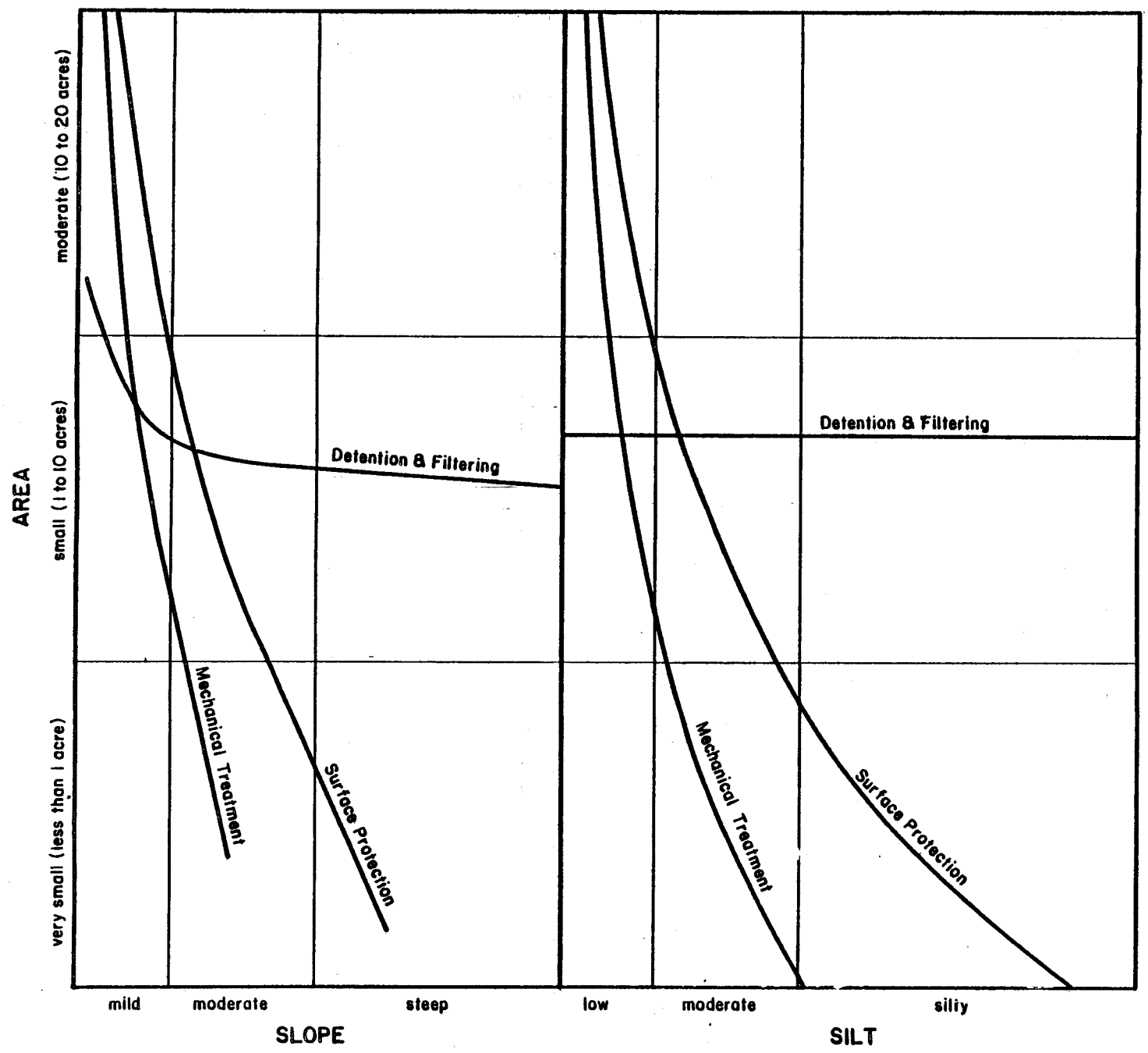


Figure 8.1. Comparison of structure groups (from Simons, Li & Associates, Inc., 1982).

Table 8.1. Ranking of Structures and Treatments.

Treatment	Area	Cost	Maintenance Requirements
1. Surface Protection Measures			
Revegetation	Best	Best	Best
Straw Mulch	Best	Good	Good
Hydraulic Mulch	Best	Average	Average
Woodchip Mulch	Average	Average	Good
Stone Mulch	Average	Average	Good
2. Mechanical Treatment Measures			
Furrowing	Good	Best	Best
Imprinting	Good	Good	Best
Pitting	Average	Average	Average
Ripping	Average	Average	Average
3. Diversion and Conveyance Structures			
Terrace	Best	Best	Best
Conveyance	(required for most systems)		
4. Detention and Filtering Structures			
Filter Fence	Best	Average	Average
Detention Structure with Rock Outlet	Good	Best	Good
Brush Barrier	Good	Best	Average
Straw Bales	Average	Good	Average

Best Good Average Fair Poor

Once structure and treatment alternatives have been identified, the maximum area for a particular alternative can be identified using the methods presented in the next section.

8.3 Determining Maximum Area for Sediment Control Measures

Methods are presented in this section to estimate the maximum area for each of the four major sediment control groups.

Surface Protection Measures

The maximum area for designing surface protection measures is directly related to the average overland flow length. The maximum overland flow length is given by the following equation:

$$L_{max} = \frac{C_1}{P_e} \tag{8.1}$$

where: L_{max} = maximum overland flow length, feet
C_1 = overland flow length coefficient
P_e = rainfall excess, inches

The overland flow length coefficient, C_1, is a function of the slope, S, roughness coefficient, K_g, the percent of soil silt, p_1, and the design sediment concentration, C_s. The slope, S, is defined in Figure 3.3, the roughness coefficient, K_g is defined in Figure 4.2 and Table 4.2, and percent silt, p_1, is given in Table 3.4. The design sediment concentration will depend on regulatory requirements (state and/or federal) applicable to the mining location. Figure 8.2 provides a graphical means of determining the overland flow length coefficient. The total rainfall depth for a storm can be determined by the curve number method, using Equation 4.4 or Figure 4.5 in Chapter IV. From these data, the maximum area is defined as:

$$A_{max} = \frac{W\ L_{max}}{43{,}560} \tag{8.2}$$

where: A_{max} = maximum area for treatments, acre
W = width, feet
L_{max} = maximum overland flow length, feet

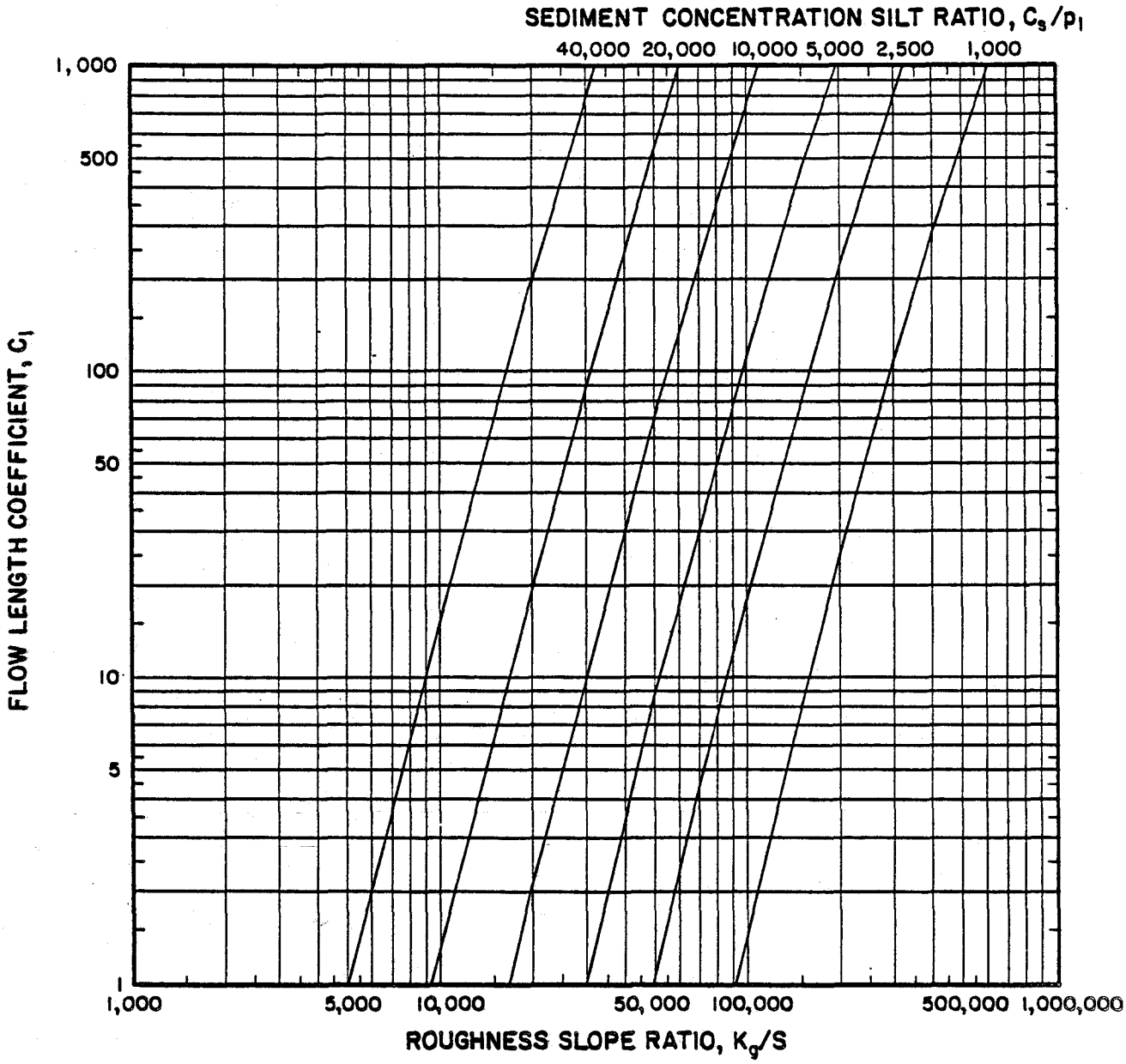


Figure 8.2. Flow length coefficient as a function of roughness, slope, silt content, and design sediment concentration (from Simons, Li & Associates, Inc., 1982).

Example 8.1: Determine the maximum allowable area for a catchment treated with straw mulch at a rate of 2 tons/acre. The catchment is 100 feet wide and has a slope of 0.03. The soil is a sandy clay loam containing 25 percent silt, and has moderately high runoff potential which classifies it as a C hydrologic soil group. The design sediment concentration is 1000 ppm, the 10-year, 24-hour storm has a depth of 4.5 inches.

From Figures 4.11 and 4.2, the cover factor and roughness coefficient are determined as 0.88 and 8,580, respectively. The curve number is 75.8 as determined from Equation 4.1 and Table 4.3 for a C hydrologic soil group.

The roughness-slope ratio is 286,000 which gives an overland flow length coefficient of 2000 (from Figure 8.1). Using Figure 4.5, the total rainfall excess is calculated to be 2.1 inches. The maximum overland flow length defined by Equation 8.11 is therefore,

$$L_{max} = 2000/2.1$$

$$= 955 \text{ feet}$$

which gives a maximum allowable area (Equation 8.2) of

$$A_{max} = 100 \cdot 955/43,560$$

$$= 2.19 \text{ acres}$$

Mechanical Treatment

The maximum allowable area for mechanical treatments is determined using the same method as for surface protection measures. The following example illustrates the use of the method for mechanical treatments.

Example 8.2: Determine the maximum allowable area for a catchment that has been contour furrowed. The catchment is 100 feet wide and has a slope of 0.03. The sandy clay loam soil contains 25 percent silt and has a moderately high runoff potential which classifies it in a C hydrologic soil group. The design sediment concentration is 1000 ppm, no vegetative cover exists on the slope. The 10-year, 24-hour storm has a depth of 4.5 inches.

From Table 5.1, the roughness coefficient is 3,500 which gives a roughness-slope ratio of 117,000. The curve number is 81 as given in Table 5.2. The total rainfall excess is 3.0 inches as determined from

Figure 4.5. From Figure 8.1, the overland flow length coefficient is 113. The maximum overland flow length is:

$$L_{max} = 113/3.0$$

$$= 37.7 \text{ feet}$$

The maximum allowable area is:

$$A_{maxt} = 37.7 \cdot 100/43{,}560$$

$$= 0.087 \text{ acres}$$

Diversion and Conveyance

The primary role of diversion and conveyance channels in a sediment control system is to provide stable waterways for removing runoff from a catchment. Diversion structures can be designed to trap coarse sediment sizes; however, these structures have limited effectiveness in controlling fine, silt-size sediment. The maximum area which can contribute runoff to a diversion and conveyance system is limited in this manual to a design peak discharge of 20 cfs. This limitation is necessary since no formal design is required for these structures. This requirement can be quickly evaluated with the following equation:

$$A_{maxd} = 40.9/P_e \qquad (8.3)$$

where: A_{maxd} = maximum area for the diversion and conveyance, acres
P_e = rainfall excess, inches

An estimate of spacing for diversion structures can be made based on the maximum overland flow length as determined for either mechanical and surface protection measures. If the spacing of diversion structures becomes unreasonably close, then additional surface treatment or use of detention and filtering structures should be considered. Care must be taken to provide an adequate, nonerosive channel lining for the diversion and conveyance channels (see Chapter VI).

Example 8.3: For the conditions in Example Problem 8.1, determine the maximum area for a diversion and conveyance system and the required diversion spacing.

The results in Example 8.1 indicate that 2.1 inches of rainfall excess occurred for the design storm. According to Equation 8.3, the maximum area for a diversion and conveyance system is:

$$A_{maxd} = 40.9/2.1$$
$$= 19.5 \text{ acres}$$

The maximum allowable overland flow length in Example 8.1 was 955 feet. Therefore, an effective diversion spacing would be a spacing of 955 feet or less.

Each diversion will catch runoff from 2.19 acres, which will give a peak discharge from the diversion of 2.3 cfs during the storm (see Chapter IV, procedure guide, Step Three). If a 0.01 slope is used for the diversion, the velocity in the channel will reach 1.4 ft/sec (assuming a Mannings' coefficient of 0.05 and 4:1 side slopes). Because this velocity is sufficient to transport most sediment sizes, a gravel or vegetative channel lining should be provided.

Detention and Filtering

Detention and filtering structures are designed to retain most of the sediment and runoff volume from the design storm. The height of these structures is limited to two feet or less, therefore the structure must be fairly long to develop the necessary storage volume. The maximum overland flow length which can contribute runoff to a detention or filtering structure is given by the following equation:

$$L_{max} = 12 \frac{C_f}{P_e} \tag{8.4}$$

where: C_f = structure length coefficient (Figure 7.2)

L_{max} = maximum allowable overland flow length, feet

P_e = rainfall excess, inches

The design procedure for detention and filtering structures should be executed to determine the actual sediment trapping efficiency of the structure. Detention and straw bale filter structures should be evaluated carefully to assure that this objective can be met. The maximum area which can be handled by a detention and filtering structure is:

$$A_{maxs} = \frac{L_d \, L_{max}}{43560} \tag{8.5}$$

where: A_{maxs} = maximum area above the structure, acres

L_d = structure length, feet

Example 8.4: Determine the maximum area which can be treated by a filter fence. The maximum length of the filter fence is 200 feet due to topographic conditions on the catchment, and the slope of the land surface is 0.03. The flow rate through the fence is 2.4 ft/hr. Rainfall excess for the 10-year, 24-hour storm is 2.1 inches and has a duration of 20 hours.

The maximum ponded depth for a filter fence is 2.0 feet (see section 7.2, Step Two). Using Equation 8.4, maximum overland flow length above the structure is:

$$L_{max} = 12.0 \, \frac{132}{2.1}$$

$$= 754 \text{ feet}$$

where C_f is from Figure 7.2 for a value of $K_f = 48$. The maximum area using equation 8.5 is

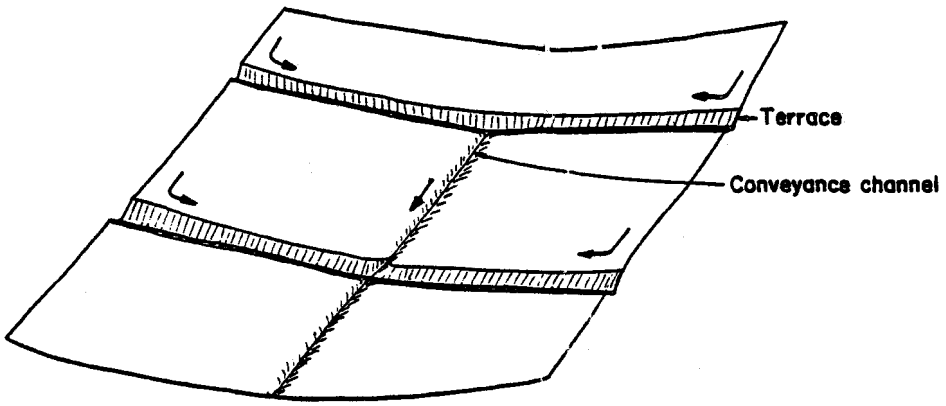
$$A_{maxs} = \frac{754(200)}{43560}$$

$$= 3.46 \text{ acres}$$

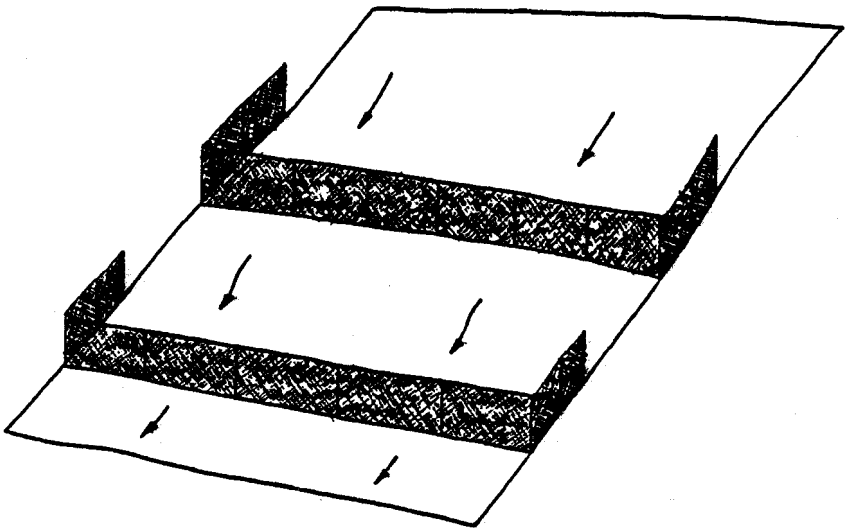
8.4 Combined Use of Structures and Treatments

Sediment control structures and treatments can be combined to form an effective sediment control system. The advantage of a combined system is that a larger area can be controlled compared to an area controlled by a single treatment or structure.

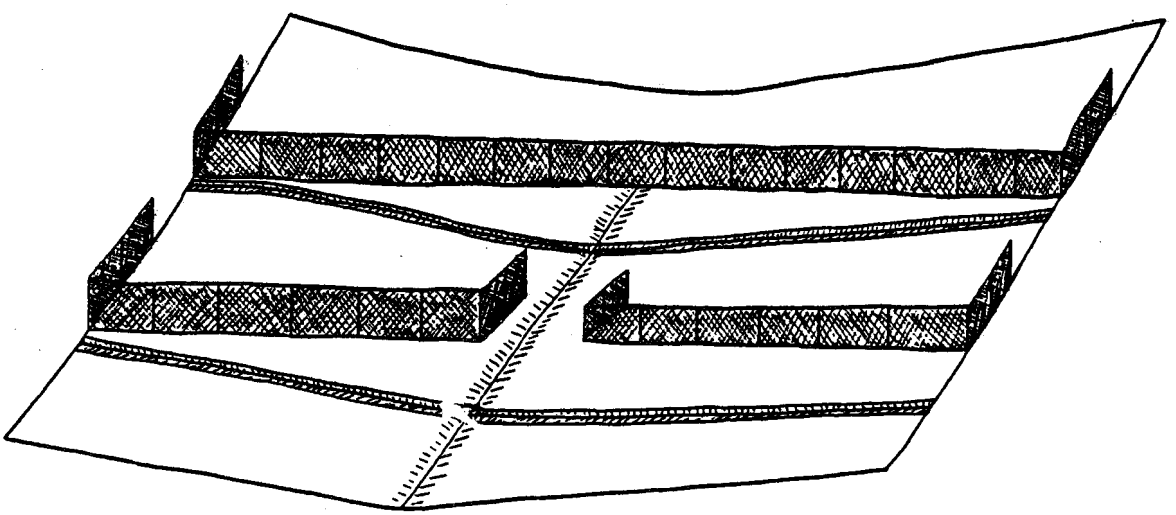
The general principle involved in developing a sediment control system is that the structures must be placed parallel to each other, rather than in series. Figure 8.3 illustrates this principle. A terrace and conveyance channel system (Figure 8.3(a)) is a good example of structures placed in a "parallel" manner. Sediment and water are conveyed by the terraces to a conveyance channel which allows each area to be controlled separately from the adjacent area. Filter fences placed directly below each other (Figure 8.3(b)) are an example of placement in "series". Sediment laden water passes through



a. Correct placement of structures in parallel on the slope.



b. Incorrect placement of structures in a series.



c. Placement of filter fences in parallel on the slope and linked with diversion and conveyance channels.

Figure 8.3. Parallel and series placement of sediment control structures.

the upslope filter fence and subsequently discharges to the area immediately adjacent to it. Since the area below the fence is relatively unstable, sediment will be detached from the soil surface. The next filter fence will therefore receive additional sediment detached by flow from the upslope filter fence, as well as from the upslope area. This "series" arrangement of the filter fence can be modified by placing small diversion channels below each filter fence and then linking these to a conveyance channel (Figure 8.3(c)).

Use of filter fence and diversion allows the maximum area draining to each diversion to increase substantially over that allowable for a surface treatment. A similar design could be developed using detention structures and diversions. The following example illustrates the design of a combined sediment control system.

Table 8.2 gives a summary of several possible combined applications of various treatments and structures.

Example 8.5: Design a combined sediment control system consisting of filter fence and terrace diversions. The width of the catchment is 200 feet and the slope of the land surface is 0.05. Rainfall excess for the 10-year, 24-hour storm is 2.1 inches. The soil is a sandy clay loam containing 25 percent silt. A surface protection of 2 tons/acre of straw mulch will be used. A design objective of 1000 ppm will be used.

From Figure 4.2, the roughness coefficient is determined to be 8,580. The roughness slope ratio is 171,600 which gives an overland flow length coefficient of 420. The maximum overland flow length for an area treated only with straw mulch would be 200 feet (from Equation 8.1). A terrace spacing of 200 feet would be costly.

The maximum overland flow length which can runoff to a filter fence is determined from Equation 8.4 where:

$$L_{max} = 12.0 \frac{108}{2.1}$$

$$= 617 \text{ feet}$$

Table 8.2. Combined Structure and Treatment Alternatives.

Possible Alternative Combinations
Filter Fence with Terrace Diversion
Brush Filter Barrier with Terrace Diversion
Straw Bale Barrier with Terrace Diversion
Detention Structure with Diversion
Surface Protection with Terrace Diversion
Mechanical Treatment with Terrace Diversion

Using a filter fence will increase the required spacing of the terrace diversions to 617 feet which is over three times longer than that for a mulch treatment alone.

The filter fence will store much water and sediment from the design storm and discharge it slowly. The filter fabric has a low flow rate per unit area (this should be determined from Test 2, Chapter VII) of approximately 0.3 gal/min/ft^2 (or 2.4 ft/hour). Maximum discharge to the terrace below the filter fence will be:

$$Q = 2(200)\left(\frac{2.4}{3600}\right)$$

$$= 0.27 \text{ cfs}$$

This is about one quarter the discharge which would have occurred if the silt fence had not been present. The discharge is sufficient to require a channel lining.

A good stand of grass-legume mixture, uncut (4 to 5 inches) will be used to line the channel. This will produce a class D retardance vegetal cover. From Figure 6.6 the Mannings' coefficient is determined to be 0.20 which gives a flow depth of 0.50 feet, for a one percent sloping terrace with 4:1 side slopes (from Figure 6.3 nomograph), and a velocity of 0.27 ft/sec. Very little sediment transport will occur under these hydraulic conditions and the grass-legume lining will be adequate.

8.5 Mean Annual Sediment Yield

The mean annual sediment yield for a small area is determined using data from 24-hour storms of various return periods. The approximate sediment yield for each return period is calculated and a weighting factor is then applied to these values which is based on the probability of each event actually occurring during a single year. Only the sediment yield for the 10-year, 24-hour storm event (G_y) must be determined to calculate the mean annual sediment yield.

The mean annual sediment yield, Gy, is defined as:

$$\bar{G}_y = (P_w/P_{pt})\, C_{rt}\, G_y \qquad (8.6)$$

where P_w = mean annual water yield in inches

P_{pt} = total expected water yield in inches

C_{rt} = total sediment yield correction factor

G_y = sediment yield for the 10-year, 24-hour storm in tons

Values of mean annual water yield are available from the Soil Conservation Service. A general map of mean annual water yield values is given in Figure 8.4 for the continental United States. It is recommended that SCS map be used on western states where mean annual sediment yield is less than 1.0 inch.

The 10-year, 24-hour sediment yield can be calculated by procedures given in Chapters 4 through 7. Worksheet 8.1 is provided to carry out the calculation of mean annual sediment yield. The following steps are used to determine mean annual sediment yield.

1. For each return period in column 1 determine the 24-hour storm volume from rainfall frequency atlas and place this value, P, in column 2.

2. Determine the total rainfall excess, P_e, for each storm using the same curve number used in determining the water yield for the 10-year, 24-hour storm (see Equation 4.4 or Figure 4.5); place these values in column 3.

3. Calculate the ratio of the rainfall excess in column 3 to the rainfall excess for the 10-year storm. Place these values in column 4.

4. For the roughness-slope ratio used in determining the sediment yield find the rainfall ratio exponent, b, from Figure 8.3.

5. Raise each rainfall excess ratio value in column 4 to the b power. Place these values in column 5.

6. Multiply column 5 by the values in column 6. This is the sediment yield correction factor and is placed in column 7.

7. Sum the values in column 7. This is the total mean annual sediment yield correction factor, C_r.

8. Multiply column 3 by column 6 to determine the expected water yield (P_p) in column 8.

9. Sum the values in column 8. This is the total expected water yield (P_{pt}).

10. Using Equation 8.6, calculate the mean annual sediment yield (G_y).

The following example illustrates the mean annual sediment yield procedure.

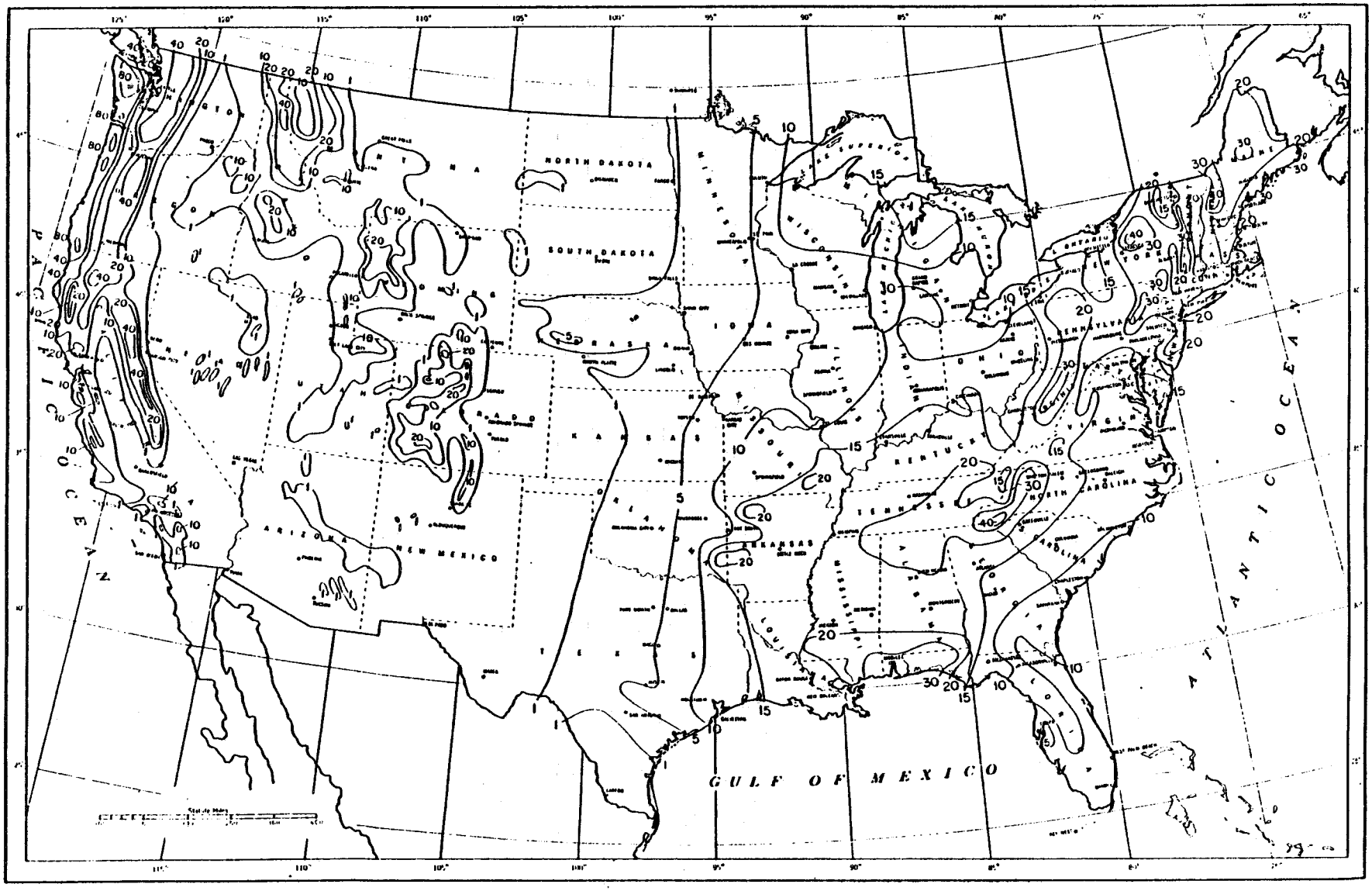


Figure 8.4. Annual inches of runoff (Pw)(after U.S. Geological Survey, 1962).

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Return Period (years)	24-Hour Rainfall, P (inches)	Rainfall Excess, P_e (inches)	Rainfall Excess Ratio R_p	R_p^b	Weighting Factor W_p	Sediment Yield Factor, C_r	Expected Water Yield, P_p
100					0.01		
50					0.01		
25					0.02		
10			1.0	1.0	0.06	0.06	
5					0.10		
2					0.50		
					C_{rt} =		

Curve number, CN = _____

Roughness-slope ratio, K_g/S = _____

Rainfall ratio exponent, b = _____

Average annual water yield, P_w = _____

Sediment yield for 10-year, 24-hour storm, $G_{y_{10}}$ = _____ tons

Mean annual sediment yield $\overline{G}_y = (P_w/P_{pt})C_{rt}G_{y10}$

= _____ tons

Worksheet 8.1. Mean Annual Sediment Yield.

Example 8.6: Compute the mean annual sediment yield for a mine site area in north central New Mexico. The sediment yield for the 10-year, 24-hour storm is 31.5 tons for a 10 acre area which has been contour furrowed. The rainfall depths for other 24-hour storm are given below (from NOAA Atlas 2, Vol. IV):

Return Period (years)	24-Hour Storm Depth (inches)
100	5.0
50	4.4
25	4.0
10	3.2
5	2.8
2	2.0

The curve number is 81, roughness is 2700, and the slope is 0.09. The average annual water yield is 0.5 inches.

Calculations are given on the attached worksheet.

Mean annual sediment yield equals less than 8 tons of sediment which is one-fourth of the sediment yield for a single 10-year storm.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Return Period (years)	24-Hour Rainfall P (inches)	Rainfall Excess, P_e (inches)	Rainfall Excess Ratio R_p	R_p^b	Weighting Factor W_p	Sediment Yield Factor, C_r	Expected Water Yield P_p
100	5.0	3.46	1.92	2.48	0.01	0.0248	0.035
50	4.4	2.89	1.61	1.94	0.01	0.0194	0.029
25	4.0	2.52	1.40	1.60	0.02	0.0320	0.050
10	3.2	1.80	1.00	1.0	0.06	0.060	0.108
5	2.8	1.45	0.81	0.75	0.10	0.0750	0.145
2	2.0	0.80	0.44	0.32	0.50	0.1600	0.400
					C_{rt} =	0.3712	0.767

Curve number, CN = 81

Roughness-slope ratio, K_g/S = 30,000

Rainfall ratio exponent, b = 1.39

Average annual water yield, P_w = 0.5

Sediment yield for 10-year, 24-hour storm, $G_{y_{10}}$ = 31.5 tons

Mean annual sediment yield $\overline{G}_y = (P_w/P_{pt})C_{rt}G_y$

= 7.7 tons

Example Problem 8.6. Mean Annual Sediment Yield.

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IX. DETAILED DESIGN EXAMPLE

The purpose of this chapter is to provide a realistic example of the design process for a sediment control system. The previous examples given for each structure and treatment groups were intended to illustrate the design procedures. Topographic, climatic, and soils data were given as background information in order to clearly present the design procedures. In this chapter the details of developing design parameters from available data are illustrated.

9.1 Site Description

A small catchment is located at the corner of a lease boundary for a mine located in central Illinois (Figure 9.1). The site has recently been regraded and topsoiled as shown on the topographic map. Planned post mining land use will be pasture and the site will be seeded with grass and legumes to support this use. It is anticipated that two growing seasons will be required to establish the permanent vegetative cover conditions which exist on the vegetative reference plot.

Access to the lease area is available from a county road. The access road within the lease boundary follows the eastern edge of the lease area. Potential areas of damage by sediment are at the culvert for the county road and at the confluence with the stream originating outside the lease area.

9.2 Hydrologic Data

Mean annual rainfall for this central Illinois site is 35 inches, the SCS type II distribution is the appropriate rainfall distribution for this area, and the 10-year, 24-hour storm volume is 4.5 inches. The mean annual rainfall is used as a guide to select vegetation and seasonal distribution of rainfall is used for timing revegetation efforts. The 10-year, 24-hour storm volume is determined from the appropriate rainfall frequency atlas, in this case the TP-40 atlas (Figure 3.2, Chapter III).

Curve numbers used for the design will be based on a case II antecedent moisture condition (see Chapter III, section 3.3). Conditions which would produce a very high antecedent moisture (case III) would be rare for a small area.

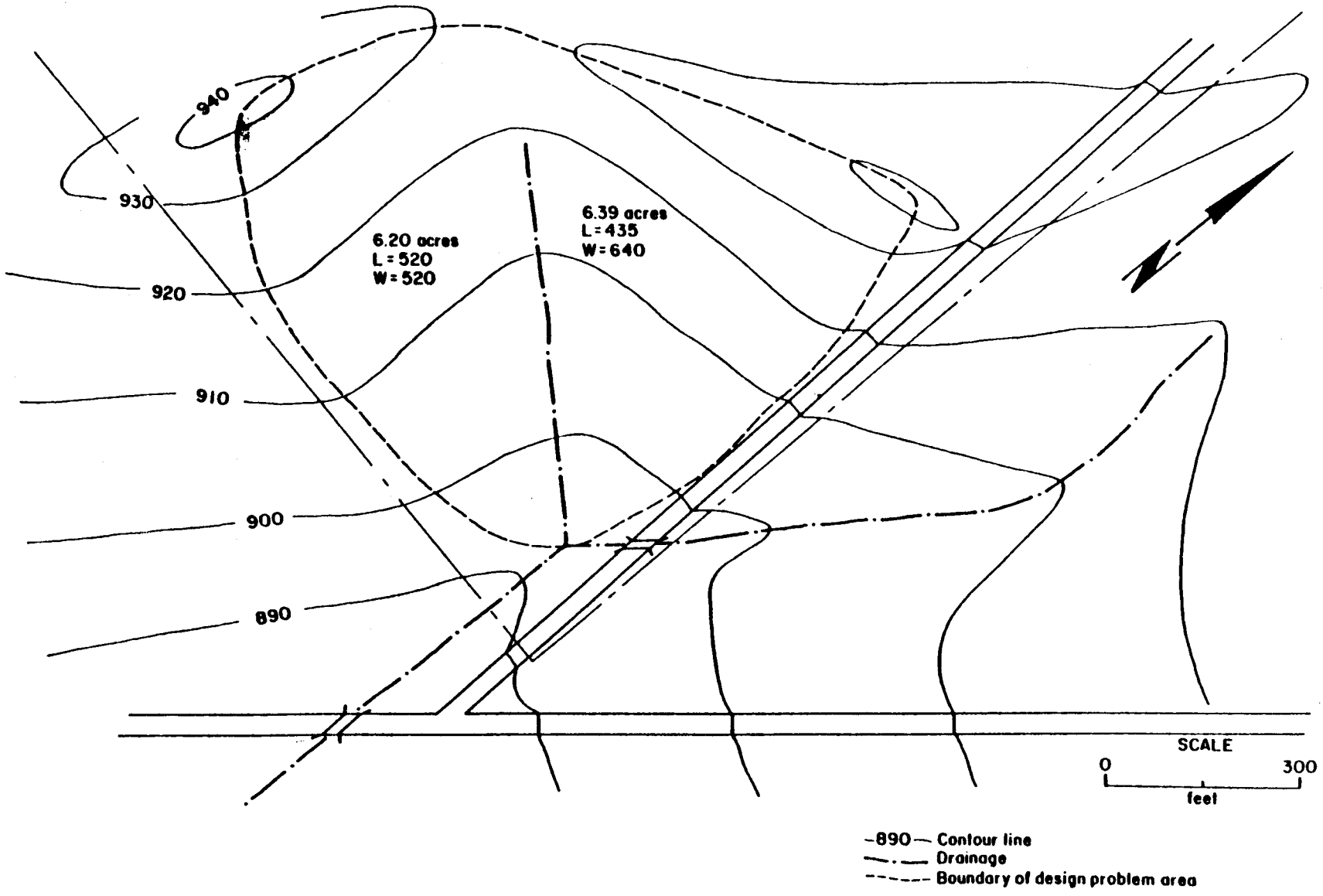

Figure 9.1. Topographic map of design problem area.

9.3 Soils Data

For the purpose of this problem, it will be assumed that only the textural classification of the soil is available. A loam soil which commonly occurs in Illinois will be used as topsoil. This soil will be assumed to have a slow infiltration rate and a moderately high runoff potential. The soil falls within the C hydrologic soil group.

9.4 Topographic Information

The catchment area shown in Figure 9.1 is complex and must be simplified in order to proceed with the sediment yield analysis. The open-book representation (described in Chapter III, section 3.5) will be illustrated here in detail. First, the catchment is divided along the main swale into two areas or planes and their respective areas determined. As shown in Figure 9.1, the right side includes 6.4 acres and the left side includes 6.2 acres.

The overland flow length and slope are then determined for each area or plane. Overland flow paths are measured and their slopes are determined at points along the main swale for each plane. An average overland flow length and slope are then determined. Results indicate lengths of 435 feet and 520 feet, and slopes of 6.8 percent and 5.5 percent for the right and left sides, respectively.

The design width for each plane is the area divided by the overland flow length. Results are 650 feet and 520 feet for the right and left sides, respectively. The slope of the main swale is determined from the actual topography and is 5.7 percent.

These data for the open-book configuration of the catchment area are summarized in Table 9.1. As can be seen from the data, the widths of the left and right planes are different. This simply indicates that the overland flow discharge per unit width of the two planes will be greater for the left plane than for the right plane. Hence, the overland flow length is the most important dimension for each phase.

Although the information in this section was developed from a topographic map of some detail, field measurements could be used. For example, the catchment area could be approximated from the mine plan and supplementary measurements of overland flow lengths and slopes could then be made in the field. Field measurements will be necessary for areas where changes in topography occur rapidly, such as stockpiles and spoil areas.

Table 9.1. Summary of Topographic Data.

	Right Side	Left Side
Area	6.39 acres	6.20 acres
Overland Flow Length	435 feet	520 feet
Slope	6.8%	5.5%
Width	640 feet	520 feet
Main Swale Slope	5%	

9.5 Sediment Control System Design

9.5.1 Selection of Alternatives

The first step in the design process is to select erosion control treatments or structures which are suitable for the site. The site terrain has mild to moderately steep slope and the soils are moderately silty. Based on these characteristics, three structure groups are selected and alternatives will be selected based on these groups. The selected groups are surface protection, diversion and conveyance structures plus surface protection, and detention and filtering structures. Individual structures which will be selected are straw mulch at 2 tons/acre, terraces with straw mulch at 2 tons/acre and filter fence.

The design sediment yield is two tons/acre/year. The allowable sediment yield for the 10-year storm can be found using the Mean Annual Sediment Yield Worksheet from Chapter VIII (Worksheet 8.1) and determining the sediment yield factor, C_{rt}, and expected water yield, P_{pt}. These factors are determined in Worksheet 9.1 with $C_{rt} = 0.438$ and $P_{pt} = 1.036$. The average annual water yield is 9.0 inches. Using Equation 8.6 and solving for the sediment yield for the 10-year, 24-hour storm gives

$$G_y = \left(\frac{P_{pt}}{P_w}\right)\left(\frac{\bar{G}_y}{C_{rt}}\right)$$

$$= \left(\frac{1.036}{9.0}\right)\left(\frac{2.0}{0.483}\right)$$

$$= 0.53 \text{ tons/acre}$$

The sediment concentration is determined using Equation 4.14. The rainfall excess is 2.13 inches for a storm of 4.5 inches and a CN value of 76.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Return Period (years)	24-Hour Rainfall, P (inches)	Rainfall Excess, P_e (inches)	Rainfall Excess Ratio R_p	R_p^b	Weighting Factor W_p	Sediment Yield Factor, C_r	Expected Water Yield, P_p
100	6.5	3.82	1.79	2.21	0.01	0.022	0.038
50	5.8	3.21	1.51	1.75	0.01	0.018	0.032
25	5.2	2.70	1.26	1.37	0.02	0.027	0.054
10	4.5	2.13	1.0	1.0	0.06	0.06	0.128
5	4.0	1.74	0.82	0.76	0.10	0.076	0.174
2	3.3	1.22	0.57	0.47	0.50	0.235	0.61
					C_{rt} =	0.438	1.036

Curve number, CN = 76

Roughness-slope ratio, K_g/S = 133,333

Rainfall ratio exponent, b = 1.36

Average annual water yield, P_w = 9.0

Sediment yield for 10-year, 24-hour storm, $G_{y_{10}}$ = ---- tons

Mean annual sediment yield $\overline{G}_y = (P_w/P_{pt})C_{rt}G_{y10}$

= ---- tons

Worksheet 9.1. Mean Annual Sediment Yield.

$$G_s = \frac{8830\ G_Y}{P_e\ A}$$

$$= \frac{8830(0.53)}{2.13(1.0)}$$

$$= 2{,}200 \text{ ppm}$$

9.5.2 Maximum Area for Structures and Treatments

The maximum area for designing a surface protection measure is a function of the roughness coefficient, K_g, the percentage of silt in the soil, P_1, The slope, S, the sediment concentration, C_s, the rainfall excess, P_e, and the width of the area, W. For the straw mulch treatment and the site these values are:

K_g = 6,800
P_1 = 0.30
S = 0.06
C_s = 2,200 ppm
P_e = 2.13 inches
W . 450 feet

The overland flow length coefficient (Figure 8.2) is 500 which gives a maximum overland flow length of 235 feet (from Equation 8.1). The maximum area for the mulch treatment is 2.4 acres. This is about 40 percent of either the left or right plane.

The maximum overland flow length is about half the actual overland flow length for either the left or right plane and a straw mulch treatment will be inadequate to meet the required design sediment yield. A reasonable terrace spacing would divide each plane in half. Some sediment deposition will occur in the terraces which will allow for an increased overland flow length to the terrace.

The maximum area which can be treated by a filter fence depends on the slope of the area, S, the duration of rainfall excess, t_e, the flow rate through the fabric, K_a, and the amount of rainfall excess, P_e. The structure length coefficient, C_f, is 86.4 from Figure 7.2 for a detention parameter of 37.4 (Equation 7.2). This gives a maximum allowable overland flow length to the structure of 485 feet. The longer the filter fence becomes, the larger the area which can be treated. However, it can be seen from the

topography (Figure 9.1) that the larger the area becomes, the less contour length is available in the catchment. A plot of contour length versus area and filter fence length versus maximum area (Figure 9.2) shows the optimum filter fence length to be 790 feet or an area of 8.8 acres. The contour length at elevation 910 is 800 feet, so the filter fence should be located at approximately this contour. The remaining 4.6 acres could be treated with straw mulch.

9.5.3 System Design

In the last two sections we identified three alternative structures and treatments and were able to quickly determine that two alternatives, terrace with straw mulch and filter fence, were feasible. At this point a cost analysis should be conducted to identify which structure is most cost-effective. Maintenance requirements for each structure should be assessed. The best structure for the site could then be selected and a detailed design conducted to estimate the actual sediment yield, determine a channel lining and other requirements.

The next two sections will illustrate the detail design of both feasible alternatives.

9.6 Detailed Design of a Terrace System

It was shown that a reasonable terrace spacing would divide the catchment in half. These terraces would be located as shown in Figure 9.3, basic data on the topography of each subarea are:

	Upper Right Side	Lower Right Side	Upper Left Side	Lower Left Side
Area	3.60	2.77	3.50	2.70
Overland Flow Length	300	250	320	250
Slope	0.068	0.058	0.055	0.045
Width	522	482	476	470

The average slopes, S, for the lower areas are somewhat flatter than the upper portions of the catchment. This is because the hillslopes are concave upward.

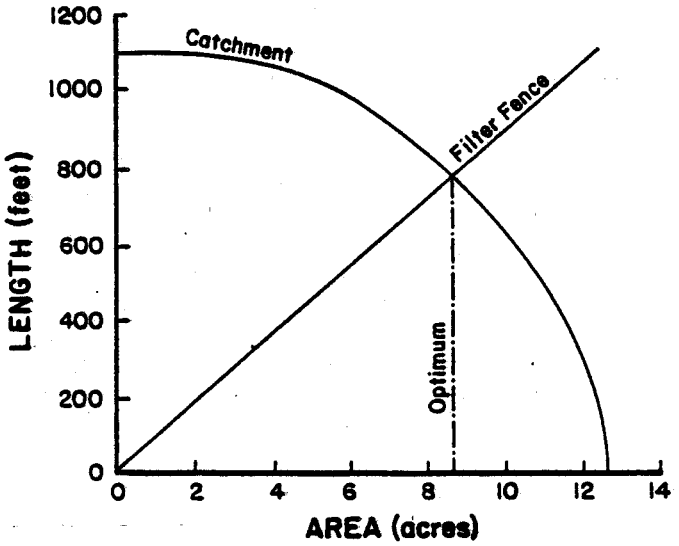

Figure 9.2. Optimum filter fence length.

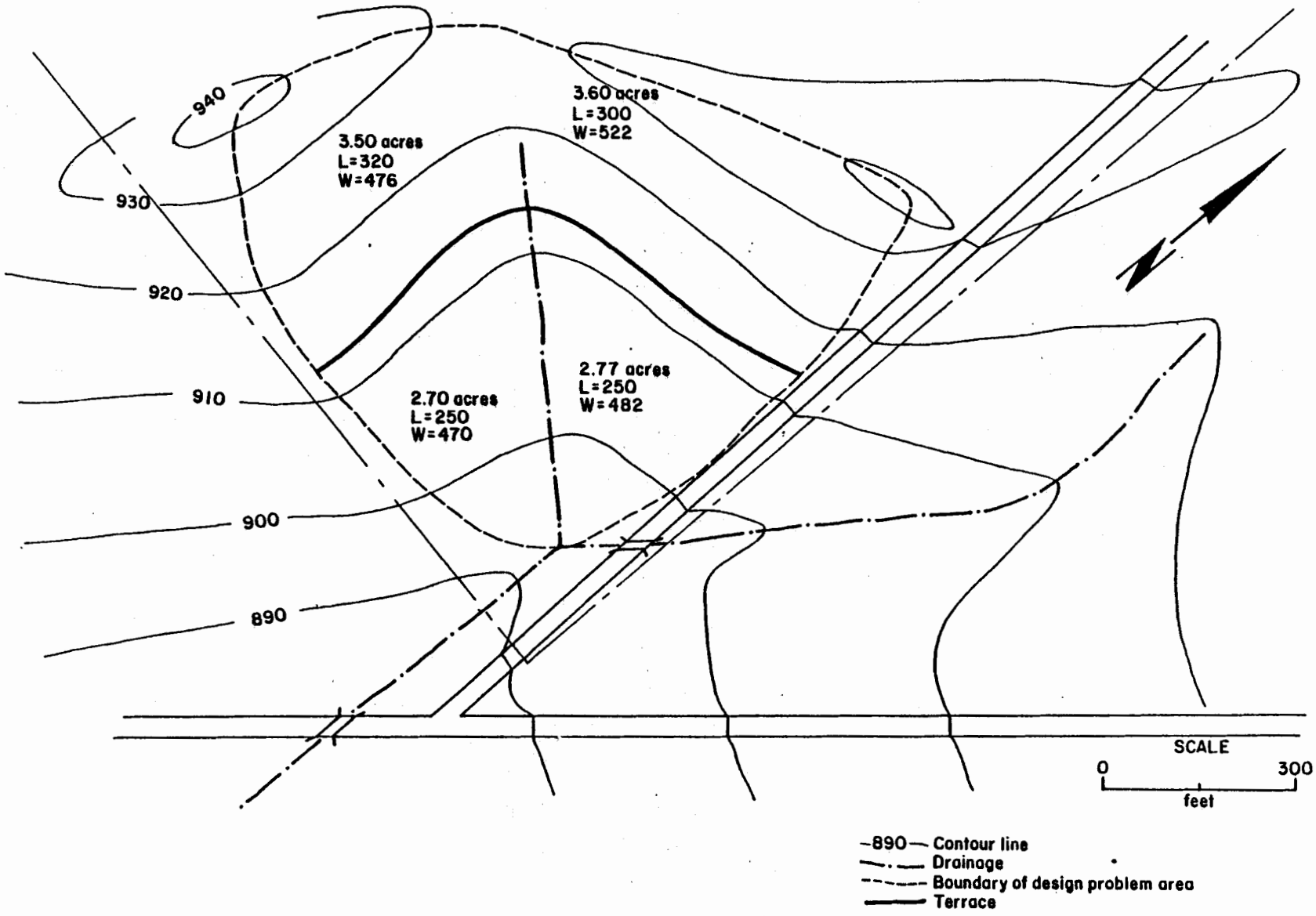

Figure 9.3. Topographic map of design problem area with terrace.

9.6.1 Terrace Design

Runoff from the upper subareas will reach the terraces. Determination of sediment yield to the terraces and the design of the terraces are given in this section.

Basic data on soil and climate are as follows:

Storm rainfall amount, P = 4.5 inches

Curve number, CN = 76

Hydrologic soil group: C

Soil texture class: Loam

Task 1. Determine the Water and Sediment Yield to the Terraces

Using the base data on soil, topography and climate, the Chapter IV sediment yield procedure is executed to determine the sediment yield from the two upper subareas. Information in steps one and two is the same for both subareas.

Step One. Particle Size Distribution

Data from Table 3.4 for a loam are as follows:

Clay:		= 10%
Silt,	P_1	= 30%
Very Fine Sand,	P_2	= 10%
Fine-Medium-Coarse Sand,	P_3	= 25%
Very Coarse Sand,	P_4	= 25%

Step Two: Cover Ratio, Roughness and Detachment Coefficients

Cover Ratio, C_g = 0.88 (from Figure 4.11)

Erodibility Factor, K_e = 0.36 (from Table 4.1)

Roughness Coefficient, K_g = 6,800 (from Figure 4.2, Table 4.2)

Detachment Coefficient, D_f = 0.55 (from Table 4.2)

Steps Three Through Seven: see attached worksheets.

Worksheets for the upper left subarea are given first and the worksheets for the upper right subarea are given next.

(1) Time (hr)	(2) Δt (hr)	(3) P/P_t	(4) P (inches)	(5) Pe (inches)	(6) ΔP (inches)	(7) ΔPe (inches)	(8) I (in/hr)	(9) Q (cfs)	(10) q (cfs/ft)
8.42		0.14	0.63	0.00					
	0.58				0.04	0.001	0.075	0.004	$.747 \times 10^{-5}$
9.00		0.15	0.68	0.001					
	2.25				0.45	0.066	0.200	0.103	$.216 \times 10^{-3}$
11.25		0.25	1.13	0.067					
	0.92				2.00	1.035	2.1766	3.938	$.827 \times 10^{-2}$
12.17		0.70	3.13	1.102					
	1.83				0.56	0.403	0.3074	0.771	$.162 \times 10^{-2}$
14.00		0.82	3.69	1.505					
	10.00				0.81	0.625	0.0810	0.219	$.459 \times 10^{-3}$
24.00		1.00	4.50	2.130					

Small area characteristics:

Area = 3.5 acres

Length = 320 feet

Width = 476 feet

Step Three worksheet - Upper Left Subarea.

(1) Δt (hr)	(2) I (in/hr)	(3) G_r (tons)
0.58	0.0750	0.01
2.25	0.2000	0.24
0.92	2.1766	11.86
1.83	0.3074	0.47
10.00	0.0810	0.18

Area = 3.50 acres

$G_r = 6.48\ \Delta t\ I^2\ A_b$ (Eq. 4.7)

Ground Cover Ratio = 88%

Width = 476 feet

$A_b = (1 - C_g)A$ (Eq. 4.8)

Step Four worksheet - Upper Left Subarea.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Δt	q	g_{t1}	g_{t2}	g_{t3}	g_{t4}	G_{t1}	G_{t2}	G_{t3}	G_{t4}	G_t
(hours)	(cfs/ft)	(tons/ ft/hr)	(tons/ ft/hr)	(tons/ ft/hr)	(tons/ ft/hr)	(tons)	(tons)	(tons)	(tons)	(tons)
0.58	$.747 \times 10^{-5}$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.25	$.216 \times 10^{-5}$	0.00009	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
0.92	$.827 \times 10^{-2}$	0.01488	0.00	0.00	0.00	1.96	0.00	0.00	0.00	1.96
1.83	$.162 \times 10^{-2}$	0.00155	0.00	0.00	0.00	0.40	0.00	0.00	0.00	0.40
10.00	$.459 \times 10^{-3}$	0.00027	0.00	0.00	0.00	0.38	0.00	0.00	0.00	0.38

Roughness Coefficient, K_g = 6,800

Slope, S = 0.055

Width = 476 feet

Step Five worksheet - Upper Left Subarea.

(1) Δt (hours)	(2) G_t (tons)	(3) G_r (tons)	(4) G_f (tons)	(5) G_s (tons)	(6) G_{s1} (tons)	(7) G_{s2} (tons)	(8) G_{s3} (tons)	(9) G_{s4} (tons)
0.58	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00
2.25	0.03	0.24	0.00	0.24	0.07	0.02	0.06	0.06
0.92	1.96	11.86	0.00	11.86	3.56	1.19	2.97	2.97
1.83	0.40	0.47	0.00	0.47	0.14	0.05	0.12	0.12
10.00	0.38	0.18	0.11	0.29	0.09	0.03	0.07	0.07

Flow Detachment Coefficient = 0.55

$G_f = D_f(G_t - G_r)$ (Eq. 4.10)

where $G_t < G_r$

Step Six worksheet - Upper Left Subarea.

	(1)	(2)	(3)	(4)	(5)
	G_{y1}	G_{y2}	G_{y3}	G_{y4}	G_y
	0.00	0.00	0.00	0.00	0.00
	0.03	0.00	0.00	0.00	0.03
	1.96	0.00	0.00	0.00	1.96
	0.14	0.00	0.00	0.00	0.14
	0.09	0.00	0.00	0.00	0.09
TOTAL YIELD	2.22	0.00	0.00	0.00	2.22

Step Seven worksheet - Upper Left Subarea.

(1) Time (hr)	(2) Δt (hr)	(3) P/P_t	(4) P (inches)	(5) Pe (inches)	(6) ΔP (inches)	(7) ΔPe (inches)	(8) I (in/hr)	(9) Q (cfs)	(10) q (cfs/ft)
8.42		0.14	0.63	0.00					
	0.58				0.04	0.001	0.0750	0.004	$.701 \times 10^{-5}$
9.00		0.15	0.68	0.001					
	2.25				0.45	0.066	0.2000	0.106	$.202 \times 10^{-3}$
11.25		0.25	1.13	0.067					
	0.92				2.00	1.035	2.1766	4.051	$.775 \times 10^{-2}$
12.17		0.70	3.13	1.102					
	1.83				0.56	0.403	0.3074	0.793	$.152 \times 10^{-2}$
14.00		0.82	3.69	1.505					
	10.00				0.81	0.625	0.0810	0.225	$.430 \times 10^{-3}$
24.00		1.00	4.50	2.130					

Small area characteristics:

Area = 3.60 acres

Length = 300 feet

Width = 522

Step Three worksheet - Upper Right Subarea.

(1) Δt (hr)	(2) I (in/hr)	(3) G_r (tons)
0.58	0.0750	0.01
2.25	0.2000	0.25
0.92	2.1766	12.20
1.83	0.3074	0.48
10.00	0.0810	0.18

Area = 3.60

$G_r = 6.48\ \Delta t\ I^2\ A_b$ (Eq. 4.7)

Ground Cover Ratio = 88%

Width = 522

$A_b = (1 - C_g)A$ (Eq. 4.8)

Step Four worksheet - Upper Right Subarea.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Δt	q	g_{t1}	g_{t2}	g_{t3}	g_{t4}	G_{t1}	G_{t2}	G_{t3}	G_{t4}	G_t
(hours)	(cfs/ft)	(tons/ ft/hr)	(tons/ ft/hr)	(tons/ ft/hr)	(tons/ ft/hr)	(tons)	(tons)	(tons)	(tons)	(tons)
0.58	.701	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.25	$.202 \times 10^{-3}$	0.00011	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.04
0.92	$.775 \times 10^{-4}$	0.01643	0.00	0.00	0.00	2.37	0.00	0.00	0.00	2.37
1.83	$.152 \times 10^{-}$	0.00174	0.00	0.00	0.00	0.50	0.00	0.00	0.00	0.50
10.00	$.430 \times 10^{-3}$	0.00031	0.00	0.00	0.00	0.48	0.00	0.00	0.00	0.48

Roughness Coefficient, K_g = 6,800

Slope, S = 0.068

Width = 522

Step Five worksheet - Upper Right Subarea.

(1) Δt (hours)	(2) G_t (tons)	(3) G_r (tons)	(4) G_f (tons)	(5) G_s (tons)	(6) G_{s1} (tons)	(7) G_{s2} (tons)	(8) G_{s3} (tons)	(9) G_{s4} (tons)
0.58	0.00	0.01	0.00	0.01	0.00	0.00	0.00	0.00
2.25	0.04	0.25	0.00	0.25	0.08	0.03	0.06	0.06
0.92	2.37	12.20	0.00	12.20	3.66	1.22	3.05	3.05
1.83	0.50	0.48	0.01	0.49	0.15	0.05	0.12	0.12
10.00	0.48	0.18	0.16	0.35	0.10	0.03	0.09	0.09

Flow Detachment Coefficient = 0.55

$G_f = D_f(G_t - G_r)$ (Eq. 4.10)

where $G_t < G_r$

Step Six worksheet - Upper Right Subarea.

	(1)	(2)	(3)	(4)	(5)
	G_{y1}	G_{y2}	G_{y3}	G_{y4}	G_y
	0.00	0.00	0.00	0.00	0.00
	0.04	0.00	0.00	0.00	0.04
	2.37	0.00	0.00	0.00	2.37
	0.15	0.00	0.00	0.00	0.15
	0.10	0.00	0.00	0.00	0.10
TOTAL YIELD	2.66	0.00	0.00	0.00	2.66

Step Seven worksheet - Upper Right Subarea.

Task 2. Determine Terrace Slope

The sediment yield to the terrances is silt. Since silt requires long settling times, the terrace slope should be as flat as possible to produce slow flow velocities. The terrace must provide adequate drainage and for this reason a slope of 0.3 percent is selected.

Task 3. Determination of Terrace Cross Section and Hydraulic Parameters

A triangular channel shape is used for the terrace since it is easily constructed using standard reclamation equipment (i.e. small dozers). The recommended side slopes for the terrace design are 3H:1V and 5H:1V as shown in Figure 6.3. The flow depths and areas are given by the nomographs in Figures 6.3 and 6.4, respectively. The Manning's n-value is determined for a grass-legume terrace by trial and from Figure 6.6 for a class "D" retardance (Table 6.2). When the product of velocity and hydraulic radius is less than 0.1 then the n-value should be selected as the maximum value in Table 6.1. In this case, the value is 0.28 for a good stand of grass-legume lining with a length of about 6 inches (section III, A.1.b of Table 6.1).

Results of the hydraulic calculations for both terrace are given in the following worksheets.

Task 4. Determine the Sediment Transport Capacity of the Terrace

Calculations of sediment transport capacity are shown on the following worksheets for the upper left and right terraces. Note that the sediment transport capacity of the terrace is zero except for the silt size during the peak of the storm. This indicates a good terrace design.

Task 5. Determination of Sediment Yield

Sediment yield for each terrace is shown on the Task 5 Worksheets. The length of the terrace used in determining the setting parameter, C_w, is the actual length as determined by direct measurement on-site or from a topographic map. The lengths of the terraces are 440 feet for the left subarea and 490 feet for the right subarea.

The average suspended sediment concentration is 1,600 ppm for the left subarea and 1,450 ppm for the right subarea.

1	2	3	4	5	6	7	8
Time Interval	Q (cfs)	n	d (ft)	A (ft^2)	V (fps)	T (ft)	d_h=A/T (ft)
1	0.004	0.28	0.14	0.163	0.025	1.1	0.07
2	0.103	0.28	0.48	1.86	0.055	3.8	0.24
3	3.94	0.135	1.44	16.5	0.238	11.5	0.72
4	0.771	0.28	1.03	8.41	0.092	8.2	0.51
5	0.219	0.28	0.64	3.27	0.067	5.1	0.32

Task Three worksheet - Upper Left Terrace.

1	2	3	4	5	6	7	8
Time Interval	Q (cfs)	n	d (ft)	A (ft^2)	V (fps)	T (ft)	d_h=A/T (ft)
1	0.004	0.28	0.14	0.163	0.025	1.1	0.07
2	0.106	0.28	0.49	1.90	0.056	3.9	0.24
3	4.051	0.145	1.49	17.8	0.227	11.9	0.75
4	0.793	0.28	1.04	8.56	0.092	8.3	0.52
5	0.225	0.28	0.65	3.34	0.067	5.2	0.32

Task Three worksheet - Upper Right Terrace.

$p_1 = 0.30 \quad p_2 = 0.10 \quad p_3 = 0.25 \quad p_4 = 0.25$

Time Interval	Δt (hrs)	T (ft)	g_t (tons/ft/hr)				G_t (tons)				
			1	2	3	4	1	2	3	4	Total
1	0.58	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	2.25	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.92	11.5	.0115	0.0	0.0	0.0	0.0365	0.0	0.0	0.0	0.0365
4	1.83	8.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	10.00	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
						TOTAL	0.0365	0.0	0.0	0.0	0.0365

Task Four worksheet - Upper Left Terrace.

$p_1 = 0.30 \quad p_2 = 0.10 \quad p_3 = 0.25 \quad p_4 = 0.25$

Time Interval	Δt (hrs)	T (ft)	g_t (tons/ft/hr)				G_t (tons)				
			1	2	3	4	1	2	3	4	Total
1	0.58	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	2.25	3.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
3	0.92	11.9	0.0101	0.0	0.0	0.0	0.0331	0.0	0.0	0.0	0.0331
4	1.83	8.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5	10.00	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
						TOTAL	0.0331	0.0	0.0	0.0	0.0331

Task Four worksheet - Upper Right Terrace.

1	2	3	4	5	6	7	8
Time Inter	C_w	P_s	Gy_1	Gy_2	Gy_3	Gy_4	Gy
1	55.3	1.0	0.0	0.0	0.0	0.0	0.0
2	7.33	1.0	0.0	0.0	0.0	0.0	0.0
3	0.565	0.44	1.34	0.0	0.0	0.0	1.34
4	2.06	0.95	0.01	0.0	0.0	0.0	0.01
5	4.51	1.0	0.0	0.0	0.0	0.0	0.0
Total Yield			1.35	0.0	0.0	0.0	1.35

$$C_w = \frac{2.2 \times 10^{-4} L_d}{V d_n}$$ (Equation 6.5)

p_s (see Figure 6.11)

Task Five worksheet - Upper Left Subarea.

1	2	3	4	5	6	7	8
Time Interval	C_w	P_s	Gy_1	Gy_2	Gy_3	Gy_4	Gy
1	61.6	1.0	0.0	0.0	0.0	0.0	0.0
2	8.02	1.0	0.0	0.0	0.0	0.0	0.0
3	0.63	0.48	1.25	0.0	0.0	0.0	1.25
4	2.25	0.92	0.01	0.0	0.0	0.0	0.01
5	5.03	1.0	0.0	0.0	0.0	0.0	0.0
Total Yield			1.26	0.0	0.0	0.0	1.26

$$C_w = \frac{2.2 \times 10^{-4} L_d}{V d_n}$$ (Equation 6.5)

P_s (see Figure 6.11)

Task Five worksheet - Upper Right Subarea.

Task 6. Deposition Depth

The volume of deposition is computed using Equation 6.7 which gives 17.5 ft^3 for the upper left subarea terrace and 28.4 for the upper right subarea terrace. This gives deposition depths of 0.10 feet for the left terrace and 0.12 feet for the right terrace.

Task 7. Terrace Design Depth

The terrace design depth includes the sum of the depths due to flow, sediment deposition and freeboard. The design depth for both terraces is therefore 2.6 feet.

9.6.2 Determination of Sediment Yield from the Lower Subareas

The lower subareas are mulched and the procedure for determining the sediment yield from these areas follows the Chapter IV procedure. The slopes of these lower subareas are flatter compared to the upper subareas because the basic shape of the catchment is concave. The average slopes for the lower left subarea is 0.045 and 0.058 for the lower right subarea. Sediment yields are 1.12 and 1.68 tons for the lower left and right subareas, respectively.

9.6.3 Summary of Results for the Terracing Alternative

The total sediment yield from the terraced catchment is 5.41 tons for the 10-year, 24-hour storm. This gives a mean annual sediment yield of 20.6 tons or 1.63 tons/acres which is below the design objective of 2.0 tons/acre. This design produces an attractive, stable postmining landscape which is low in cost and requires little long-term maintenance.

9.7 Detailed Design of a Filter Fence System

The second design alternative is to use a filter fence to trap sediment. The fence will be placed parallel to the contour of the catchment at elevation 900 and will catch sediment from 8.6 acres of the catchment (Figure 9.4). The

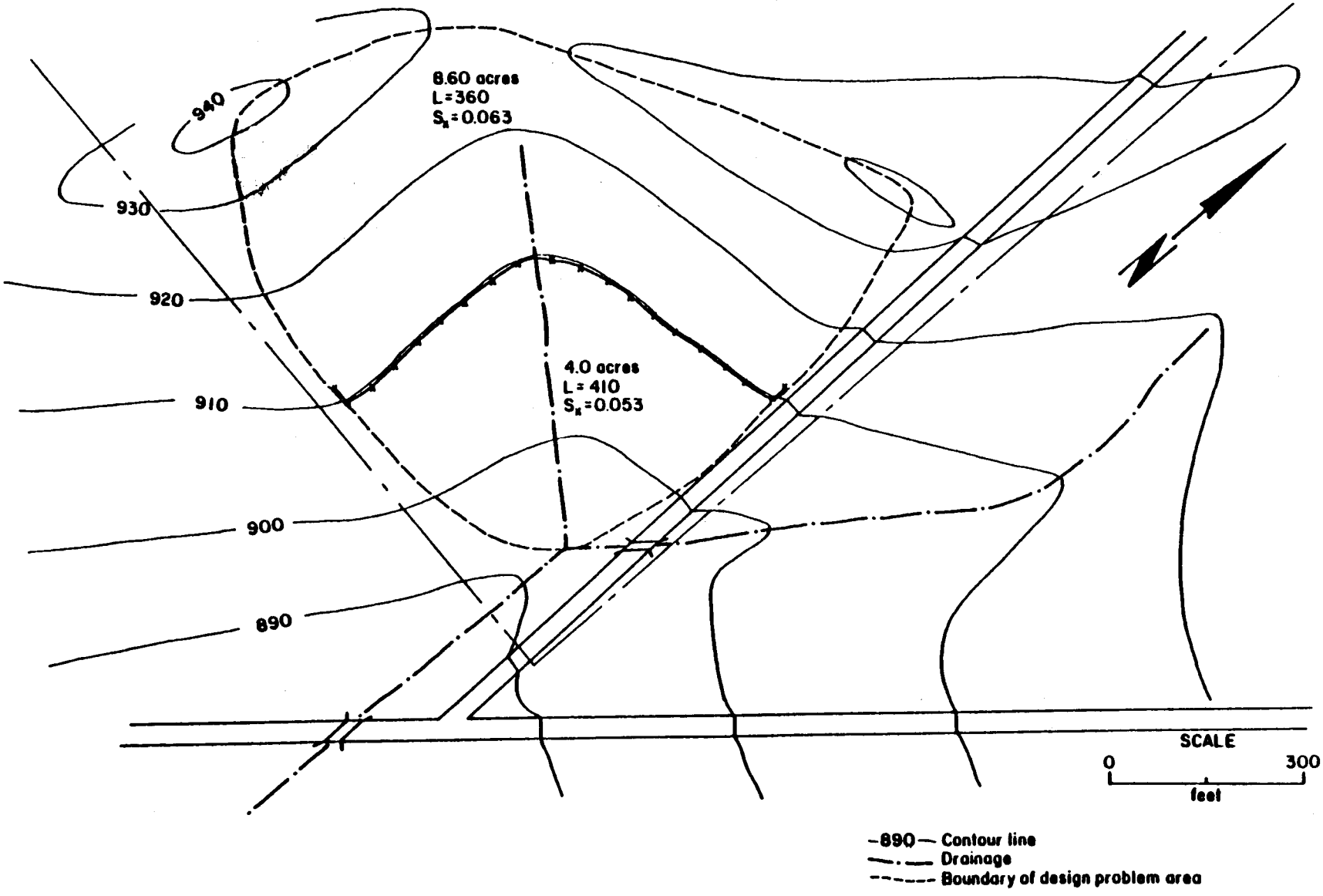

Figure 9.4. Topographic map of design problem area with filter fence.

entire catchment will be mulched with straw at the rate of 2.0 ton/acre. Basic data for computing the sediment yield to the filter fence is as follows:

Roughness coefficient, $K_g = 6{,}800$

Overland flow slope, $S_x = 0.063$

Overland flow length, $L = 360$ feet

Sediment yield to the fence is 6.36 tons, all of which is in the silt size range. Below the fence, the remaining 4.0 acres have a sediment yield of 2.69 tons. Basic data on the lower area are as follows:

Overland flow slope, $S_x = 0.053$

Overland flow length, $L = 410$ feet

Details of the calculation for determining the sediment yield from the filter fence are given on the attached worksheet.

There should be a small diversion below the filter fence to control the seepage through the fence. The diversion can be designed based on the peak flow rate through the fence. This flow rate is equal to the flow rate per unit area (0.000667 ft/sec) multiplied by the maximum area

$$Q_{max} = 0.000667\ (2)(400)$$
$$= 0.53 \text{ cfs}$$

Using a grass lined diversion similar to the one used for the terrace alternative (4:1 side slopes, 0.3 percent slope, and Class D retardance) gives the following hydraulic conditions

Manning's $n = 0.28$

Flow depth, $d = 0.89$ feet

Flow velocity, $\bar{\bar{v}} = 0.08$ ft/sec

No sediment transport will occur for these conditions. The diversion channel should extend to the main swale which should also be lined with grass.

Overall the sediment yield for the 10-year, 24-hour storm on the catchment treated with a filter fence and straw mulch is 2.88 tons. This is a mean annual sediment yield of 11.0 tons of sediment or 0.87 tons/acre, which meets the design objective of 2.0 tons/acre. The filter fence design is a good short-term solution to the erosion problem, although it is moderately expensive and will require maintenance. The design life of the structure is under two years.

Worksheet - Detention and Filtering Structures.

Step One: Volume of Water and Sediment Yield

Rainfall Excess, P_e = 2.13 inches

Catchment Area, A = 8.6 acres

Actual Sediment Yield, G_y = 6.36 tons

$$\forall_{sw} = 3{,}630\ P_e A + 20.2\ G_y$$
$$= 3{,}630(2.13)(8.6) + 20.2(6.36)$$
$$= 66{,}600 \text{ cu.ft.}$$

Step Two: Minimum Structure Length

Maximum Allowable Ponded Depth, d_{max} = 2.0 feet

Duration of runoff, t_e = 15.6 hours

Flow rate per unit area, K_a = 2.4 ft/hr

Upland slope, S_x = 0.063

Detention Parameter

$$K_f = 1/2\ K_a\ t_e\ d_{max}$$
$$= 1/2(2.4)(15.6)2$$
$$= 37.4$$

Structure Length Coefficient, C_f = 85.1

Minimum Structure Length

$$L_{min} = \forall_{sw}/C_f$$
$$= 66{,}600/85.1$$
$$= 783 \text{ feet}$$

Actual structure length used, L_d = 800 feet

Worksheet (continued).

Step Three: Sediment Trapping Efficiency

Sediment Size (mm)	Actual[1] Sediment Yield G_y (tons)	Fall[2] Velocity w(ft/sec)	Trap[3] Efficiency e_s	Sediment[4] Trapped G_d (tons)
0.010	6.36	----	0.97	6.17
0.0707	0.00	----	1.0	0.00
0.316	0.00	----	1.0	0.00
1.414	0.00	----	1.0	0.00
Total	6.36	/////////	/////////	6.17

(1) From input data

(2) See Table 7.1 (Not needed for filter structures)

(3) For Filter Structures see Figure 7.2

For Detention Structures:

For Sand Sizes:

$e_s = 1 - 4\ (K_a/w)\ (L_f/L_d)\ S_x$

Rock outlet flow rate, K_a = ____----____ ft/sec

Rock outlet length, L_f = ____----____ feet

For the silt size:

$$C_w \quad \frac{2.2 \times 10^{-4}\ L_d}{K_a L_f S_x}$$

= ____----____

$e_s = p_s$ from Figure 6.11

(4) $G_d = e_s G_y$

Worksheet (continued).

Volume of sediment deposition

$$V_s = 20.2\ G_d$$

$$= \underline{125} \text{ cu.ft.}$$

Depth of sediment deposition

$$d_d = \sqrt{2V_s S_x / L_d}$$

$$= \sqrt{2 \times 125 \times 0.063/800}$$

$$= \underline{0.14} \text{ feet}$$

Step Four: Mean Concentration of Effluent

$$C_s = 8{,}830\ (G_y - G_d)/P_e A$$

$$= 8{,}830\ (6.36-6.17)/(2.13 \times 8.6)$$

$$= \underline{92} \text{ ppm}$$

Step Five: Required Structure Height

If d_d is greater than 0.5 feet then add additional freeboard, d_f

$$d_f = d_d - 0.5$$

$$= \underline{0.0} \text{ feet}$$

Total height

$$\text{Structure Height, } H_d = \sqrt{\frac{L_{min}}{L_d}\, d_{max}} + 0.5 + d_f$$

$$= \sqrt{783/800 \times 2} + 0.5 + 0.14$$

$$= \underline{2.6} \text{ feet}$$

APPENDIX A

DETAILED PROCEDURE FOR DETERMINING A PARTICLE SIZE DISTRIBUTION

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PROCEDURAL GUIDE:

The particle size groups which need to be identified for use with the sediment yield procedure are:

clay: less than 0.002 mm

p_1 = silt (si): 0.002 mm - 0.05 mm (x_g=0.01)

p_2 = very fine sand (vfs): 0.05 mm - 0.1 mm (x_g=0.0707)

p_3 = fine, medium & coarse sand: 0.1 mm - 1.0 mm (x_g=0.316)

p_4 = very coarse sand: 1.0 mm - 2.0 mm ([x_g=geometric mean] x_g=1.41)

The SCS surveys and soil series descriptions do not give these groups directly, although they do give the general textural class of the soil, e.g., loam, clay loam, or sandy clay as well as data on particle size distribution. By using these two sets of soil information, i.e., general textural class and data on the particular size distribution, the required soil particle size groups can be determined.

First, the required particle size groups except for the silt group (p_1) and clay can be determined by using the particle size distribution data. These size distribution data are expressed in soil series as cumulative percentages less than 3 inches passing the:

#4 sieve (<4.74 mm)

#10 sieve (<2 mm)

#40 sieve (<.42 mm)

#200 sieve (<.074 mm)

These cumulative percentages provide data points for determining a particle size frequency distribution curve using the log probability method.

First the range of values corresponding to the sieve number are plotted on log probability paper (Figure A.1). Then, a straight line is drawn close to the mean of each of the plotted ranges, giving a cumulative frequency distribution. By extrapolating the line down to the 0.05 mm size, the 3 larger particle size groups (p_2, p_3, p_4) used in the design analysis can be determined. The particle sizes are read from the cumulative frequency distribution line and the percent in the particle size class is determined by subtracting out the next smaller class.

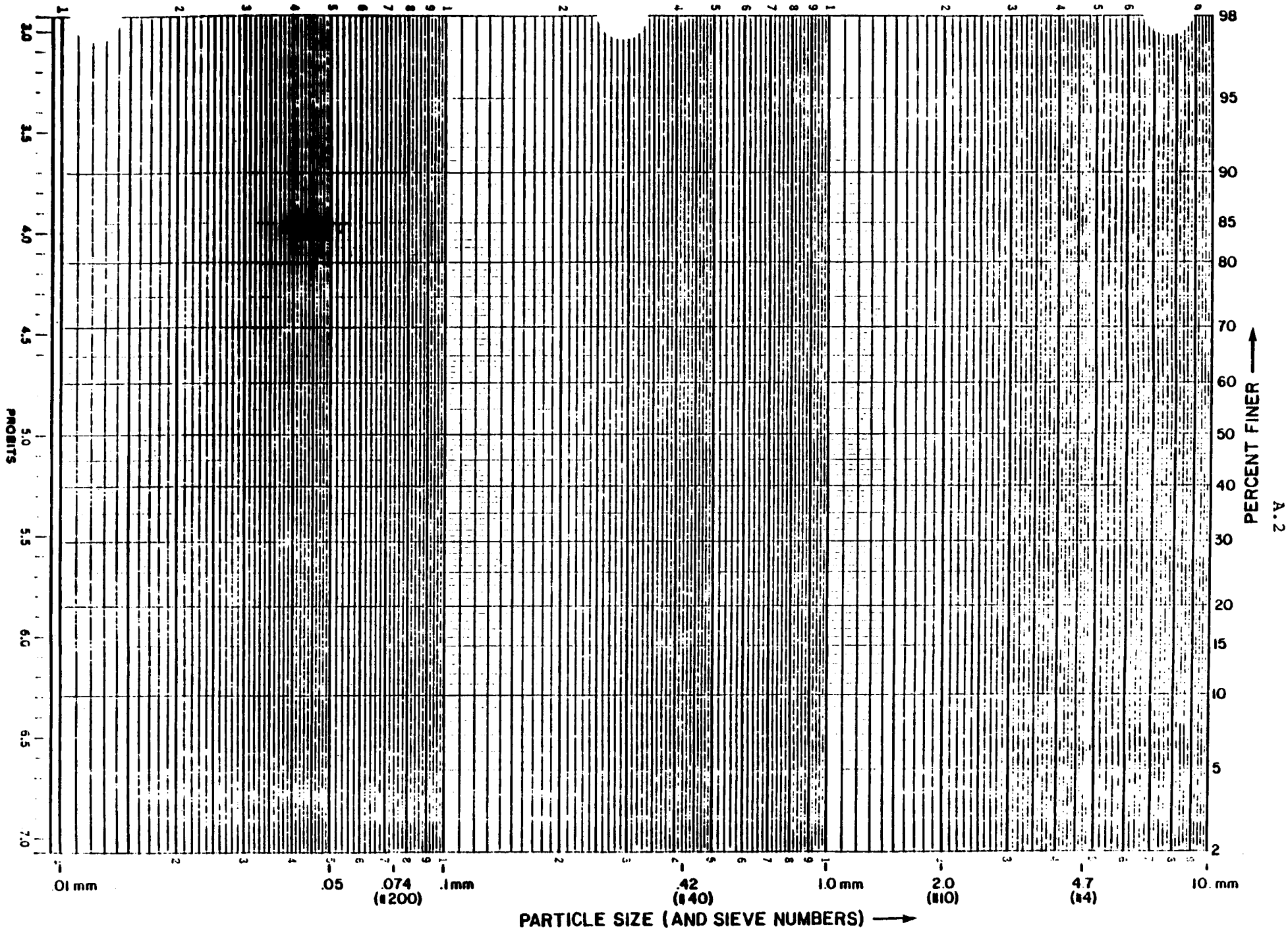

Figure A.1. Log-probability paper.

Silt (p_1) is estimated from the textural class given in a soils description. A textural class is simply a name given to each soil which designates the ranges of sand, silt and clay it contains. Table A.1 defines the textural classes and their associated sand, silt and clay components. Because this classification is based on the <2 mm particle sizes, the percent silt in a particle class must be adjusted to the percentages upon which the frequency distribution method is based, namely the <3 inch particle sizes. This adjustment is included below in a step-by-step procedure for determining the particle size groups using SCS soil series information:

*1. Plot the cumulative percent given in SCS series description at appropriate points on Figure A.1.

*2. Draw a straight line through the values (or range of values) and extrapolate the line to 0.05 mm size.

*3. Determine the cumulative percent corresponding to the required size classes (0.05, 0.1, 1.0, 2.0 on x axis).

*4. Subtract the next smaller percent from each reading which gives the percent for the 3 coarsest particles size groups (0.05-0.1 mm; 0.1-1.0 mm; 1.0-2.0 mm) (based on <3 inch size sample).

*5. To determine p_1 (0.002-0.05), identify the assigned texture class given in the soil series description.

*6. Determine the mean silt percent corresponding to the assigned texture class for the given soil (Table A.1).

*7. Multiply the mean silt percent by the cumulative percent <2 mm (see step 3) to give the percent 0.002-0.05 mm (percent <3" size).

*8. Subtract the cumulative percent of the three large particle sizes plus the percent 3 inches to 2 mm from 100 to give the clay percentage.

Table A.1. Percent Sand, Silt and Clay in Textural Classes (<2 mm sized particles)

Textural Class	Range in Percent		
	sand (2.0-0.05 mm)	silt (0.05-0.002 mm)	clay (<0.002 mm)
Sand*	85-100	0-15	0-10
Loamy Sand*	70-90	0-30	0-15
Sandy Loam*	43-80	0-50	0-20
Loam	23-52	28-50	7-27
Silt Loam	0-50	50-88	0-27
Silt	0-20	80-100	0-12
Sandy Clay Loam	45-80	0-28	20-35
Clay Loam	20-45	15-53	27-40
Silty Clay Loam	0-20	40-73	27-40
Sandy Clay	45-65	0-20	35-55
Silty Clay	0-20	40-60	40-60
Clay	0-45	0-40	40-100

*Coarse : Greater than 25 percent coarse sand

Fine : 50 percent or more fine sand; less than 25 percent coarse sand

Very Fine: 50 percent or more very fine sand

EXAMPLE:

1. Given: SCS soil series data.

USDA Texture	Percentage <3 Inches Passing Sieve			
	No. 4 (4.7 mm)	No. 10 (2.0 mm)	No. 40 (0.42 mm)	No. 200 (0.074 mm)
Loam	100-95	85-95	80-90	45-65

2. Plot data (Figure A.2) according to Steps *1 through *8 above.

3. Tabulate data.

Particle Size (mm)	Cumulative Frequency (Mean) %	Particle Size Class mm	% (<3" size)
<0.05	50	0.002-0.05*(p_1)	37
<0.1	62	0.05-0.1(p_2)	12
<1.0	90	0.1-1.0(p_3)	28
<2.0	94	1-2.0(p_4)	4

*From Table A.1 where loam has a mean of 39 percent (of <2 mm sample). This is multiplied by 94 percent, which is the % of <2 mm sized particles from <3" size sample

4. Percent Clay = 100 - (37 + 12 + 28 + 4 + 6) = 13%
(from Step *8 above)

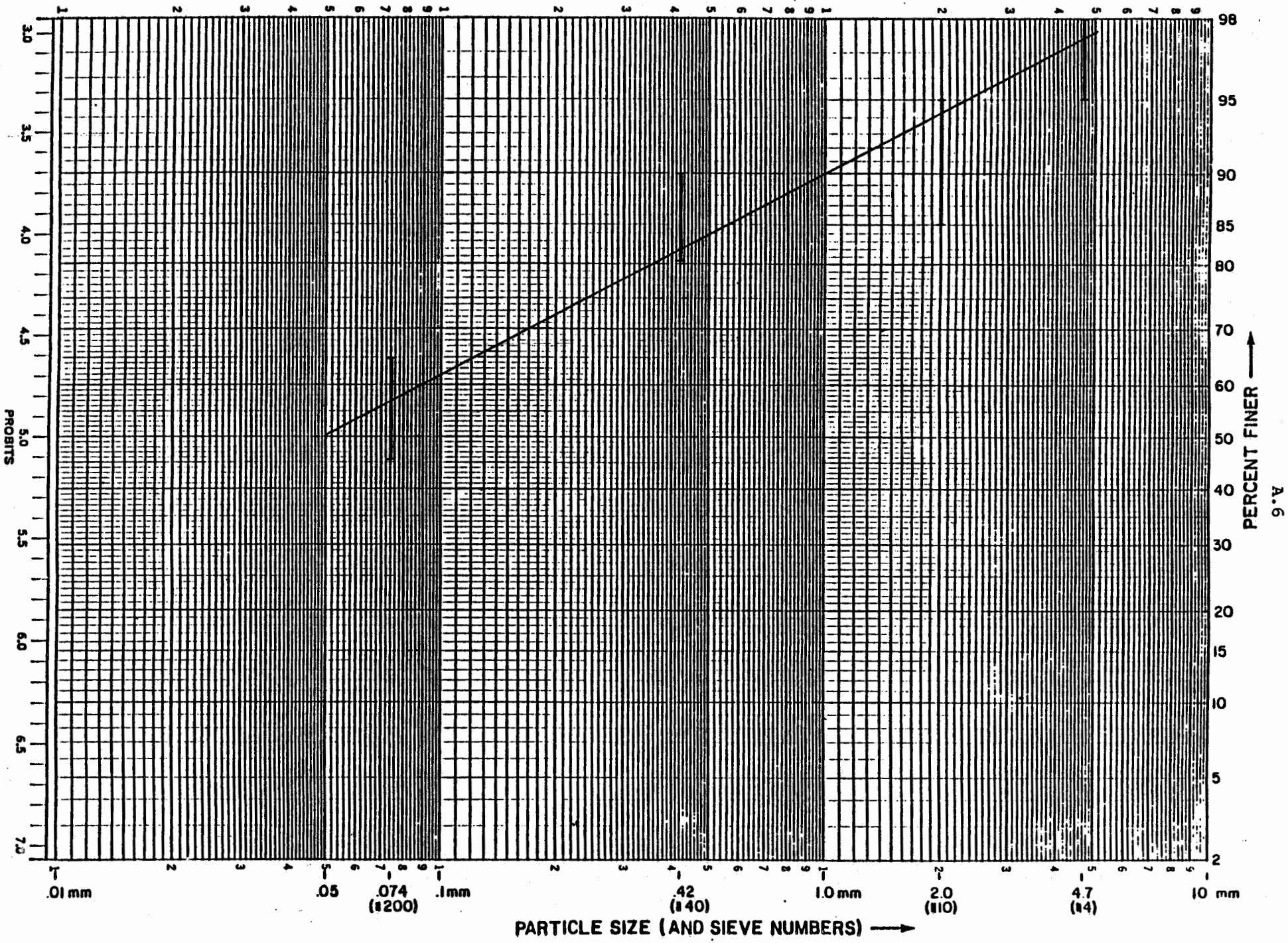

Figure A.2. Particle size distribution of example soil.

APPENDIX B

DETAILED PROCEDURE FOR DETERMINING AN ERODIBILITY VALUE, K_e

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PROCEDURAL GUIDE

Values of K_e can be obtained from soil series descriptions in SCS surveys or, when values have not been published, determined from the soil erodibility nomograph developed by Wischmeier, et al., (1971) (Figure B.1). The percent sand ranging from 0.1 - 2 mm and the percent silt plus very fine sand (0.05 - 0.1 mm) (left section of nomograph) can be readily obtained from the particle size distribution method (Appendix A).

Relative permeability classes (lower right section of Figure B.1) refer to the entire soil profile and are coded from 1 (rapid) to 6 (very slow). These classes correspond to permeability rates given in a soil survey or, if not available, the rates can be deduced from routine soil profile descriptions. Field or laboratory measurements of permeability are usually not necessary. The permeability rates which correspond to the six classes and general guidelines for assessing these classes in the field are given in Table B.1. The relationships and correlation between the permeability classes and the four soil-hydrologic groups, A-D, as defined in the SCS curve number method (section 3.1) are given in Table B.2.

The structural classes (upper right section of Figure B.1) refer to the aggregation of soil particles into clusters which are separated from other aggregates by planes or surfaces of weakness. The structural classifications, e.g. granular or platey, are given in SCS survey descriptions and can be used to place a soil into its appropriate nomograph code, 1-4, as defined in Table B.3. Detailed field descriptions of structure which are necessary at a disturbed or topsoiled site are also given in Table B.3. These guides are a useful supplement to soil series descriptions because site specific conditions are then taken into account.

The final parameter needed to estimate K_e from the nomograph is organic matter content. It is recommended that 4 percent organic mater content be used for those soils having greater than 4 percent content unless additional available data suggest otherwise. If information on organic matter is not available in a soil series description, it can be determined by laboratory analysis using the dry combustion method or Walkley-Black wet combustion method given in Black (1965).

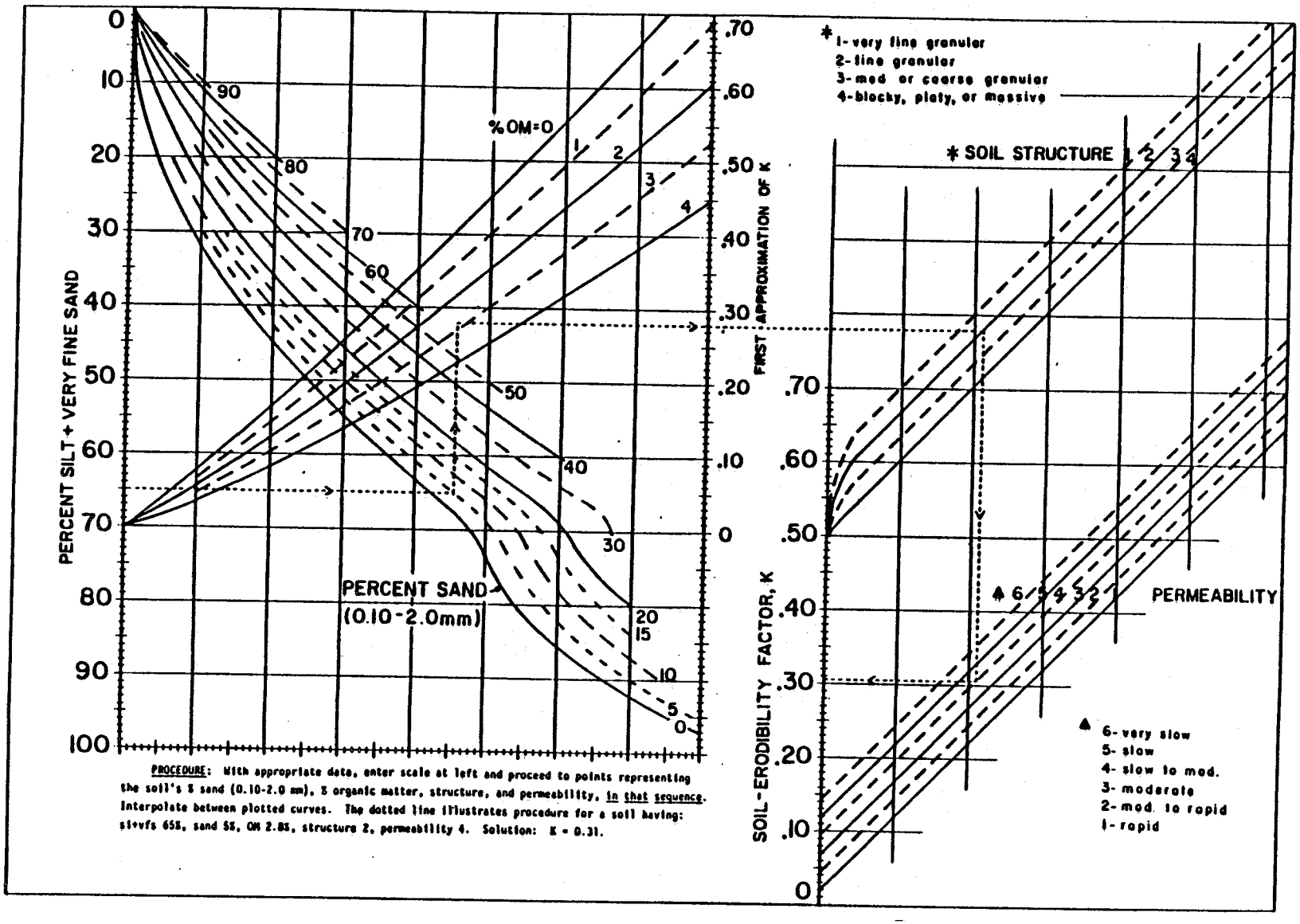

Figure B.1. Soil erodibility nomograph (from Wischmeier, et al., 1971).

Table B.1. Assessment of Permeability Classes.

Permeability Class	Permeability rates in/hr*	Nomograph 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

*Based on saturated flow through saturated undisturbed core under 1/2-inch head

(In the absence of measurements or classes, soils and minesoils can be placed into classes by evaluating structure, particle sizes, porosity, cracking and other characteristics which appear to control the soil's permeability. Generally, it is necessary to assess the soil horizons (layers) and determine which layer is least permeable (controlling layer.)

Table B.2. Approximate Relationships Between Permeability Codes and Soil-Hydrologic Group.

Permeability Class Code	Guideline	Corresponding Soil-Hydrologic Group (CN Method)
1-2	Gravelly, sandy soils; very well drained; deep; well developed; includes soils which remain open and do not form surface seal; intake is not restricted.	A (High)
3	Moderately coarse to moderately fine texture; moderate or strong subsoil structure with textures coarser than silty clay loam.	B (Moderate)
4	Moderately coarse to moderately fine texture; includes silty clays and silty clay loams; weak angular or subangular blocky structure with moderate permeabilities.	
5	Moderately fine grained soils; soils underlain by massive clays or silty clays.	C (Low)
6	Soils underlain by fragipans; high-swelling clay soils; shallow soils over nearly impermeable layers; may include soils within a permanently high water table.	D (Very Low)

Table B.3. Assessment of Structure Classes.

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

Field Structure Guidelines

Very fine granular: refers to particles subspherical in shape which are generally nonporous. "Very fine" includes aggregates <1 mm in size.

Fine granular: refers to 1-2 mm sized aggregates

Medium-coarse granular: refers to 2-10 mm sized aggregates

Platy: refers to particles arranged along a plane - roughly horizontal

Blocky: refers to particles arranged in a polygon shape bounded by flat or slightly rounded surfaces or planes

Massive: refers to coherent soils which have no observable aggregation pattern or distinct arrangement of natural lines of weakness.

To improve the estimated K value for clay pans and expanding shales, which commonly occur in mining areas, two separate erodibility factors for "dry" and "wet" seasons may be desirable. The permeability ratings should be reduced during the wet season but not during thunderstorms occurring in the dry season. The U.S. Forest Service (1980) recommends the following computation for weighted annual mean K values for wet and dry seasons:

$$K' = \frac{(K_w M_w + K_d M_d)}{M_w + M_d}$$

where

K' = weighted mean erodibility,

K_w = soil erodibility during wet season,

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.

An example procedure for determining K_e from the nomograph is given in Figure B.1. A methodology for determining or estimating all soils data (Appendix A - Particle Size Distribution and Appendix B - Soil Erodibility) is illustrated in a step-by-step flow chart in Figure B.2.

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Black, C.A. (ed). 1965. Methods of Soil Analysis, Agron. Mono. Ser. 9, Amer. Soc. Agron., Madison, Wisconsin, 1572 p.

U.S. Department of the Army. 1970. Laboratory Soils Testing, Department of the Army, Office of Chief Engineers, EM 1110-2-1906.

U.S. Forest Service. 1980. An Approach to Water Resources Evaluation of Non-Point Silva Cultural Sources, Envir. Protection Agency, Athens, Georgia, EPA-IAG-D6-0660.

Wischmeier, W.H., C.B. Johnson, B.V. Cross. 1971. A Soil Erodibility Nomograph for Farmland and Construction Sites, J. Soil & Water Conservation, pp 189-192.

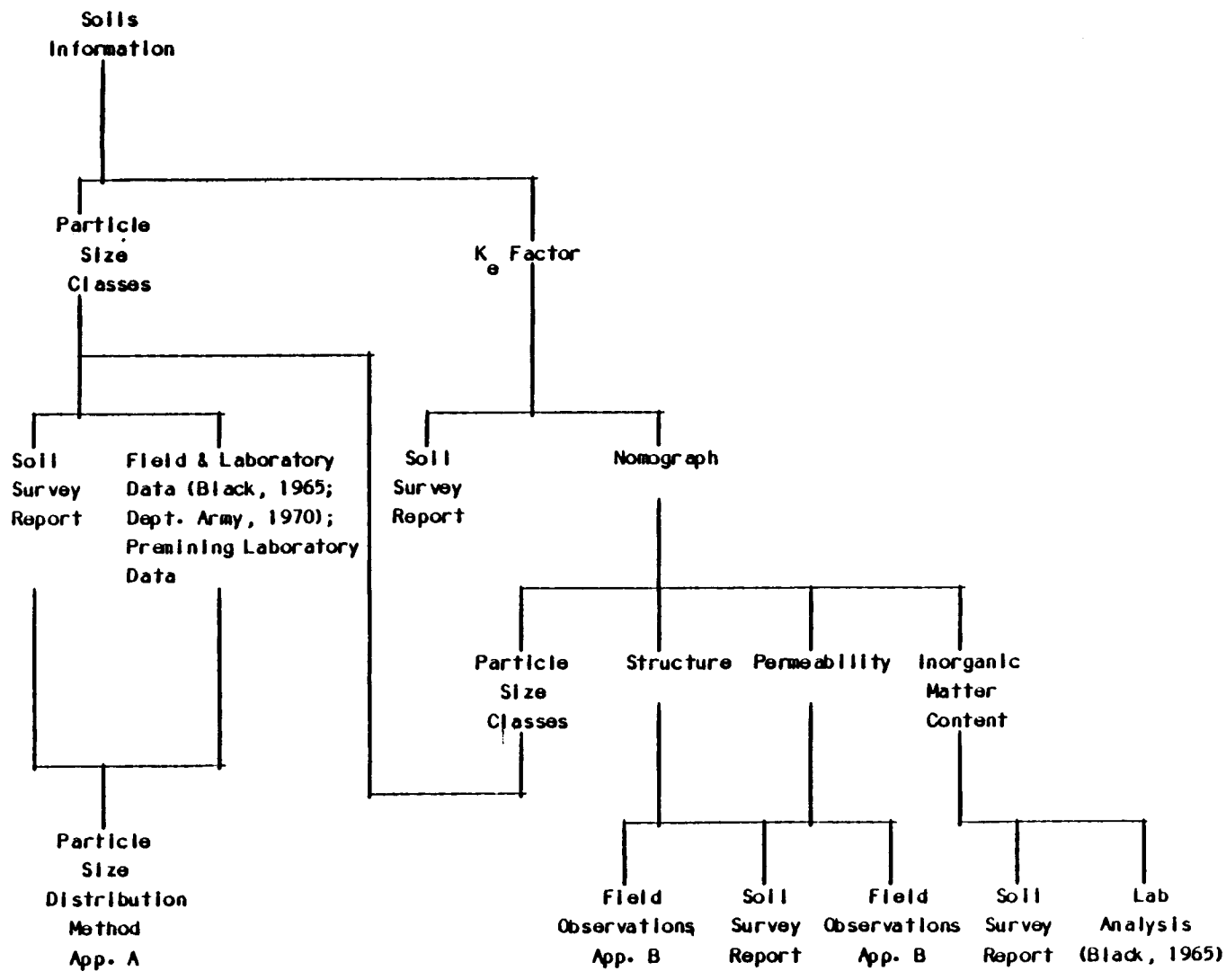

Figure B.2. Flow chart for acquiring data for soils and surficial material.

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APPENDIX C

BASIC EQUATIONS USED IN DEVELOPING DESIGN NOMOGRAPHS

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I. OVERLAND FLOW SEDIMENT TRANSPORT EQUATIONS

$$g_t = a_1 q^{b_1}$$

where: $a_1 = 1.8 \times 10^a S^c K_g^d$

$b_1 = b + e \log S + fK_g + gK_g \log S$

where: g_t = sediment transport in tons/ft/hour

q = unit discharge of water in cfs/ft

S = slope

K_g = roughness

a_1, b_1, a, b, c, d, e, f, g are constants

Size	1.414	0.316	0.0707	0.010
a	2.3528	4.2803	5.41128	6.03605
b	0.8953	0.93503	1.18880	1.24488
c	1.4956	1.57333	0.94274	0.60139
d	-0.4795	-1.17952	-1.20217	-1.166244
e	0.0255	-0.00603	-0.13248	-0.070568
f	5.788×10^{-4}	-4.879×10^{-5}	-1.0857×10^{-5}	-4.0342×10^{-6}
g	-2.9483×10^{-3}	-4.1868×10^{-4}	-5.9671×10^{-5}	-9.56907×10^{-6}

II. CRITICAL DISCHARGE FOR OVERLAND FLOW

$$q_c = C_1 (K_g/S)^2$$

where: q_c = critical unit discharge of water in cfs/ft

C_1 = critical flow coefficient

Size	C_1
1.414	6.85×10^{-9}
0.316	7.65×10^{-11}
0.0707	8.57×10^{-13}
0.010	2.42×10^{-15}

III. DIVERSION AND CONVEYANCE SEDIMENT TRANSPORT EQUATIONS

$$g_t = aV^b d_h^c$$

where: g_t = sediment transport rate in tons/ft/hour

V = velocity in feet/second

d_h = hydraulic depth in feet

a, b, c are constants

Size	1.414	0.316	0.0707	0.010
a	0.0140	0.0792	0.1323	0.943
b	3.917	3.461	3.348	3.230
c	0.554	0.433	0.540	0.628

IV. CRITICAL VELOCITY FOR CHANNEL FLOW

$$V_c = a\, d_h^{0.667}$$

where: V_c = critical velocity in ft/sec

d_h = hydraulic depth in feet

a = constant

Size	1.414	0.316	0.0707	0.010
a	1.41	0.666	0.315	0.119

V. MAXIMUM OVERLAND FLOW COEFFICIENT

$$C_1 = 43{,}560 \left[15{,}894 \frac{P_1}{C_s} a \ (0.50)^b \right]^{\frac{1}{1-b}}$$

where: C_1 = overland flow coefficient

P_1 = decimal percent of silt in soil

C_s = sediment concentration in parts per million

a and b are constants, where

$$a = 2.794 \times 10^5 \ (K_g/S)^{-0.917}$$

$$b = 1.246 + 4.024 \times 10^{-4} \sqrt{\frac{K_g}{S}} - 3.12 \times 10^{-8} \frac{K_g}{S}$$

VI. STRUCTURE LENGTH COEFFICIENT

$$C_f = a + b \ (t_e K)$$

where: C_f = structure length coefficient

t_e = duration of rainfall excess in hours

K = flow rate per unit area in ft/hr

a and b are constants, where

$$a = 1.862 S_x^{-1.016}$$

$$b = 1.707 \ S_x^{0.05976}$$

S_x = slope immediately above the structure

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APPENDIX D

ESTIMATING COST OF TREATMENTS, STRUCTURES AND MATERIALS

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Cost Estimation

The cost of implementing erosion control practices is variable depending on the region, site conditions, eg. slope, aspect and soil, size of the area, proximity of materials, labor rates, and timing of installment. More importantly, cost will be highly dependent on whether erosion control work is done concurrently with or closely following the mining operation and if mining equipment and labor are utilized. Therefore, it is difficult to generalize regionally or nationwide on a year-round basis.

With this in mind, realistic approximations of cost data have been collected and summarized in Table D.1. Additional sources of information are: state highway departments, mining companies, and SCS.

Cost data are organized into the following categories: surface protection measures, mechanical treatments, and diversion, conveyance, detention and filtering systems. Surface protection measures (Table D.1a) include mulches, chemical stabilizers, nets, blankets, mats, tackifiers, revegetation measures (seed and fertilizer) and combined treatments. The cost of liming, soil testing or gypsum application which may be required before implementing surface protection measures are not included. The costs incurred during topsoiling are included under revegetation. Associated costs not included are temporarily stabilizing a topsoil stockpile and final reclamation of the area disturbed by the stockpile. The mechanical treatments included in Table D.1b are only those described and specified in Chapter IV. Cost data for the four practices - diversion, conveyance, detention and filtering - are combined in Table D.1c. Items from this table can be combined or used singularly when analyzing costs of designing these erosion control measures.

The unit cost data are usually expressed as the pay item unit cited in the standard specifications for each particular treatment or structure (Chapters IV to VII). Cost data represent the range of costs incurred to contractors for materials, equipment operation, and installation unless otherwise specified. Maintenance costs which are extremely variable and dependent on climate and site-specific conditions, are not included in the cost estimates unless specified. Unit costs for mechanical treatments have been divided into two parts depending on whether equipment is owned or rented (contracted).

To assist in assessing total costs of each erosion control practice (or combined practices) a worksheet is provided in Table D.2. Although not specified for each particular erosion practice, cost of renting or buying equipment to construct or emplace structures or treatments is an important item for consideration. Unless contracted, these costs include rental or purchase amount, taxes, insurance, fuel, maintenance, and depreciation. Many types of equipment may already be available on site at a mining operation, eg. dozers, crawlers, trucks, scrapers and front end loaders. Other implements may be purchased or rented from farm or rangeland dealers in the area, eg. seeders, plows, and disks. Irrigation equipment may also be needed to maintain a seeded and mulched area for one or several growing seasons.

Labor costs will vary widely, depending on the type or combinations of treatments or structures required on the site. Some of the costs of labor are included in "total cost" estimates in Table D.1. Initial work required to prepare a site before actually implementing a control practice may be incorporated into the mining and postmining work, eg. leveling and grading spoil material. Hence, the overall cost of a treatment may be minimized by premine planning and coordination with the active mining operation.

Most treatments and structures require a substantial amount of labor in achieving the most cost-effective result. If properly designed, implemented, and monitored during the early stages of reclamation, overall cost will be minimized because periodic maintenance costs will be greatly reduced.

Installation of any of the erosion control practices involves supervision and sometimes design costs. When incurred, the costs will depend on the complexity of the treatment or structure and on whether the company or a contractor does the work. Utilization of mining company personnel, mining and postmining overburden manipulation, and mining equipment can greatly decrease the price of implementing a control measure.

The cost-effectiveness of an erosion control practice is an essential piece of information for final appraisal of a total control design plan. As suggested earlier, cost (and cost-effectivness) is a function of site-specific conditions, climate and design objective for reduction in sediment yield. The cost-effectivess of a particular design should be compared to that of another design only when both designs fulfill the same sediment reduction objective. The cost analysis can then be used to determine the most cost-effective design

to achieve the required sediment reduction at a site.

Several different practices and combinations of methods and materials should be evaluated using Tables D.1 and D.2 before a final design is accepted. For example, if mulching is selected, several alternative materials are available. The least expensive choice will take advantage of material and equipment available on site, such as wood chips from the clearing operation or gravel from the overburden.

In summary, overall costs are highly variable and must be assessed critically at a site before finalizing a design. The costs given in Table D.1 are realistic approximations (not maximums or minimums) and provide a means of estimating relative costs associated with a particular erosion control structure or measure.

References

Brown, L.F. 1982, in press. A Definition of Mined-Land Reclamation and Its Relationship With the Use of Topsoil as an Amendment to Aid Revegetation, Am. Mining Congress (mtg. in Denver, Colorado, 1981).

Table D.1. Cost Data for Erosion Control Practices.

D.1a. Surface Protection Measures

Surface Protection Measures	Unit Cost (includes materials only unless specified)
Mulch	
Conwed Wood Fiber	$.20/lb - $400/ton
Silva Wood Fiber	$.10/lb - $200/ton
Stone and Gravel	$5.60/ton (Total Cost)
Straw (mechanically crimped)	$100-200/ton (Total Cost)
Woodchips	$42.30/ton (Total Cost)
Turifiber	$.12/lb - $244/ton
Wood Fiber	$.11/lb - $222/ton
Hydro Mulch (grass seed/ cellulose fiber)	$615/ton (Total Cost)
Chemical Stabilizer	
Aero Spray	$3.40/gal
Terratack	$6.20/lb
Genequa	$3.90/gal
Asphalt (Tackifier)	$1.20/gal
Nets, Blankets, Mats	
Holdgro (paper and nylon)	$2,130/acre
Excelsior (curlex)	$1,500/acre
Jute Mesh	$2,800-6,000/acre
Enkamat	$16,553-24,200/acre
Mulch with Chemical Stabilizer and Tackifier	
Straw/Asphalt	$288/gal
	$480/gal applied (Total Cost)
Wood Fiber/Terratack	$123/package (100 lb)
Wood Fibert/Aerospray	$304/500 lb/45 gal
Wood Fiber/Genequa 743	$277/500 lb/45 gal
Wood Fiber/Petroset SB	$252/500 lb/45 gal
Straw/Curasol AK	$371/1.5 ton/40 gal
Wood Fiber/Dow Mulch Binder	$198/500 lb/45 gal
Straw/Terratack	$291/1.5 ton/45 lb
Straw/Dow Mulch Binder	$286/1.5 ton/45 lb

Table D.1. (continued).

D.1a. Surface Protection Measures (continued)

Surface Protection Measures	Unit Cost (includes materials only unless specified)
Revegetation Measures	
Seeds - Average Total Cost of Seeds (grass, clover, etc.) and Seeding Cost (rate varies with soil and seed type)	$11/lb
Seeds - Weeping Lovegrass	$2/lb
Crimson Clover	$1/lb
Tall Fescue	$.50/lb
Kentucky Bluegrass	$2/lb
Redtop	$4/lb
Crown Vetch	$10/lb
Red Clover	$1.50/lb
Flat Pea	$6/lb
Fertilizer - Nitrogen	$.65/lb
Seed and Mulch - Hydromulch (seed/ cellulose fiber)	$615/ton (Total Cost)
Basic Regrading and Reseeding	$1,500/acre
Maintenance (purchase and application of maintenance fertilizer)	$50/acre
Respreading Topsoil Without Stockpiling	$500/acre
Stockpiling and One Move of Topsoil (may require more than 1 move)	$2,800/acre
Total Cost (average over 4-6 years)[1]	$1,700-7,150/acre

[1]From Brown, 1982 (in press)

Table D.1. (continued).

D.1b. Mechanical Treatments

Mechanical Treatment	Unit Cost (Total Cost) Hired Contractor	Own Equipment
Contour Furrowing	$20-50/acre	~$15/acre
Pitting	$20-50/acre	~$15/acre
Ripping	$60-120/acre	~$50/acre
Land Imprinting	-----	~$10-20/acre

D.1c. Diversions, Conveyance, Detention and Filter Systems

Diversion, Conveyance, Detention, Filtering	Unit Cost (includes materials, equipment operation, emplacement)
Diversion, Lined	$5-10/lin ft
Diversion Unlined	$1.50-4.50/lin ft
Perimeter Berm	$1-2/cu yd
Silt Fence	$3-6/lin ft
Straw Bale Barrier	$3-7.50/lin ft $9-22.50/bale
Brush Barrier	$5-10/sq yd
Rock Outlet	
Riprap	$25-35/cu yd
Aggregate	$20-30/cu yd
Plastic Filter Fabric	$1-3 sq yd

Table D.1. (continued).

D.1c. Diversions, Conveyance, Detention and Filter Systems (continued)

Diversion, Conveyance, Detention, Filtering	Unit Cost (Total Cost)
Check Dam - Riprap	$25-35 cu yd
Waterways	
Grass-Lined, Seeded	$2-5/sq yd
Grass-Line, Sodded	$7-10/sq yd
Riprap	$25-35/cu yd
Miscellaneous Treatment	
Excavation	$5-15/cu yd
Raking	$40-45/acre
Hauling	$.20-.30/ton/mi
Scarification (about 1 ft deep)	$40/acre

Table D.2. Worksheet for Calculating Total Cost of Installing an Erosion Control Measure.

Equipment		
Rental		_____
Purchase		_____
Company Owned		_____
	Subtotal	_____
Labor		
Outside Labor		_____
In-House Labor Force		_____
	Subtotal	_____
Material		
On-Site Material		_____
Other Material		_____
	Subtotal	_____
Miscellaneous		
Soil Preparation		_____
Maintenance		_____
Topsoil Stockpile Stabilization and Reclamation		_____
	Subtotal	_____
Supervision, Design, Contingencies		
	Subtotal	_____
	TOTAL	_____

APPENDIX E

GLOSSARY

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Abstraction. That amount of rainfall which does not runoff due to infiltration, detention storage, or interception by vegetation.

> **Initial abstraction.** That amount of rainfall abstracted during the beginning of the storm. See Retention.

Acid soil. A soil giving an acid reaction throughout most or all of the portion occupied by roots (precisely, pH <7.0; practically, pH <6.6).

Alkaline soil. Any soil horizon having a pH greater than 7.3.

Amendment. Any materials, eg. gypsum, sawdust, lime or synthetic conditioner, worked into the soil to make it more productive.

Arid. Regions or climates that lack sufficient moisture for crop production without irrigation. The upper limits of precipitation vary according to temperature conditions. In temperate regions, an upper average annual limit is 8 to 10 inches.

Broadcast seeding. Scattering seed on the surface of the soil.

Buffer strip. 1. Unaffected areas between the mining operation and areas designated for other public or private use. 2. Strips of grass or other erosion resistant vegetation between or below surface or auger mining disturbance.

Canopy. The cover of leaves and branches formed by the tops or crowns of plants.

Check dams. Small dam constructed in a gully or other small water course to decrease the stream flow velocity, minimize channel scour, and promote deposition of sediment.

Clay. 1. Particle size or soil separate consisting of particles sizes <0.002 mm in equivalent diameter. 2. Soil textural class.

Compaction. The closing of the pore spaces among the particles of soil and rock, generally caused by running heavy equipment over the area as in the process of leveling the overburden material of strip mine banks.

Contour. An imaginary line connecting points of equal height above sea level as they follow the relief of the terrain.

Contour furrowing. A mechanical treatment for controlling erosion by creating trenches or furrows on the contour of the slope.

Contour stripping or surface mining. The removal of overburden and mining from a coal seam that crops out or approaches the surface at approximately the same elevation in steep or mountainous terrain.

Conveyance channel. A stabilized drainageway used to collect water from diversions and overland flow areas and to deliver it from the site to the established disposal area.

Cover, crop. A close growing crop grown primarily for the purpose of protecting and improving soil between periods of regular crop production.

Cover, ground. Any vegetation producing a protecting mat on or just above the soil surface.

Cover factor. The ratio of cover area to total area.

Curve number. Coefficients used for estimating surface runoff depth from rainstorms.

Density, vegetative. The percentage of ground surface that appears to be completely covered by vegetation when viewed directly from above.

Deposition. The accumulation of material dropped because of a slackening movement of the transporting agent - water.

Detachment. The removal of transportable fragments of soil material from a soil mass by an eroding agent, usually falling raindrops or running water. Through detachment soil particles are made ready for transport - soil erosion.

Direct seeding. A method of establishing a stand of vegetation by sowing seed on the ground surface.

Diversion. Channel constructed across the slope for the purpose of intercepting surface runoff. Changing the accustomed course of all or part of a stream.

Drop structure. A structure constructed across the channel to adjust the effective slope of the channel.

Erodibility. See Soil erodibility.

Erosion. 1. The wearing away of land surface by running water, wind, ice, or other geological agents, including such processes as gravitational creep. 2. Detachment and movement of soil or rock fragments by water, wind, ice, or gravity.

The following terms are used to describe different types of erosion:

Accelerated erosion. Erosion much more rapid than normal, natural, or geologic erosion, primarily as a result of the influence of the activities of man or, in some cases, of other animals or natural catastrophies that expose base surfaces, for example, fires.

Geological erosion. The normal or natural erosion caused by geological processes acting over long geologic periods and resulting in the wearing away of mountains, the building up of floodplains, coastal plains, etc. Syn: Natural erosion.

Gully erosion. The erosion process whereby water accumulates in narrow channels, over short periods, and removes the soil from this narrow area to considerable depths, ranging from 1 to 2 feet to as much as 75 to 100 feet.

Natural erosion. Wearing away of the earth's surface by water, ice, or other natural agents under natural environmental conditions of climate, vegetation, etc., undisturbed by man. Syn: Geological erosion.

Normal erosion. The gradual erosion of land used by man which does not greatly exceed natural erosion. See Natural erosion.

Rill erosion. An erosion process in which numerous small channels only several inches deep are formed. Occurs mainly on recently cultivated soils.

Sheet erosion. The removal of a fairly uniform layer of soil from the land surface by runoff water.

Splash erosion. The spattering of small soil particles caused by the impact of raindrops on wet soils. The loosened and spattered particles may or may not be removed subsequently by surface runoff.

Erosive. Refers to wind or water having sufficient velocity to cause erosion. Not to be confused with Erodible as a quality of soil.

Fertility. The quality of soil that enables it to provide nutrients in adequate amounts and in proper balance for the growth of specified plants when other growth factors, such as light, moisture, temperature, and the physical condition of the soil are favorable.

Filtering efficiency. Ratio of weight of sediment trapped in the filter material to the weight of incoming sediment.

Gravel. Aggregate consisting of mixed sizes of 1/4 inch to 3 inch parameters.

Gully. See Erosion.

Hardpan. A hardened soil layer in the lower A or in the B horizon caused by cementation of soil particles with organic matter or with materials such as silica, sesquioxides, or calcium carbonate. The hardness does not change appreciably with changes in moisture content, and pieces of the hard layer do not slake in water.

Hydraulic conductivity. See Permeability.

Hydraulic radius. Ratio of cross section area to wetted perimeter.

Hydrograph. Graph showing the variation in time of some hydrological observation data.

Hydrology. The science that relates to the water systems of the earth.

Hydroseeding. Dissemination of seed hydraulically in a water medium. Mulch, lime, and fertilizer can be incorporated into the sprayed mixture.

Hyetograph. Chart displaying temporal or areal distribution of precipitation.

Infiltration. The flow of a liquid into a substance through pores or other openings, connoting flow into a soil in contradistinction to percolation, which connotes flow through a porous substance.

Inlet. The upstream end of any structure through which water may flow.

Intermittent stream. A stream or portion of a stream that flows only in direct response to precipitation. It receives little or no water from springs and no long-continued supply from melting snow or other sources. It is dry for a large part of the year, ordinarily more than 3 months.

Isopluvial map. Map showing contour lines of equal precipitation, often defined on an average annual basis.

Land imprinting. Mechanical treatment for controlling erosion by creating a geometric surface resulting in microbasins and v-furrows.

Lime. Lime, from the strictly chemical standpoint, refers to only one compound, calcium oxide (CaO); however, the term lime is commonly used in agriculture to include a great variety of materials that are usually composed of the oxide, hydroxide, or carbonate of calcium or of calcium and magnesium. The most commonly used forms of agricultural lime are ground limestone (carbonates), hydrated lime (hydroxides), burnt lime (oxides), marl, and oyster shells.

Mulch. Natural or artifical material used to provide more desirable moisture and temperature relationships for plant growth. It is also used to control unwanted vegetation.

Overland flow. Water usually storm runoff, flowing in a thin layer over the ground surface.

Overland flow detachment. See Detachment.

Particle size distribution. The amount of the various soil separates or individual soil particles in a soil sample, usually expressed as percent weight of clay, silt and sand (or subdivisions thereof).

Permeability. The quality of a soil horizon that enables water or air to move through it. The permeability of a soil may be limited by the presence of one nearly impermeable horizon even though the others are permeable.

pH. A numerical measure of the hydrogen ion concentration. It is used to indicate acidity and alkalinity. The neutral point is pH 7.0; pH values below 7.0 indicate acid conditions and those above 7.0 indicate alkaline conditions.

Pitting. Mechanical treatment for controlling erosion by creating small basins or pit on the contour of the slope.

Physical process. Describes the occurrence or continuing development which involve change of a physical entity usually at or near the earth's surface; caused by forces or agents such as water, wind, gravity, temperature differential.

Rainfall detachment. See Detachment.

Rainfall excess. That portion of rainfall that becomes runoff discharged from an area.

Reclamation. The process of reconverting mined land to its former or other productive uses.

Regrading. The movement of earth over a surface or depression to change the slope of the land surface.

Rehabilitation. Implies that the land will be returned to a form and productivity in conformity with a prior land use plan, including a stable ecological state that does not contribute substantially to environmental deterioration and is consistent with surrounding esthetic values.

Retardance classification. A qualitative description of the resistance to flow offered by various types of vegetation.

Retention. The amount of precipitation on a drainage area that does not escape as runoff. It is the difference between the total precipitation and total runoff.

Revegetation. Plants or growth that replaces original ground cover following land disturbance.

Revetment. A facing of stone or other material, either permanent or temporary, placed along the edge of a stream to stabilize the bank and protect it from the erosive action of the stream.

Rill. See Erosion.

Ripping. Erosion control mechanical treatment which shatters subsoil layers thereby increasing soil water movement.

Riprap. Broken rock, cobbles, or boulders placed on earth surfaces, such as the face of a dam or the bank of a stream, for protection against the action of water (waves). Also applied to brush or pole mattresses, or brush and stone, or other similar materials used for soil erosion control.

Rock-fill dam. A dam composed of loose rock usually dumped in place, often with the upstream part constructed of handpacked or derrick-placed rock and faced with rolled earth or with an impervious surface of concrete, timber, or steel.

Runoff. That portion of the precipitation on a drainage area that is discharged from the area in stream channels. Types include surface runoff, ground water runoff, or seepage.

Saline soil. Non-sodic soil containing sufficient soluble salts to impair productivity.

Sand. 1. A particle size or soil separate consisting of particle sizes 0.05 to 2.0 mm in equivalent diameter. 2. Soil textural class.

Scarify. To loosen or stir the surface soil without turning it over. Also, in the case of legume seeds, abrasion of the hard coat to decrease time required for germination.

Sediment. Solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its site of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level.

Sediment delivery. The total amount of sediment discharged by the flow during a given time interval. The total amount of sediment discharged from a watershed measured at a downstream point.

Sediment supply. The total amount of sediment detached by raindrop impact and overland flow.

Sediment transport capacity. The rate at which the stream is capable of carrying sediment.

Sediment yield. The total amount of sediment that passes any section of a stream.

Seedbed. The soil prepared by natural or artificial means to promote the germination of seed and the growth of seedlings.

Semiarid. A term applied to regions or climates where moisture is normally greater than under arid conditions (>8 to 10 inches) but still definitely limiting to the growth of most crops. Dryland farming methods or irrigation generally is required for crop production. The upper limit of average annual precipitation in the temperate semiarid regions is as low as 15 to 20 inches.

Side slopes. The slope of the sides of a canal, dam, or embankment. It is customary to name the horizontal distance first as 1.5 to 1.0, or frequently 1-1/2:1, meaning a horizontal distance of 1.5 feet to 1 foot vertical.

Silt. 1. A particle size or soil separate consisting of particle sizes 0.002 to 0.05 mm in equivalent diameter. 2. A soil textural class.

SIMSED model. Simplified sediment yield model. A simplified procedural method for estimating on-site soil loss; a mathematical model based on physical processes.

Sheet flow. See Overland flow.

Sodded waterway. Grassed waterway vegetated by sodding with adapted grass species.

Sodic soil. Non-saline soil containing sodium which interferes with plant growth.

Soil. 1. The unconsolidated mineral and organic material on the immediate surface of the earth that serves as a natural medium for the growth of land plants. 2. The unconsolidated mineral matter on the surface of the earth that has been subjected to and influenced by genetic and environmental factors of parent material, climate (including moisture and temperature effects), macro- and micro-organisms, and topography, all acting over a period of time and producing a product soil that differs from the material from which it is derived in many physical, chemical, biological, and morphological properties and characteristics. 3. A kind of soil; that is, the collection of soils that are alike in specified combinations of characteristics. Kinds of soil are given names in the system of soil classification. The terms the soil and soil are collective.

Soil erodibility. A physical property of soil expressing its susceptibility to erosion due to raindrop splash and sheet wash processes.

Soil series. The basic unit of soil classification being a subdivision of a family and consisting of soils that are essentially alike in all major profile characteristics except the texture of the A horizon.

Soil structure. The combination or arrangement of primary soil particles into secondary particles, units, or peds.

Soil textural classification. General class of a soil denoting a particular percentage of clay, silt and sand, eg. loam, clay loam. Note: clay, silt and sand are particle sizes as well as a textural class.

Subsoil. The B horizon of soils with distinct profiles. In soils with weak profile develoment, the subsoil can be defined as the sol below the plowed soil (or its equivalent of surface soil) in which roots normally grow. Although a common term, it cannot be defined accurately. It has been carried over from early days when soil was conceived only as the plowed soil and that under it as subsoil.

Surface soil. That part of the upper soil of arable soils commonly stirred by tillage implements or an equivalent depth (5 to 8 inches) in nonarable soils.

Suspended solids. Sediment that is in suspension in water but that will physically settle out under quiescent conditions (as differentiated from dissolved material).

Tacking (mulch). The process of binding mulch fibers together by the addition of a sprayed chemical compound.

Terrace. An embankment or combination of an embankment and channel constructed across a slope to control erosion by diverting.

Terrace outlet channel. Channel, usually having a vegetative cover, into which the flow from one or more terraces is discharged and conveyed from the field.

Terrace types.

Absorptive: A ridge type of terrace used primarily for moisture conservation.

Bench: A terrace approximately on the contour, having a steep or vertical drop to the slope below, and having a horizontal or gentle sloping part. It is adapted to steeper slopes.
Drainage: A broad, channel-type terrace used primarily to conduct water from the area at a low velocity. It is adapted to less absorptive soil and regions of high rainfall.

Topsoil. The unconsolidated earthy material that exists in its natural state above the rock strata and that is or can be made favorable to the growth of desirable vegetation.

Toxic spoil. Includes acid spoil with pH below 4.0. Also refers to spoil having amounts of minerals such as aluminum, manganese, and iron that adversely affect plant growth.

Type I storm distribution. A design model for the time distribution of storm rainfall for the coastal side of the Sierra Nevada and Cascade Mountains, and Alaska and Hawaii.

Type II storm distribution. A design model of the time distribution of storm rainfall for the remaining states, Puerto Rico, and Virgin Islands. (See Type I).

Toe berm. A berm of "bench" of compacted and vegetated soil constructed at the toe of the slope.

Universal Soil Loss Equation. An equation used for predicting soil loss and designing erosion control systems; A = RKLSCP where A = average annual soil loss; R = rainfall factor, K = erodibility factor; L = length of slope; S = % of slope; C = cropping and management factor; and P = conservation factor.

Watersheds. Total land area above a given point on a stream or waterway that contributes runoff to that point.

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