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.

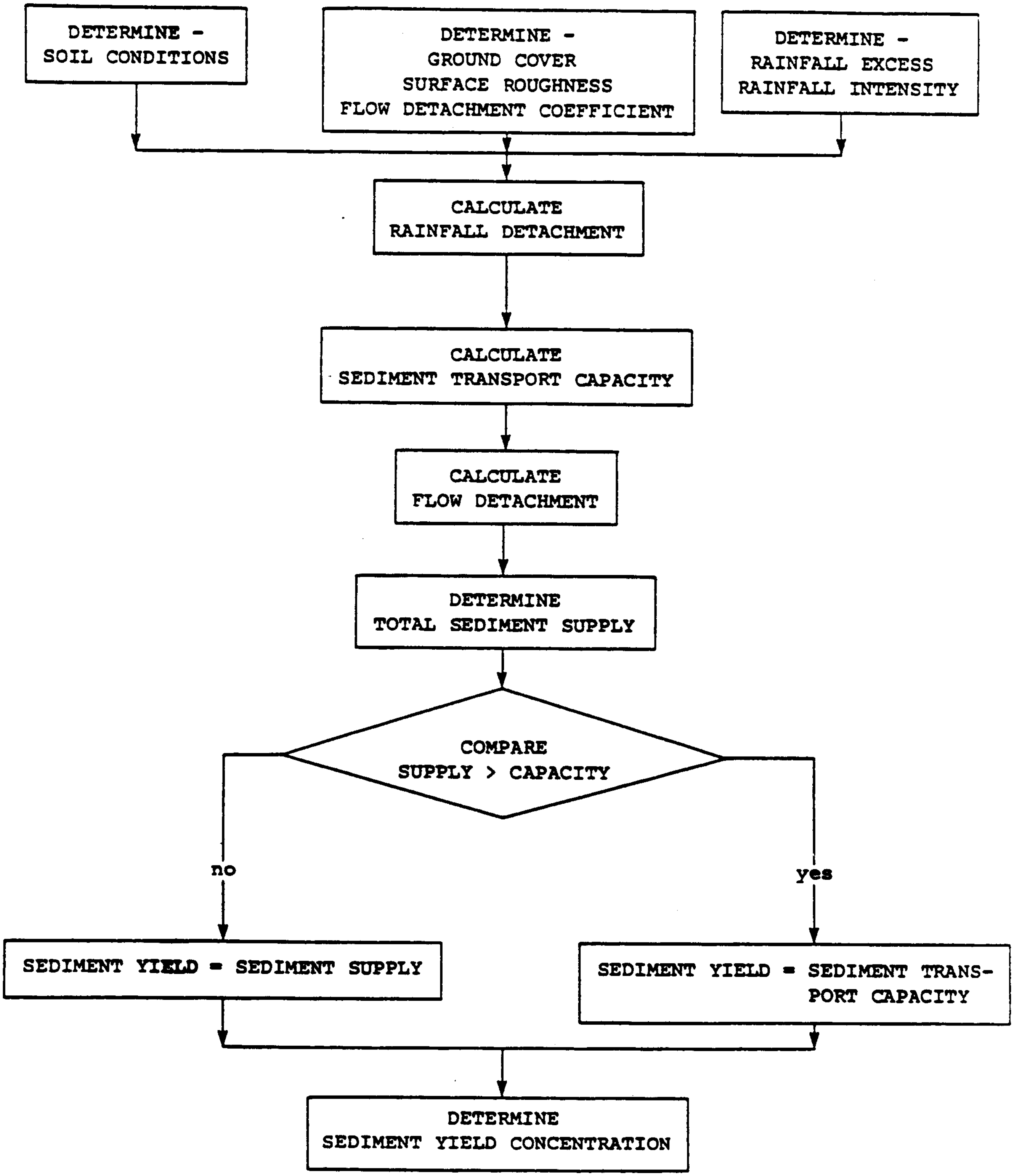


Figure 4.1. Flow chart of design procedure for surface protection measures.

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.

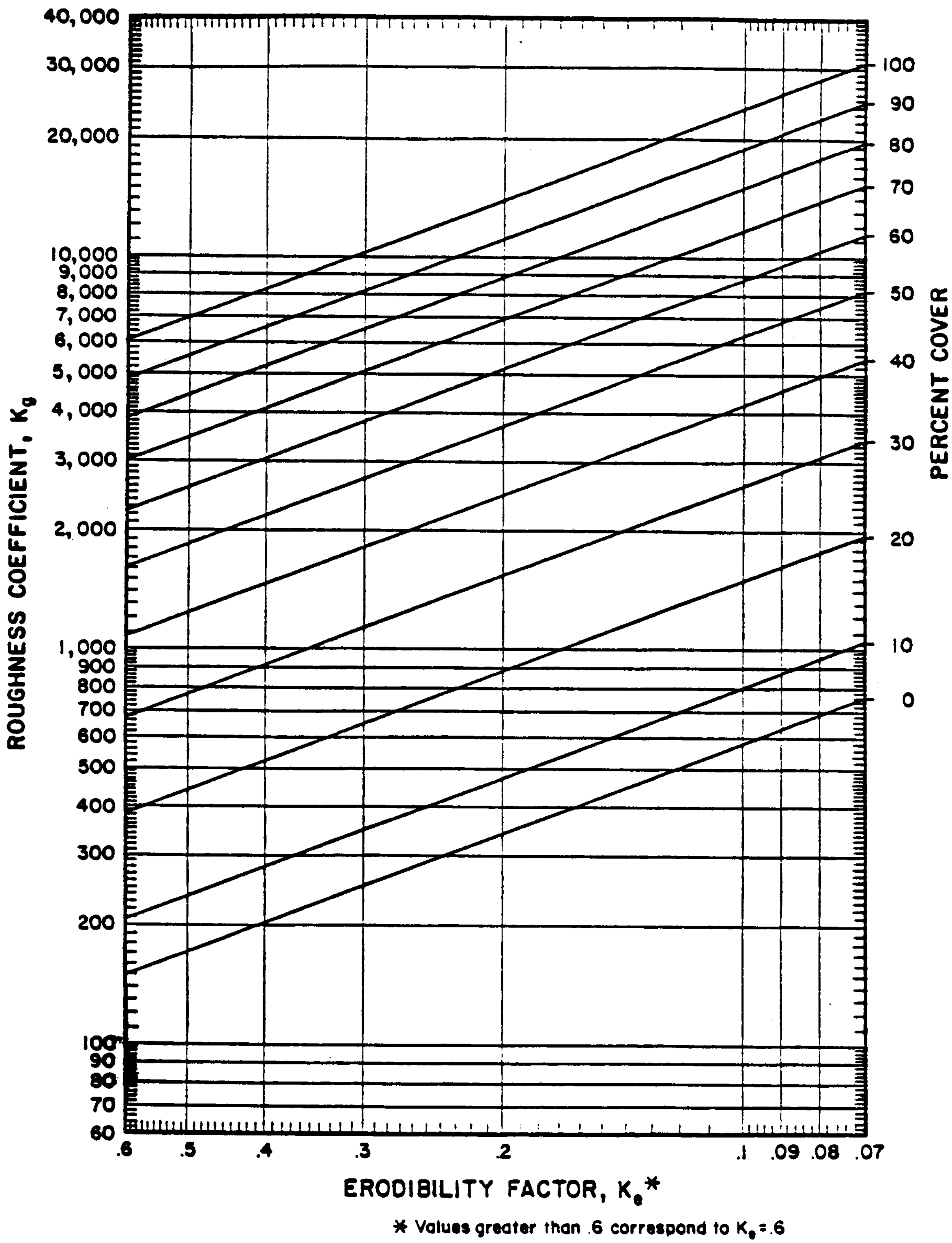


Figure 4.2. Relationship between erodibility factor, percent cover, and roughness coefficient (from Simons, Li & Associates, Inc., 1982).

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

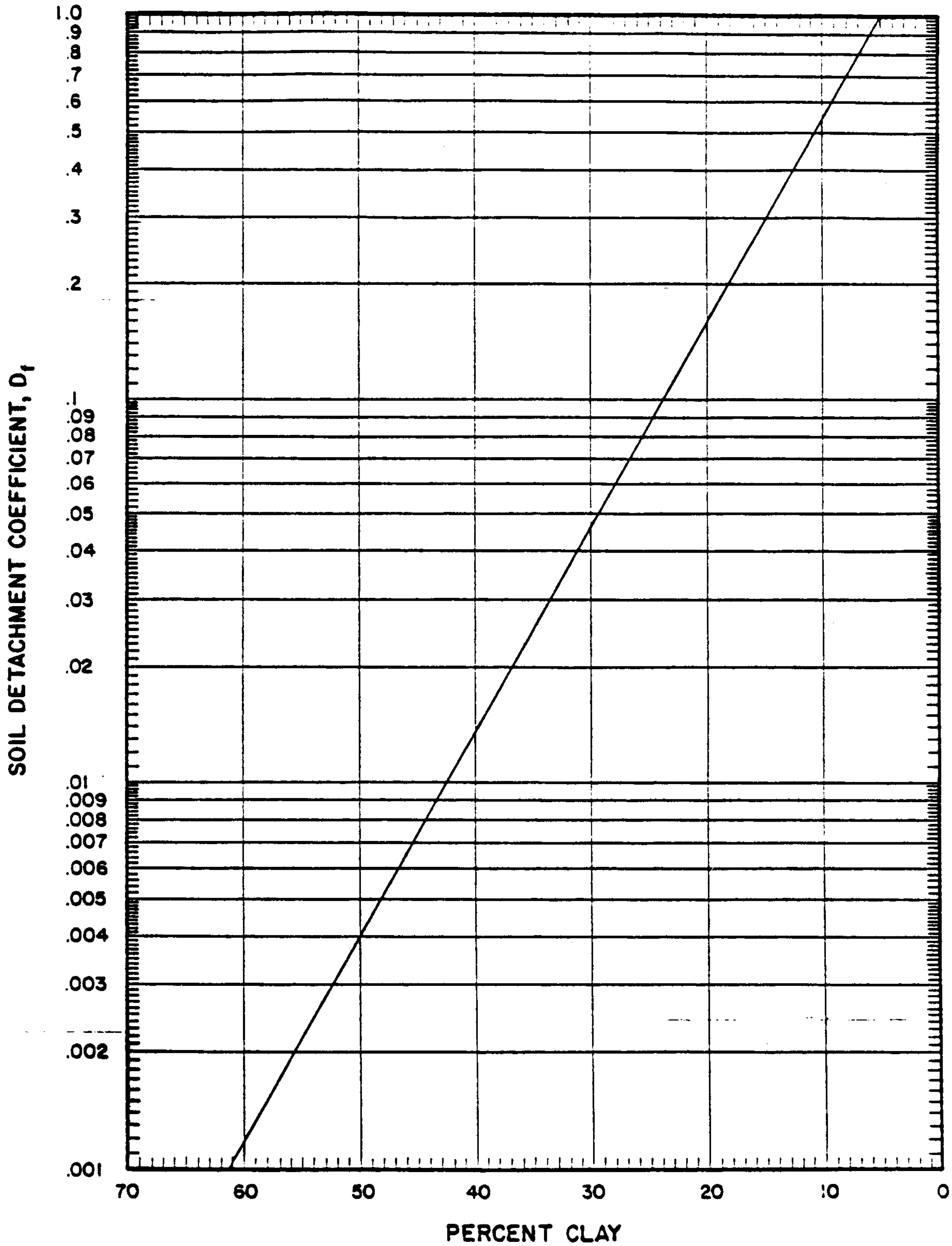


Figure 4.3. Soil detachment coefficient versus percent clay (from Simons, Li & Associates, Inc., 1982).

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.

$$CN = CN_H - (CN_H - CN_L)C_g \quad (4.1)$$

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

$$P_o = 0.2\ S \quad (4.2)$$

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.

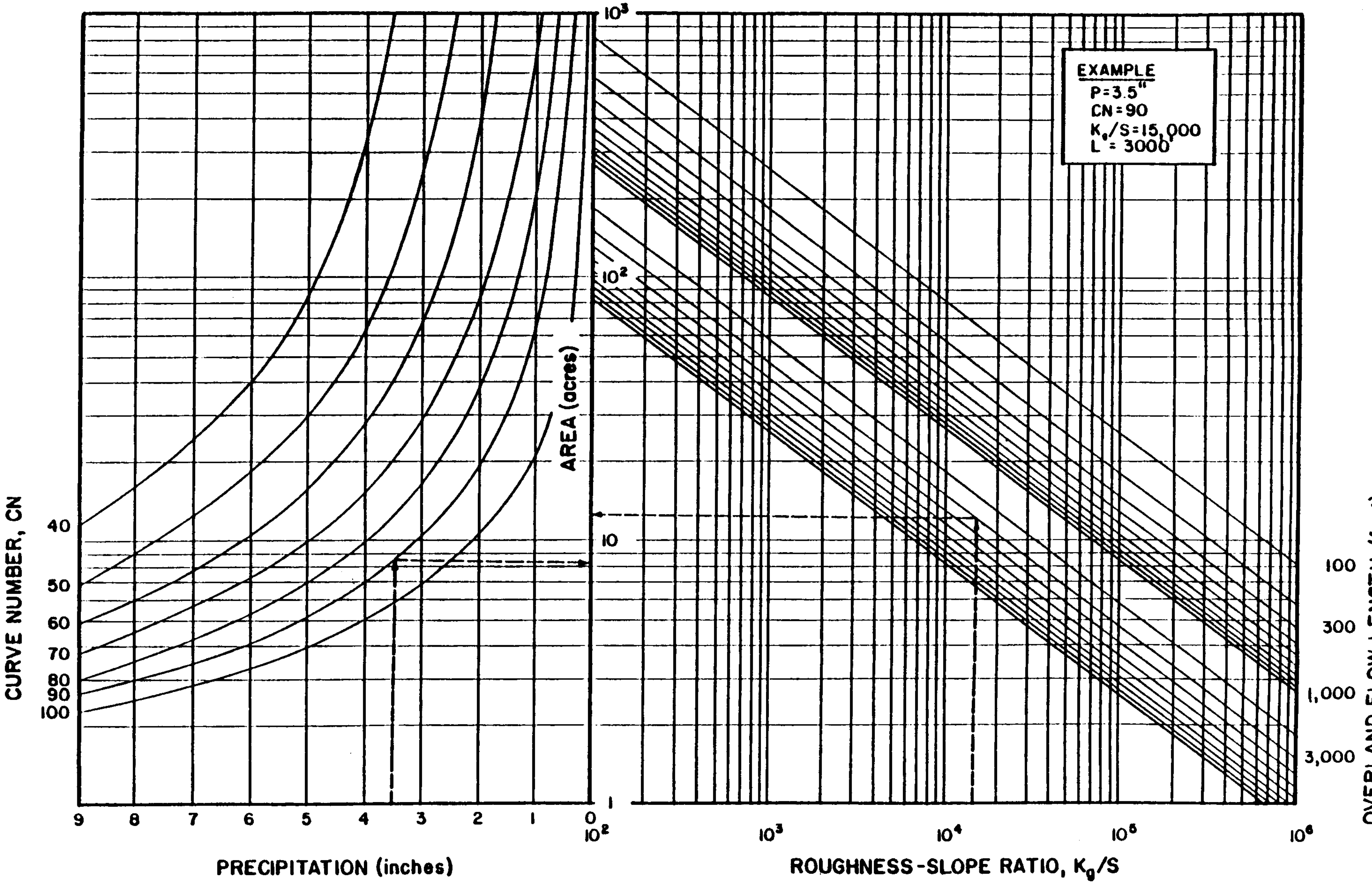


Figure 4.4. Maximum allowable area (from Simons, Li & Associates, Inc. 1982).

where: P_o = the initial abstraction, inches

S = the maximum potential abstraction, inches.

S is a function of curve number (CN) where

$$S = \frac{1000}{CN} - 10 \qquad (4.3)$$

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

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

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.

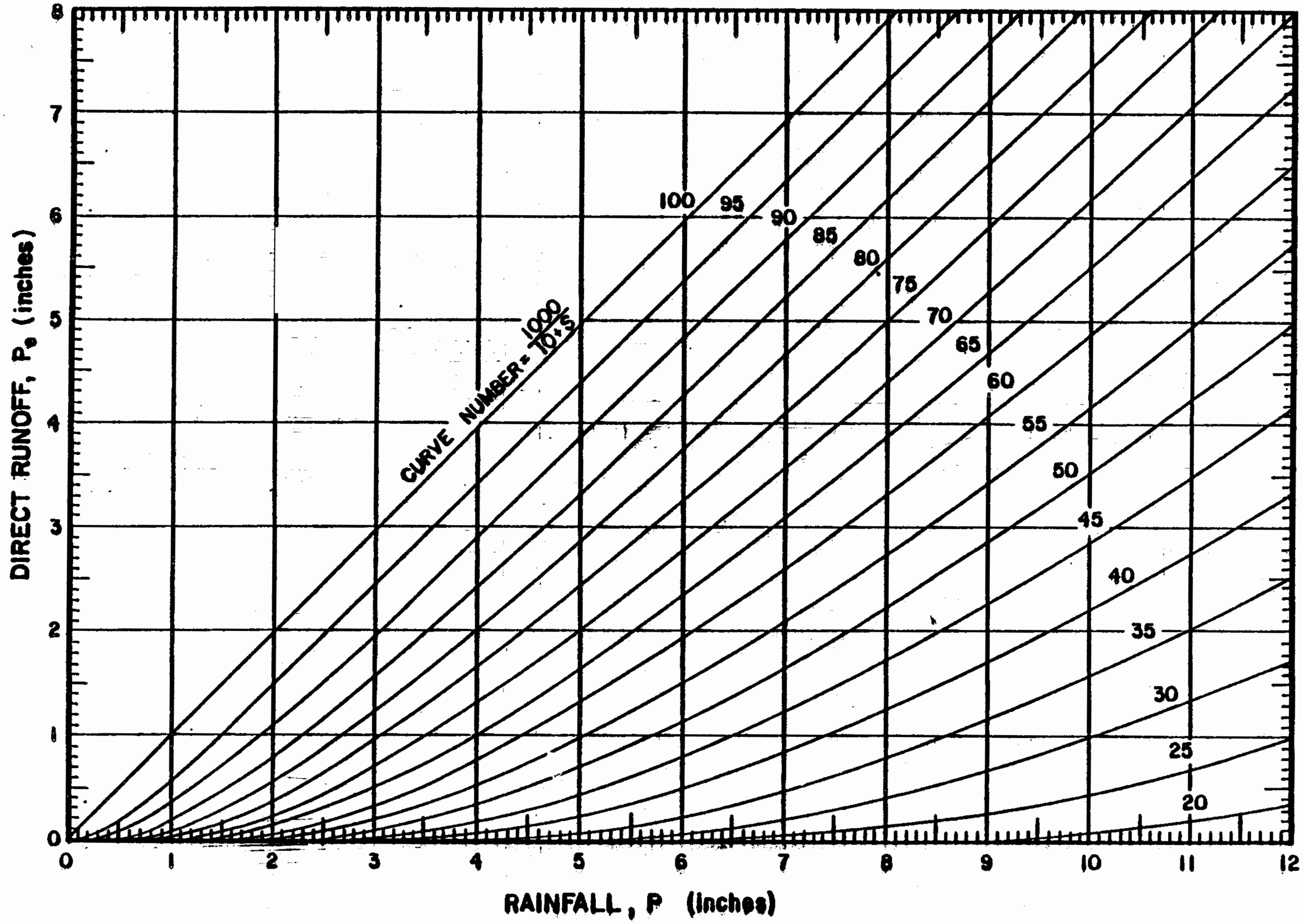


Figure 4.5. Solution of runoff equation (after Mockus & Victor, 1955).

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

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 = ____________

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

Worksheet 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)

Roughness Coefficient, K_g = ______________

Slope, S = ______________

Width = ______________

Worksheet 4.3. Step Five worksheet.

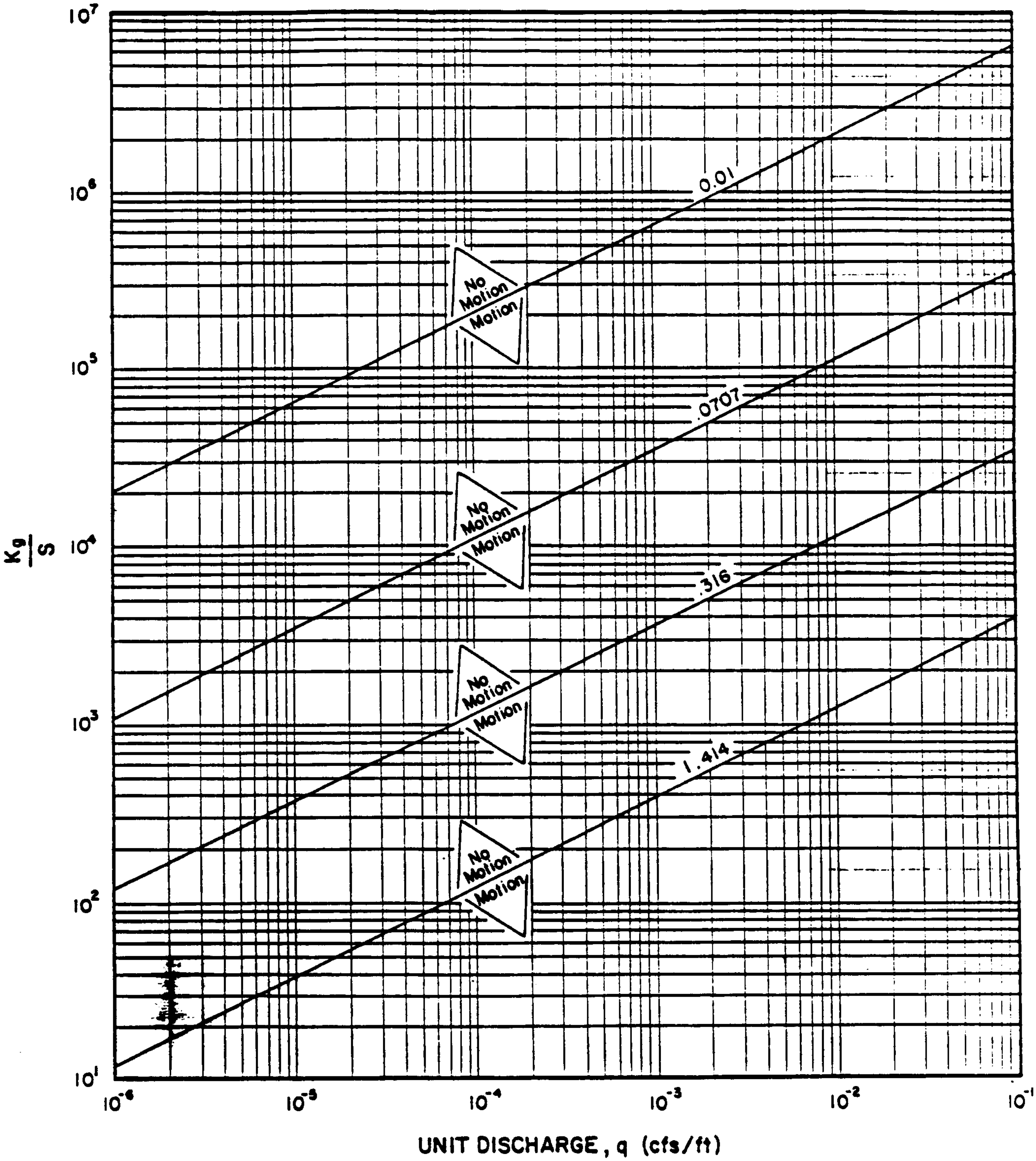
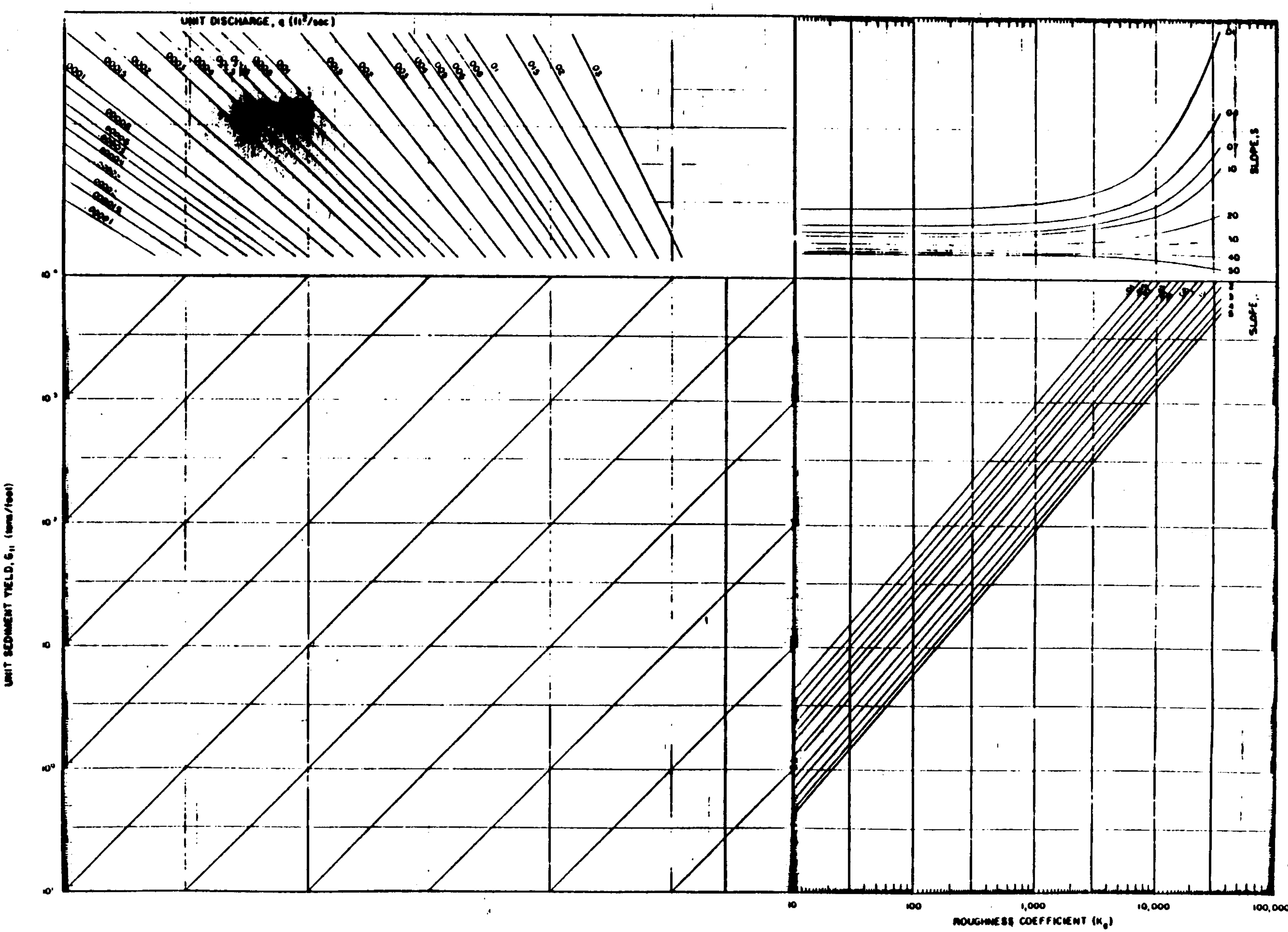
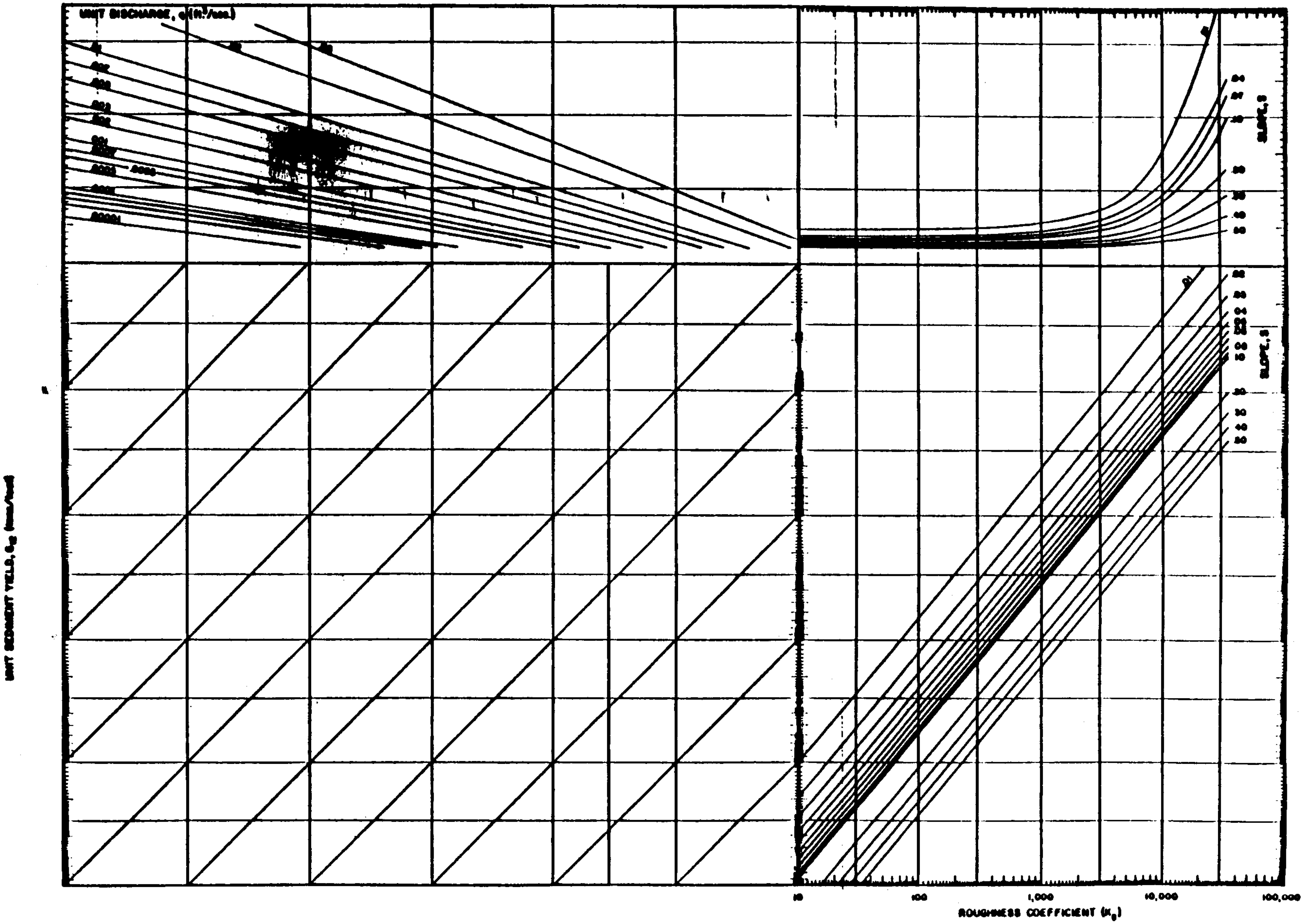


Figure 4.6. Critical discharge (from Simons, Li & Associates, Inc., 1982).



.01
D=.[redacted]

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



D=.0707

Figure 4.8. Sediment transport rate, D=.0707

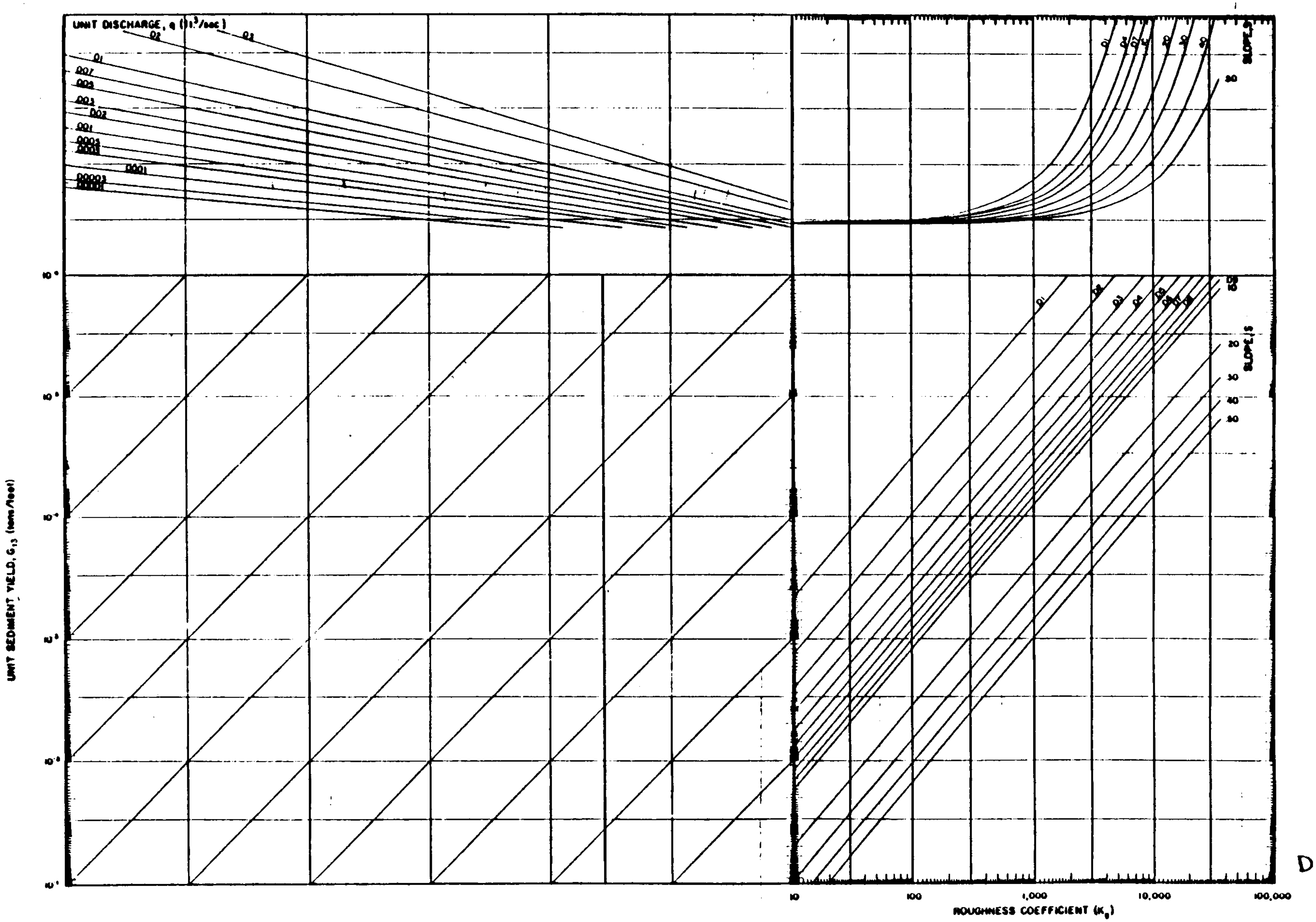
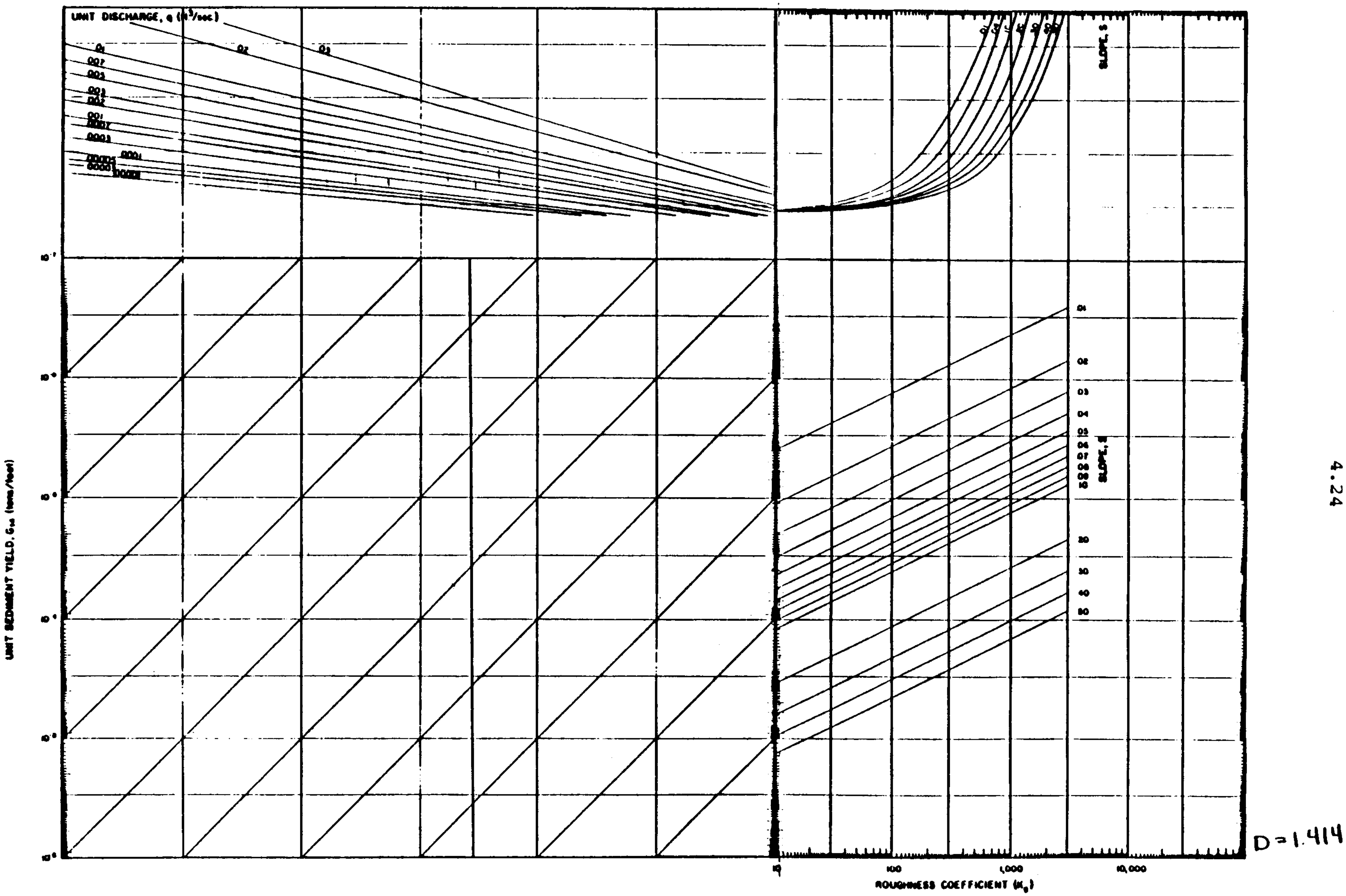


Figure 4.9. Sediment transport rate, D=.316.



4.24

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.

<u>Step Six</u>: **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

$$G_f = D_f(G_t - G_r) \quad (4.10)$$

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

$$G_s = G_r + G_f \quad (4.11)$$

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.

Step Seven: 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) G_{y1}	(2) G_{y2}	(3) G_{y3}	(4) G_{y4}	(5) 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

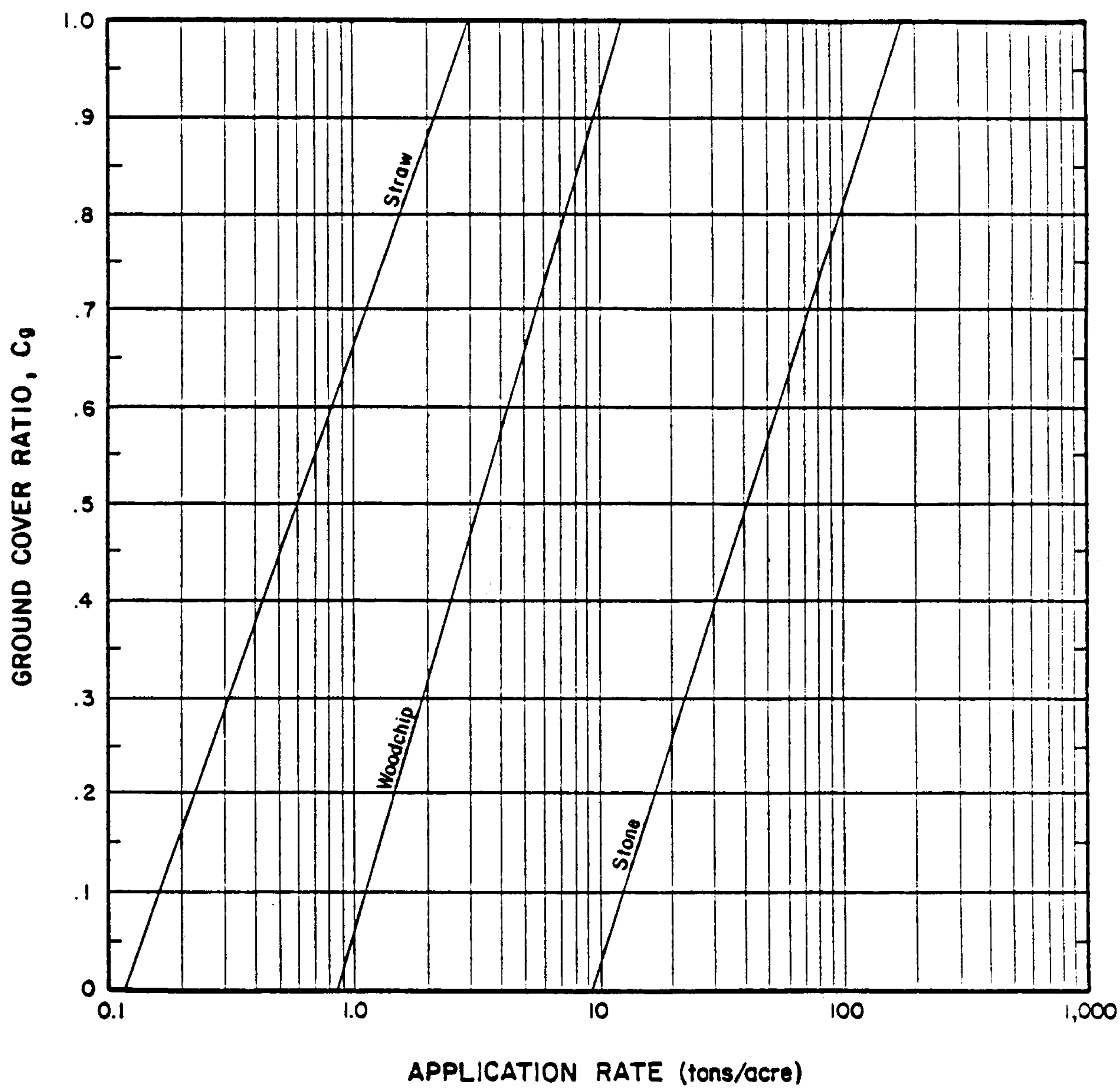


Figure 4.11. Mulch application rate versus cover ratio (from Simons, Li & Associates, Inc., 1982).

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.

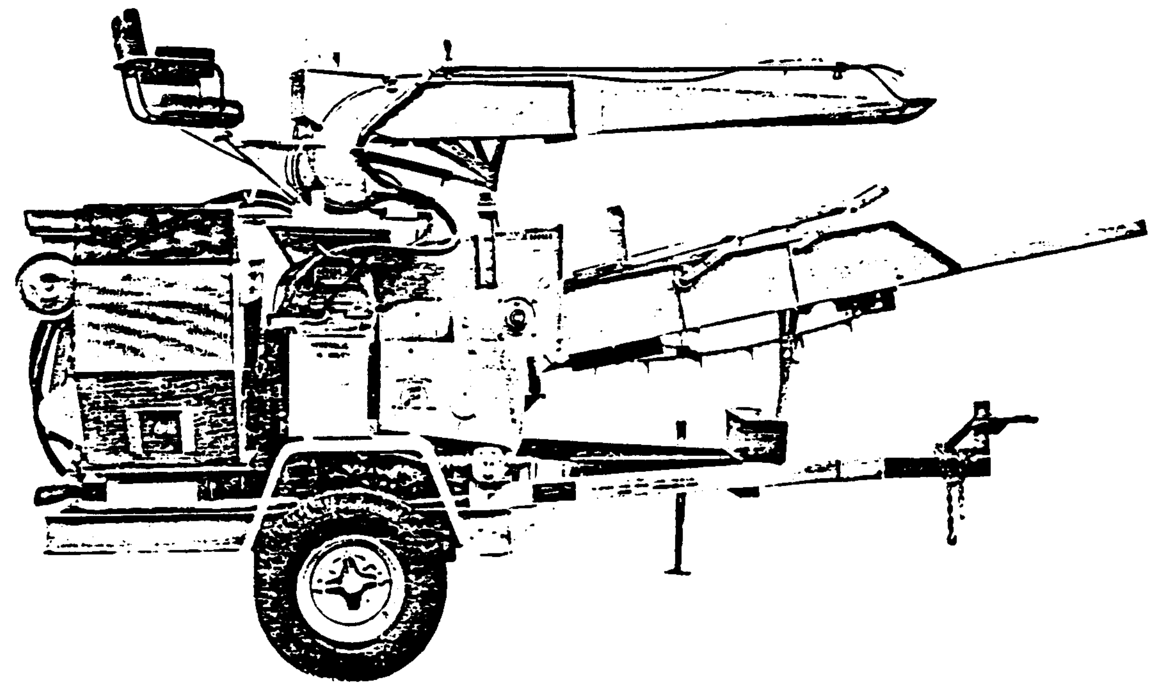


Figure 4.12. Power mulch spreader (from USDA Forest Service, 1979).

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.

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
	Coarse Aggregates (From AASHTO M 43)						
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).

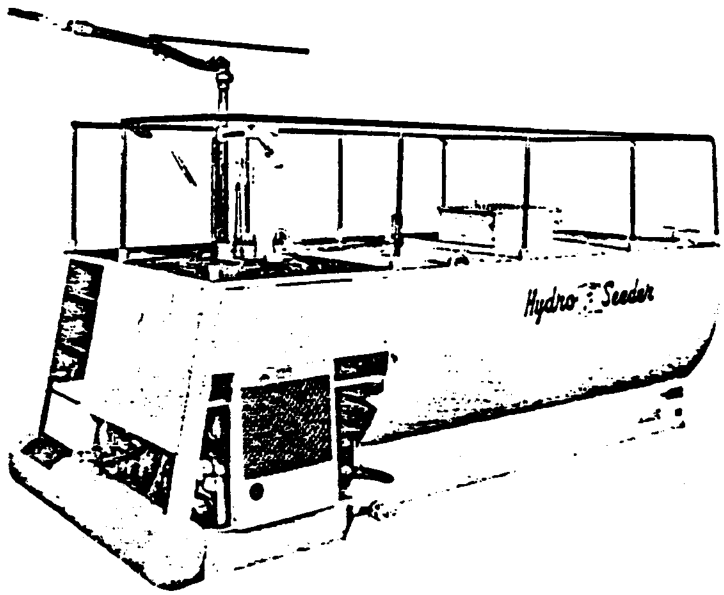


Figure 4.13. Hydraulic mulching spreader to be mounted on a trailer or truck frame (from USDA Forest Service, 1979).

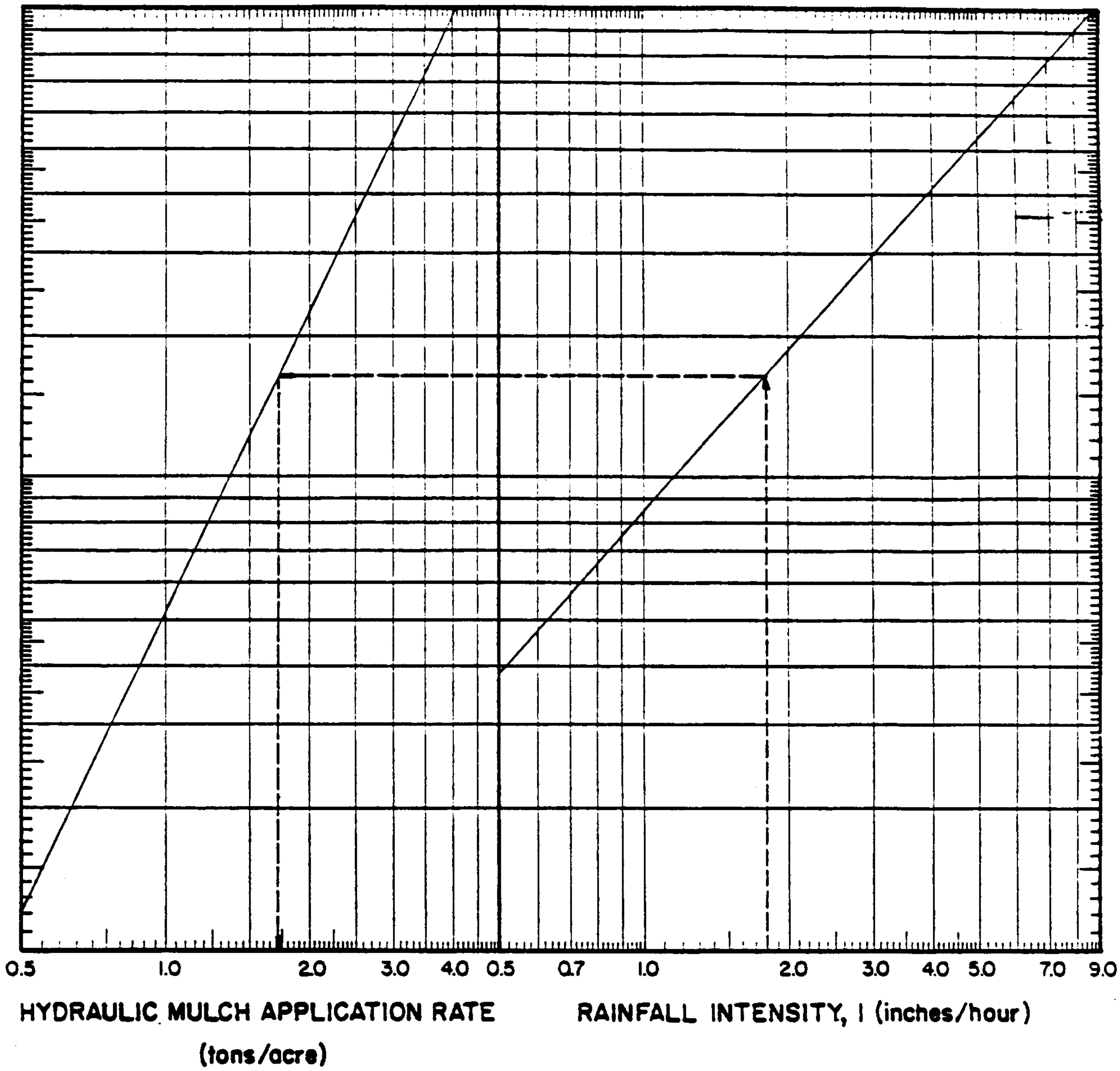


Figure 4.14. Maximum allowable rainfall intensity for hydraulic mulches (from Simons, Li & Associates, Inc., 1982).

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.

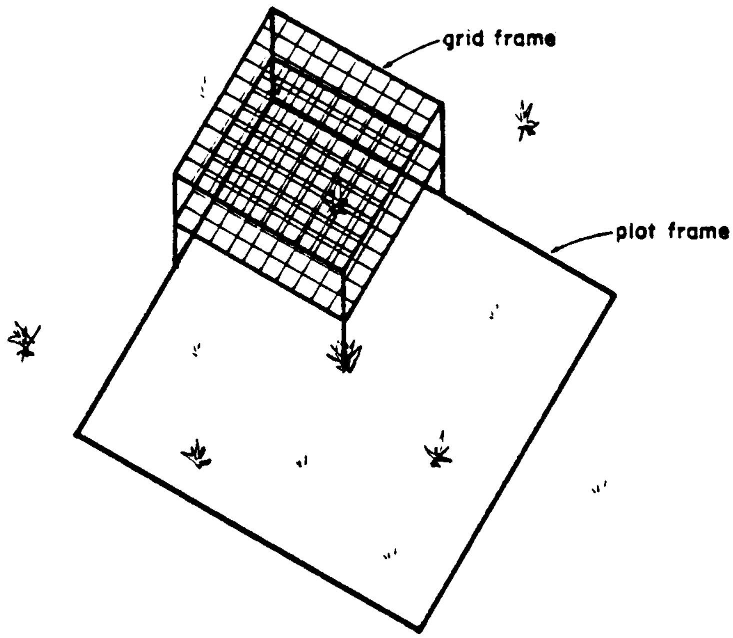


Figure 4.15. Sampling plot frame and grid frame covering one quadrant of the sample plot.

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.

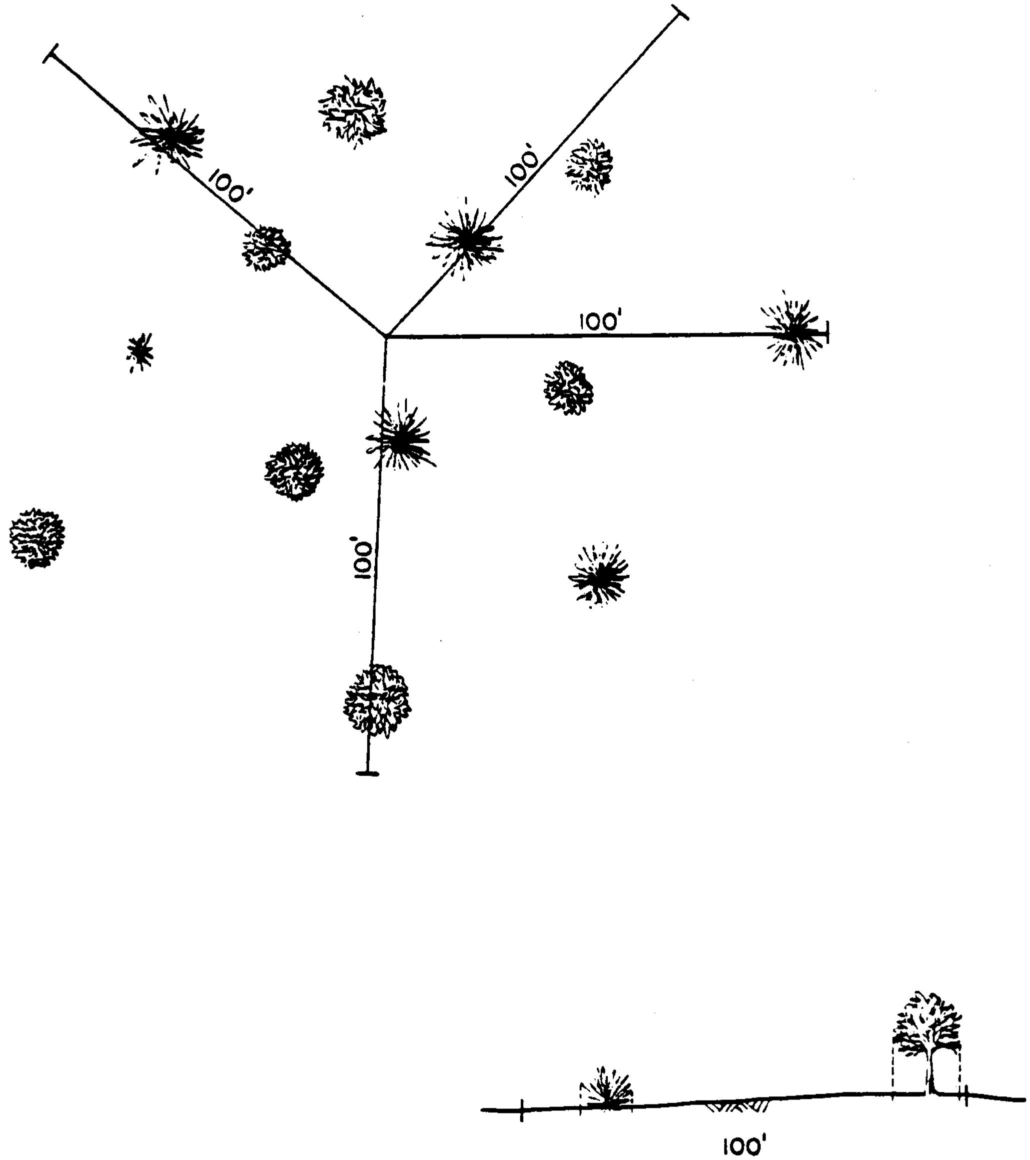


Figure 4.16. Transect method of determining ground cover.

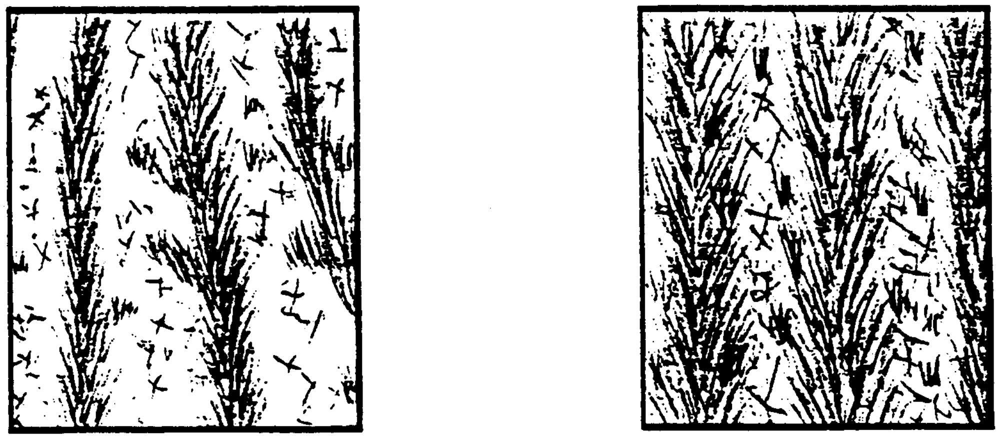


Figure 4.17. Grass stands, such as creeping red fescue, 1st (left) and 4th (right) growing seasons.

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.

<u>Basis of Payment</u>. 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.

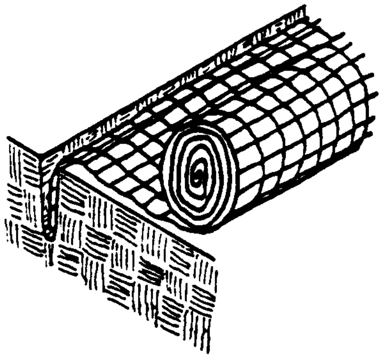
Product	Cover Factor, C_N	Contact Factor, F
Jute Mat	0.40	1.0
Excelsior	0.80	0.5
Woven Paper	(check with manufacturer)	0.0
Plastic Netting	0.01	0.0

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).

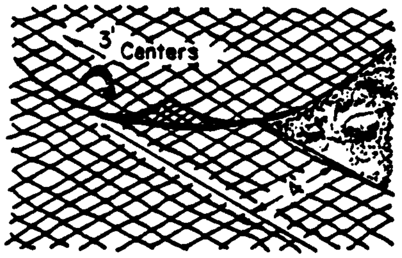
Mulch Netting should be used for small areas or to repair erosion damaged areas. Netting is useful on steep slopes which are not accessible to equipment. Figure 4.18 illustrates important application requirements which must be followed when installing mulch netting on slopes.

In-Service Performance

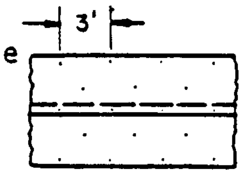
All mulches should be inspected periodically, especially after rainstorms, to check for excessive rill erosion. Where erosion is observed, additional mulch should be applied. Netting should be inspected after rainstorms for failure. If washouts occur, netting should be reinstalled after repairing the 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.

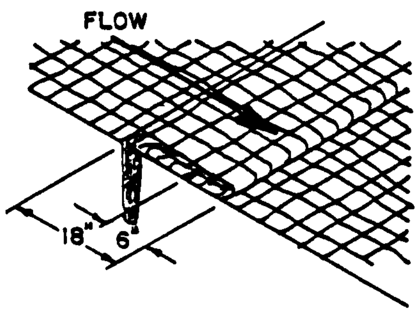


Anchor Slot: Bury the up-channel end of the net in a 6" deep trench. Tamp the soil firmly. Staple at 12" intervals across the net.

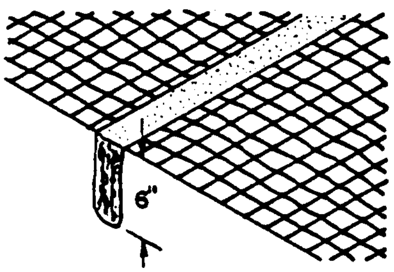


Overlap: Overlap edges of the strips at least 4". Staple Every 3 feet down the center of the strip.

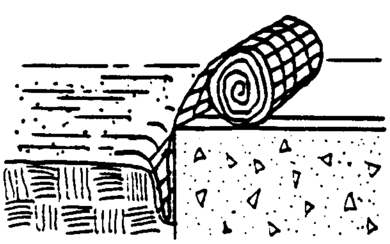




Joining Strips: Insert the new roll of net in a trench, as with the Anchor Slot. Overlap the up-channel end of the previous roll 18" and turn the end under 6". Staple the end of the previous roll just below the anchor slot and at the end at 12" intervals.



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.

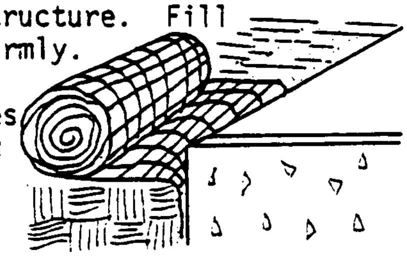


Figure 4.18. Installation of netting and matting (Conwed Products Brochure. In: VSWCC, 1980).

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

Ground Cover Ratio = 0.00

Width = 660 feet

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

$A_b = (1 - C_g)A$ (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) G_{y1}	(2) G_{y2}	(3) G_{y3}	(4) G_{y4}	(5) 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

Ground Cover Ratio = 0.78

Width = 660 feet

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

$A_b = (1 - C_g)A$ (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	0.0000180	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) G_{y1}	(2) G_{y2}	(3) G_{y3}	(4) G_{y4}	(5) 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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