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.

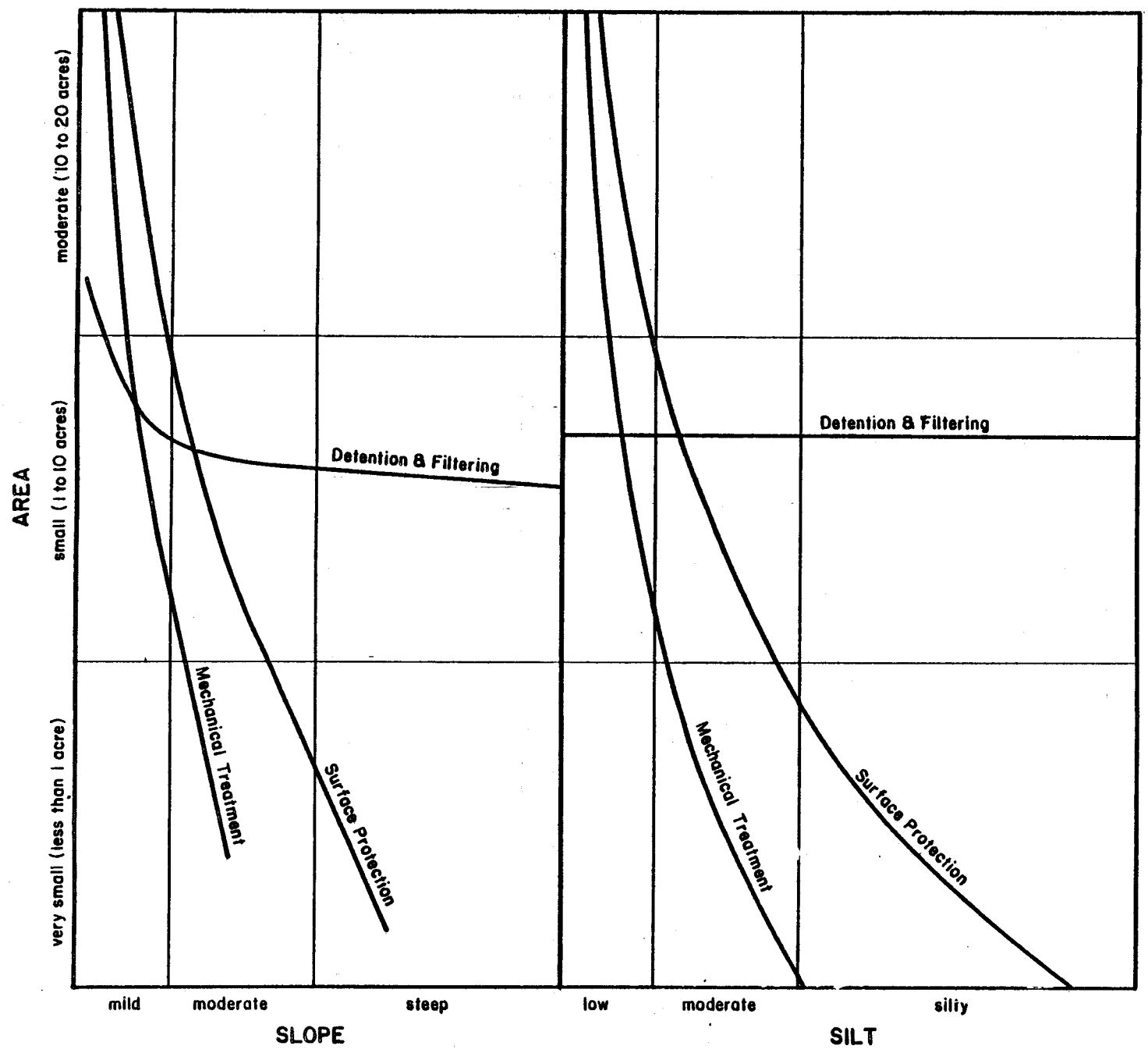


Figure 8.1. Comparison of structure groups (from Simons, Li & Associates, Inc., 1982).

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

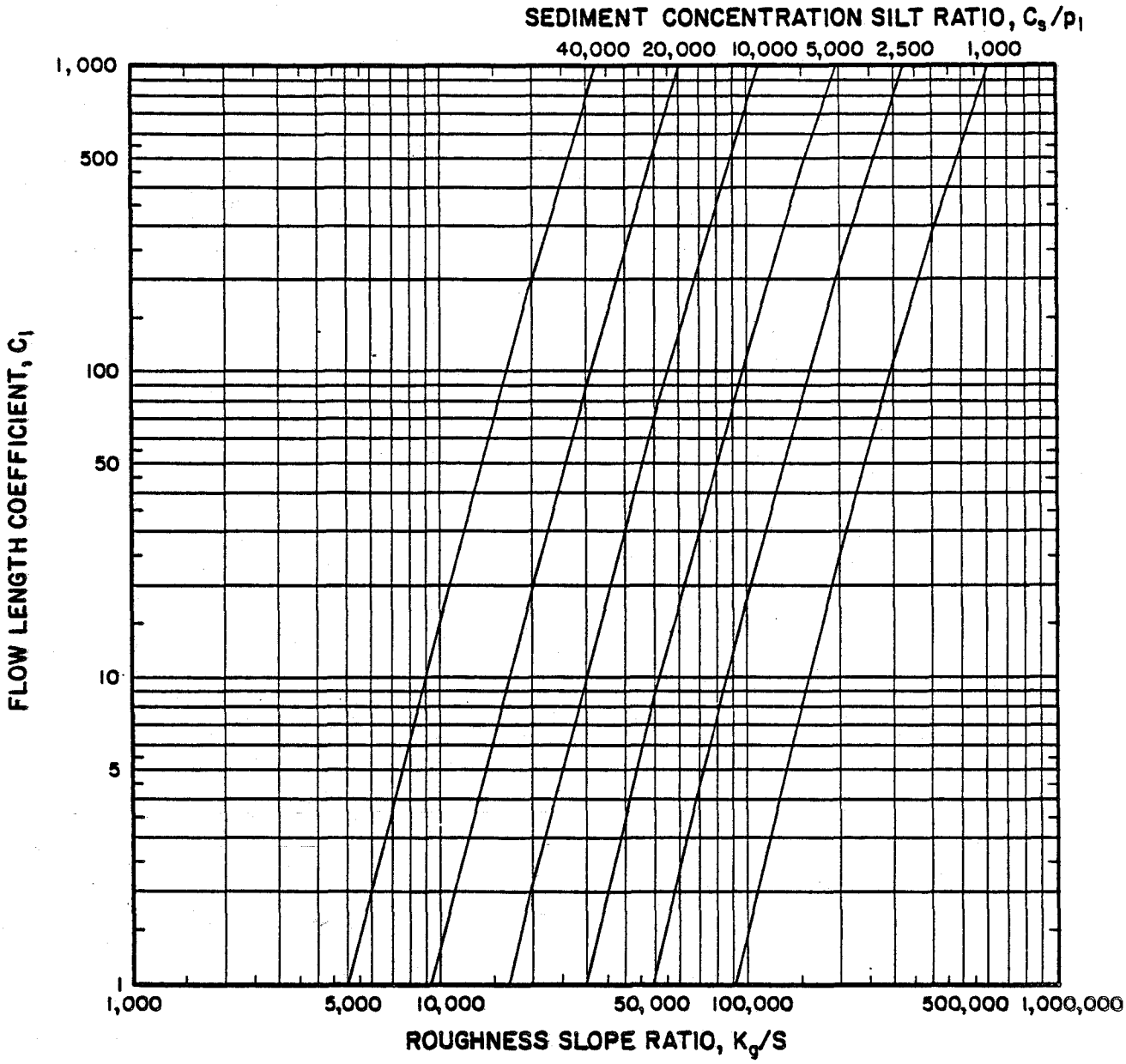


Figure 8.2. Flow length coefficient as a function of roughness, slope, silt content, and design sediment concentration (from Simons, Li & Associates, Inc., 1982).

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

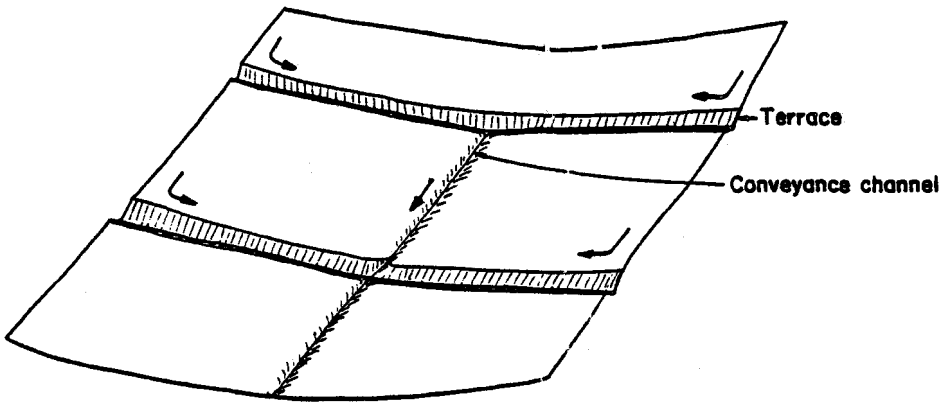
$$A_{maxs} = \frac{754(200)}{43560}$$

$$= 3.46 \text{ acres}$$

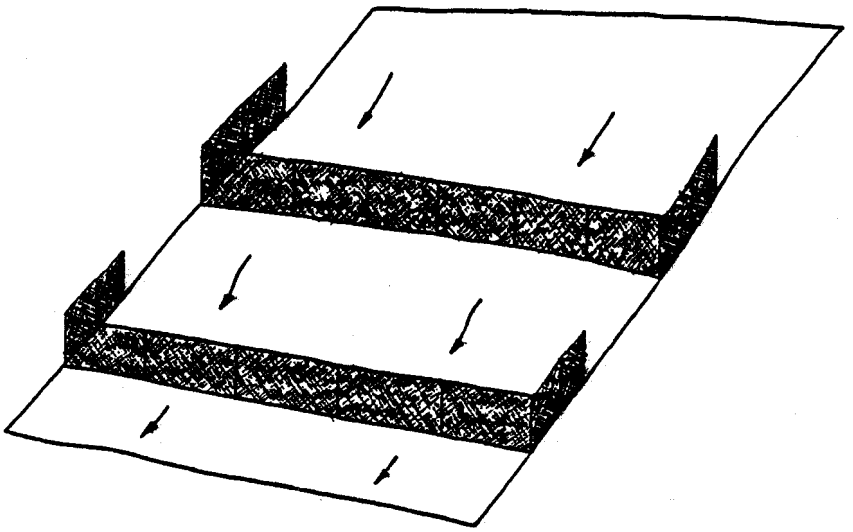
8.4 Combined Use of Structures and Treatments

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.

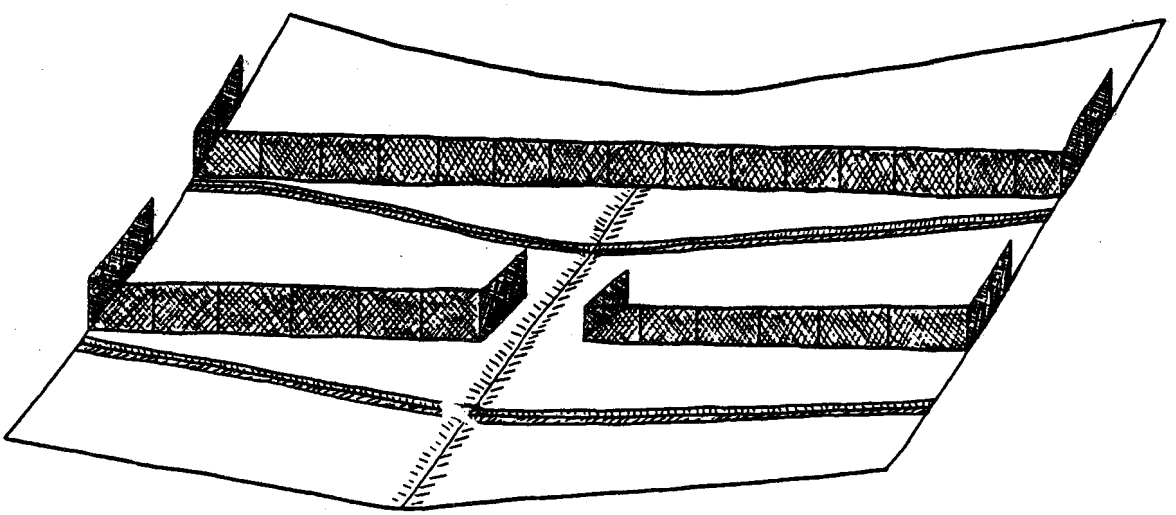
The general principle involved in developing a sediment control system is that the structures must be placed parallel to each other, rather than in series. Figure 8.3 illustrates this principle. A terrace and conveyance channel system (Figure 8.3(a)) is a good example of structures placed in a "parallel" 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.

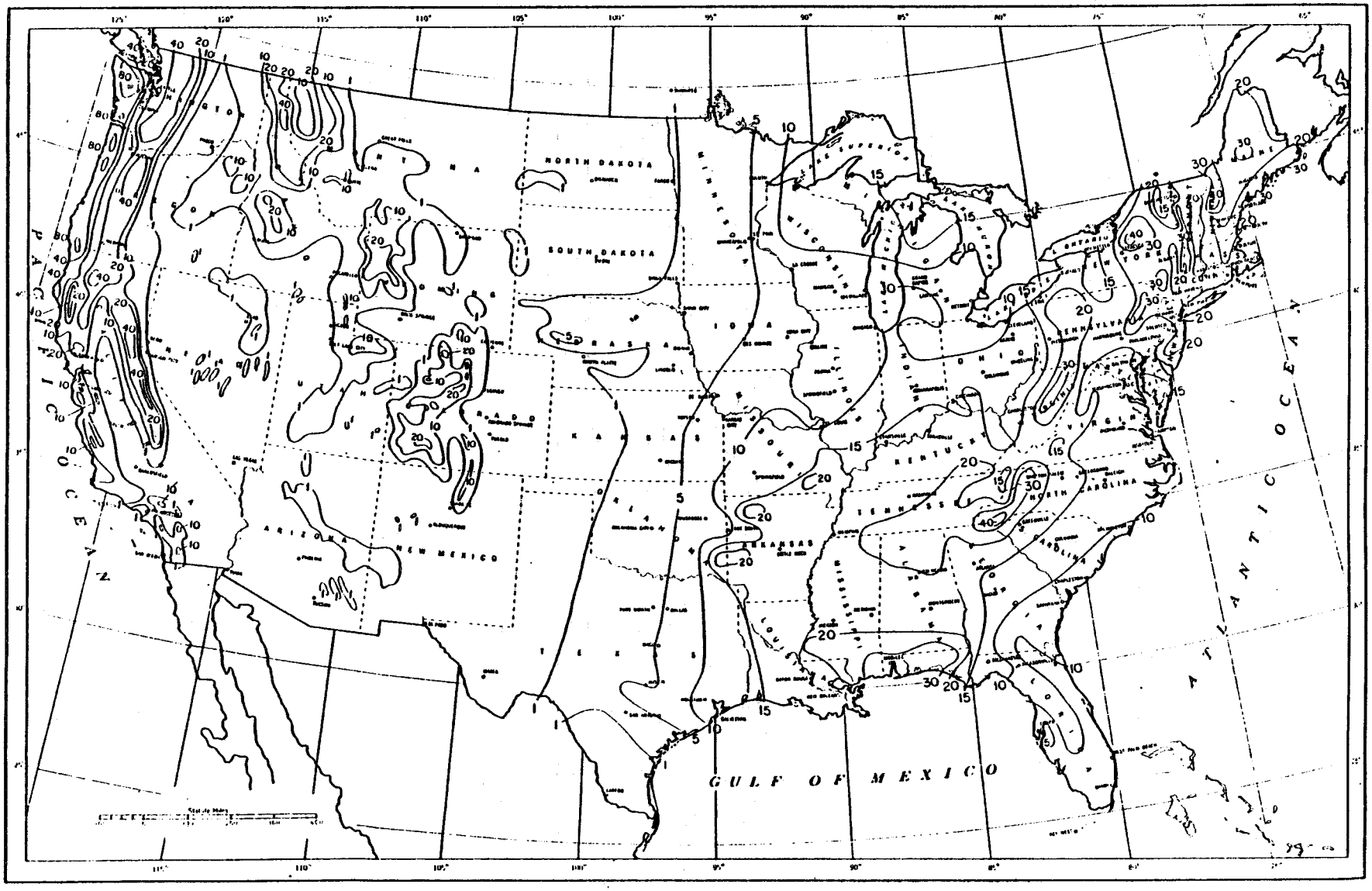


Figure 8.4. Annual inches of runoff (Pw)(after U.S. Geological Survey, 1962).

(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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